

Assessing macroinvertebrate responses in the Mooi River Catchment within and ecological water requirements framework

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SUMMARY

Freshwater ecosystems; rivers in particular, are amongst some of the most threatened ecosystems on earth which is directly linked to the fact that the ecological integrity of rivers and other freshwater ecosystems is a direct reflection of all the activities taking place in the areas they drain. Rivers become vulnerable by being exposed to a variety of disturbance associated with rapidly growing human populations. People depend on water for activities such as irrigation, electricity generation and waste disposal. South Africa adopted a new water legislation that promoted equity, sustainability, representatively and efficiency through water management by decentralizing, new local and regional institutions; where registration and licencing is necessary. The role of Resource Directed Measures (RDM) is to ensure the protection of water resources, by protecting ecosystem functioning and maintaining a desired state of health of aquatic and groundwater dependent ecosystems. Resource Quality Objectives (RQO) offer a direction which management could pursue in order to achieve desired protection of a resource while also expressing the acceptance or unacceptance of impacts and activities on a water resource. In RDM, Ecological Water Requirements (EWR) basically quantify the water regime in terms of quality, quantity and timing that is required to ensure the adequate functioning and future persistence of aquatic ecosystems.

The Mooi River is situated in the North-West Province of South Africa, within the Upper Vaal Water Management Area. The Wonderfontein Spruit sub-catchment is the north-eastern reach, dominated by mining and farming activities in the lower parts. The Loop Spruit sub-catchment is the eastern reach, dominated by livestock as well as crop farming and joins the Mooi River downstream of the town of Potchefstroom. The Mooi River system is important for maintaining the quality of potable water of Potchefstroom and surrounding areas. However, this system is under constant threat from anthropogenic pollution arising from both agricultural and mining activities in its catchment. The successful management of river ecosystems and changes in river systems resulting from human or natural influences, need to be assessed and measured. Macroinvertebrates make good candidates to assess aquatic ecosystem quality since they can respond in many ways to environmental stresses.

The Macroinvertebrate Response Assessment Index (MIRAI) is an approach that should be undertaken to relate drivers and the resultant habitat to the aquatic macroinvertebrate condition. The approach uses macroinvertebrate abundance and presence, as well as macroinvertebrate preferences for flow modifications, habitat preferences and water quality when determining the Present Ecological Status (PES) of macroinvertebrates. The result is the Ecological Category (EC), which is a basic indication of the river condition as a percentage of what it should be or the

expected. Taxonomic based approaches apply several metrics such as single metrics and indices and multi metric indices developed and used in biomonitoring based on macroinvertebrate community structure. Family level taxonomic determinations in biomonitoring have been the focal point of most research but with lack in integrated taxonomic and trait based evaluations. Taxonomy based descriptions are limited in their ability to define ecological responses to stress. Most traits are predictable in the manner in which they will react to stress because trait response to disturbance can be put in context, but also possess discriminatory capabilities. Trait Based Approaches are a promising area for the use of biomonitoring data in causal diagnosis by use of phenotypic characters of taxa in the area of traits analysis.

This study tested the hypothesis that the macroinvertebrate assemblage responses and functional structures will reflect the presence of disturbances in the ecosystem of the Mooi River catchment. Five reaches were established by grouping 21 sampled sites along the catchment. Collected macroinvertebrates were classified up to family level and subjected to the MIRAI to determine the Ecological Categories of the reaches. The water quality metrics for MR1 (32.6%), MR2 (32.2%), MR3 (31.3%) showed the highest deviation from reference conditions, and MR4 and MR5 were 43.4% and 41.2% respectively. The EC of four reaches, namely MR1 (46.73%), MR2 (45.51%), MR3 (44.64%) and MR4 (52.62%) were in Ecological Class D which is a largely modified state; and water quality was the most altered metric, as measured by the response of the macroinvertebrate assemblages. In MR5, both water quality and flow metrics were had a score of 41.2%, which meant that both these metrics were in the lower limits of Class D. The MR5 bordered on being seriously modified Ecological Class D/E.

Traits and ecological preferences information were obtained mainly from a South African macroinvertebrate trait database. Nine macroinvertebrate traits with 43 categories were assigned, which were habitat preference, velocity preference, water quality preference, hydraulic habitat preference, functional feeding groups, respiration, body size, body shape, as well as locomotion. The general outline of the catchment after application of macroinvertebrate traits showed the relative highest abundances being allocated to GSM taxa and were most abundant in MR2 (44.94%); taxa who prefer very slow flows ($<0.1\text{m/s}$) who were most abundant in MR2; highly tolerant taxa most abundant in MR5; taxa that is indifferent to hydraulic habitat conditions and was most abundant in MR3; predators most abundant in MR4; gill breathers who were most abundant in MR3; taxa with variable body shapes most abundant in MR3; small-sized macroinvertebrates ($>5\text{-}10\text{ mm}$) most abundant in MR3 as well as taxa who are swimmers that were most abundant in MR2. The results confirm the presence of impacts associated with various anthropogenic activities already documented in the Mooi River catchment and therefore suggest that monitoring of the catchment be strategic and adaptive to EWR because trait information hold potential to also inform

the RQO. This study concluded that the implementation of macroinvertebrate traits along with other commonly used EWR methods could be valuable towards the quality of assessments for water resource management.

Keywords: Mooi River, macroinvertebrates, traits, ecological water requirements, resource quality objectives, biomonitoring,

TABLE OF CONTENTS

ACKNOWLEDGEMENTS	i
SUMMARY	ii
LIST OF TABLES	vii
LIST OF FIGURES	ix
LIST OF ABBREVIATIONS	xi
CHAPTER 1: INTRODUCTION	3
1.1. Background.....	3
1.2. Aim and objectives of the study	5
1.2.1. Aim.....	5
1.2.2. Objectives	5
1.3. Hypothesis	6
1.4. Mini-dissertation structure.....	6
CHAPTER 2: LITERATURE REVIEW	8
2.1. South African National Water Act (NWA) (Act No. 36 of 1998)	8
2.2. Resource Directed Measures (RDM) (DWAF, 1999)	9
2.3. Resource Quality Objectives	12
2.4. Water Management Areas (WMA) in South Africa.	16
2.5. Ecological Water Requirements (EWR)	19
2.6. Impacts on the Mooi River catchment.....	20
2.7. Macroinvertebrates in biomonitoring.....	21
2.8. Macroinvertebrate Response Assessment Index (MIRAI).....	23
2.9. Trait Based Approaches (TBA)	26
CHAPTER 3: MACROINVERTEBRATE RESPONSE ASSESSMENT INDEX AND MACROINVERTEBRATE TRAITS METHODOLOGY.	30
3.1. Study area.....	30
3.2. Methodology.....	36
3.2.1. Sampling methodology.....	37
3.2.2. MIRAI methodology (Thirion, 2007)	37
3.2.2.1. Determination of the Ecological Category (EC)..	39
3.2.2.2. Macroinvertebrate trait selection.....	40
3.3. Data analysis.....	42
CHAPTER 4: RESULTS	56
4.1. Introduction.....	56
4.2. Macroinvertebrate abundance.	56
4.3. Macroinvertebrate Ecological Categories (EC)	69
4.4. Macroinvertebrate traits.....	75

4.4.1. Habitat preference.....	75
4.4.2. Water quality preference.	76
4.4.3. Velocity preference.....	77
4.4.4. Hydraulic habitat preference.....	78
4.4.5. Functional feeding groups (FFG).....	79
4.4.6. Respiration.	80
4.4.7. Body shape	81
4.4.8. Body size	82
4.4.9. Locomotion	83
CHAPTER 5: DISCUSSION.....	85
CHAPTER 6: CONCLUSIONS AND RECOMMENDATIONS	95
6.1 Conclusions.....	95
6.2 Recommendations	95
CHAPTER 7: REFERENCES	97

LIST OF TABLES

Table 2-1: Resource Quality Objectives (RQO) numerical limits set for Mooi River as gazette for the Upper Vaal catchment (DWS, 2016).....	13
Table 2-2: Present Ecological State (PES) and four MIRAI metric group rating systems (Thirion, 2007).....	19
Table 3-1: Physical characteristics of the study sites adopted from Erasmus (2017) and Pretorius (2017).....	35
Table 3-2: List of expected macroinvertebrate taxa in the Mooi River catchment (Thirion, 2007; DWS 2014).....	36
Table 3-3: Classification system used to assess the macroinvertebrate community ecological category of the Mooi River catchment with a description of each class, adopted from Kleynhans <i>et al.</i> (2008).....	35
Table 3-4: Selected macroinvertebrate traits and corresponding categories.....	40
Table 3-5: Macroinvertebrate trait categories assigned in MR1.....	43
Table 3-6: Macroinvertebrate trait relative abundance in MR1.....	45
Table 3-7: Macroinvertebrate trait categories assigned in MR2.....	46
Table 3-8: Macroinvertebrate trait relative abundance in MR2.....	48
Table 3-9: Macroinvertebrate trait categories assigned in MR3.....	49
Table 3-10: Macroinvertebrate trait relative abundance in MR3.....	50
Table 3-11: Macroinvertebrate trait categories assigned in MR4.....	51
Table 3-12: Macroinvertebrate trait relative abundance in MR4.....	53
Table 3-13: Macroinvertebrate trait categories assigned in MR5.....	54
Table 3-14: Macroinvertebrate trait relative abundance in MR5.....	55
Table 4-1: Mooi River reaches and their respective number of taxa.....	57
Table 4-2: Macroinvertebrate taxa and MIRAI metrics collected in MR1.....	58
Table 4-3: Macroinvertebrate taxa and MIRAI metrics collected in MR2.....	60
Table 4-4: Macroinvertebrate taxa and MIRAI metrics collected in MR3.....	62
Table 4-5: Macroinvertebrate taxa and MIRAI metrics collected in MR4.....	64
Table 4-6: Macroinvertebrate taxa and MIRAI metrics collected in MR5.....	67
Table 4-7: MIRAI score sheet for MR1.....	69
Table 4-8: MIRAI score sheet for MR2.....	70

Table 4-9: MIRAI score sheet for MR3.....71

Table 4-10: MIRAI score sheet for MR4.....72

Table 4-11: MIRAI score sheet for MR5.....73

LIST OF FIGURES

Figure 1-1: Water scarcity in Africa including South Africa (Fischer and Heilig, 1997).....	2
Figure 1-2: Water use in South Africa (Markus, 2018).....	3
Figure 2-1: Seven steps for establishment of the RQO (Dickens <i>et al.</i> , 2011).....	11
Figure 2-2: The three additional steps added for RQO determination for the implementation of modified management (adapted from Dickens <i>et al.</i> , 2011).....	12
Figure 2-3: Water Management Areas in South Africa (NWRS, 2012).....	18
Figure 3-1: Sampling sites in the Loop Spruit and Mooi River as extracted from Erasmus (2017).....	32
Figure 3-2: Sampling sites in the Wonderfontein Spruit and Mooi River as extracted from Pretorius (2017).....	33
Figure 3-3: Map of the study area showing the Mooi River reaches. MR1 (blue), MR2 (orange), MR3 (green), MR4 (red) and MR5 (yellow).....	34
Figure 4-1: Macroinvertebrate assemblage abundance of the Mooi River catchment.....	56
Figure 4-2: A summary of the ecological category (EC) scores of the Mooi River macroinvertebrate assemblages.....	74
Figure 4-3: A summary of the metric group scores of the Mooi River macroinvertebrate assemblages; flow modification (FM), habitat preference (HP) and water quality (WQ).....	74
Figure 4-4: Macroinvertebrate habitat preference of the Mooi River macroinvertebrate assemblages; bedrock biotope (B) cobbles/stones biotope (C), vegetation (V), gravel, sand and mud biotope (GSM) and water column (W).....	76
Figure 4-5: Water quality preference of the Mooi River macroinvertebrate assemblages; highly sensitive taxa (HS), moderately sensitive taxa (MS), moderately tolerant taxa (MT), and highly tolerant taxa (HT).....	77
Figure 4-6: Macroinvertebrate velocity preference of the Mooi River macroinvertebrate assemblages; very fast flow (VF), moderately fast flow (MF), slow flow (S), very slow flow (VS).....	78
Figure 4-7: Hydraulic habitat preference of the Mooi River macroinvertebrate assemblages; riffles biotope (RI), pools biotope (P), rapids biotope (RA), and indifferent taxa (IND).....	79
Figure 4-8: Functional feeding groups of the Mooi River macroinvertebrate assemblages; predator (P), deposit feeder (DF), scraper (SC) filter feeder (FF), and grazer (GR).....	80
Figure 4-9: Modes of respiration of the Mooi River macroinvertebrate assemblages; tegument/cutaneous breathers (T/C), gill breathers (G), aerial: lungs, plastron and other apparatus (A).....	81

Figure 4-10: Body shape trait of the Mooi River macroinvertebrate assemblages; streamlined body (ST), flattened body (FL), tubular/cylindrical body (T/C), spherical body (SP) and variable taxa (V).....	82
Figure 4-11: Body size trait of the Mooi River macroinvertebrate assemblages; very small body (VS), small body (S), medium body (M), large body (L), variable body size (V).....	83
Figure 4-12: Modes of locomotion of the Mooi River macroinvertebrate assemblages; where climber (CL), crawler (CR), sprawler (SP), skater (SK), swimmer (SW), burrower (B), variable.....	84

LIST OF ABBREVIATIONS

DO	Dissolved Oxygen
DWA	Department of Water Affairs
DWAF	Department of Water Affairs and Forestry
DWS	Department of Water and Sanitation
EC	Ecological Category
EIS	Ecological Importance and Sensitivity
EPT	Ephemeroptera, Plecoptera and Trichoptera
EWR	Ecological Water Requirements
FFG	Functional Feeding Groups
GSM	Gravel, Sand and Mud
IUA	Integrated Units of Analysis
IWRM	Integrated Water Resource Management
MC	Management Class
MEA	Millennium Ecosystem Assessment
MIRAI	Macroinvertebrate Response Assessment Index
NWA	National Water Act
NWRS	National Water Resource Strategy
PES	Present Ecological Status
RCC	River Continuum Concept
RDM	Resource Directed Measures
RQO	Resource Quality Objective
RU	Resource Unit
SA	South Africa
SASS5	South African Scoring System version 5
TBA	Trait Based Approaches
TDS	Total Dissolved Solids
TSS	Total Suspended Solids
UL	Unit L
UN	United Nations
WMA	Water Management Area
WRCS	Water Resource Classification System
WReMP	Water Resources Modelling Platform
WRM	Water Resource Management
WWTP	Waste Water Treatment Plant

CHAPTER 1: INTRODUCTION

1.1. Background

All ecosystems need water to maintain their ecological processes and their associated communities of fauna and flora. With population increase and economic growth most river catchments are subjected to various ecologically unsustainable land use and development activities (Lake and Bond, 2007). Evidence has shown that freshwater ecosystems, rivers in particular, are amongst some of the most threatened ecosystems on earth, which is directly linked to the fact that the ecological integrity of rivers and other freshwater ecosystems is a direct reflection of all the activities taking place in the areas they drain (Dallas and Day, 2004).

Environmental change together with the increasing population size continue to increase pressure on ecosystems, especially on their functions as well as services (Millennium Ecosystem Assessment, 2005). Many river systems are exposed to a wide range of disturbances due to the rapidly growing human population because with an increase in human activities often comes degradation of water resource quality (Jun *et al.*, 2016). Even though aquatic biodiversity is assumed to be critical for the provision of many ecosystem services, the understanding and knowledge regarding links between biodiversity and ecosystem services is not always fully understood (Allan and Castillo, 2007). Exploring and understanding the different responses of biodiversity to human induced drivers as well as the effects of biodiversity on ecosystem services is key for the development of any future scenarios with regards to the effects of environmental change around the world.

South Africa (SA) receives an average annual rainfall of 497 mm per year, which is significantly less than the global average of 860mm (Mantel *et al.*, 2010). The country also experiences varying periods of floods and droughts that influences the amount of surface water found across S. A. In the western parts, hot dry conditions dominate that results in high evaporation rates. According to Fischer and Heilig (1997) global water scarcity would have affected an estimated 62% of the world population by the year 2030 (Figure 1-1). Freshwater pollution is further intensified by the ever increasing rate in agriculture, urbanization, deforestation and damming of rivers (Millennium Ecosystem Assessment, 2005). Water demands increase annually due to the constant rise in population numbers which gradually lead to increase in food production and supply as well as intensified industrial activities to meet the demand (Millennium Ecosystem Assessment, 2005). This also leads to increasing demand for different water users (Figure 1-2). In SA, a vast majority of water usage occurs in the agriculture industry which is also the country's largest income generator. The main use of water in the agricultural sector is by means of irrigation. The second

highest water users are urban areas where large numbers of various types of developments constantly take place. An increase in overall water scarcity and stress in SA has led to the implementation of strict water restrictions and management by government especially with the recent droughts from 2015 to 2017 (du Plessis, 2019). The significance of the value of ecosystem services to human well-being is recognised in SA, because of the links between biodiversity and human welfare (Le Maitre *et al.*, 2007). However, most human activities eventually contribute towards the pollution of freshwater bodies, which are already under threat from over exploitation.

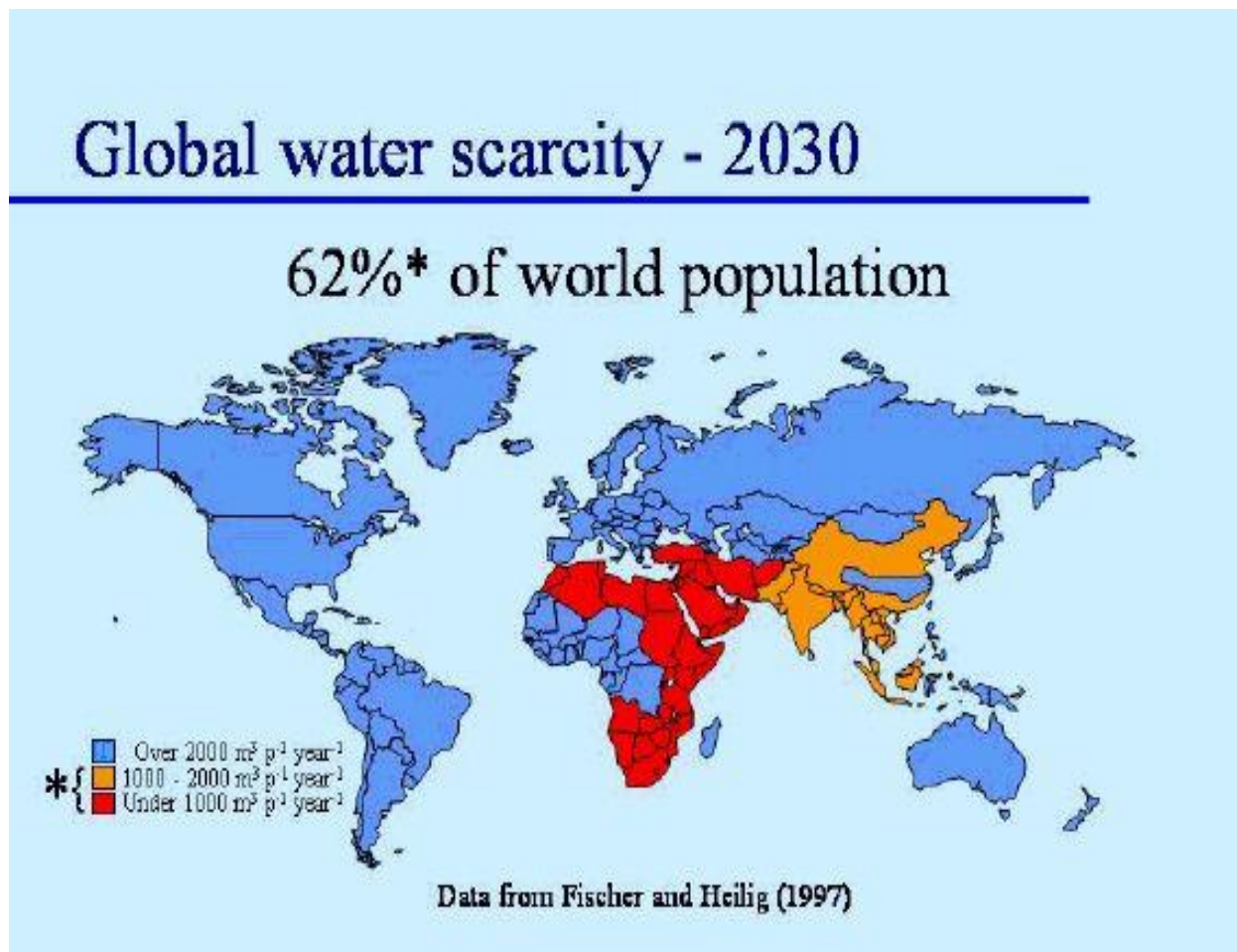


Figure 1-1: Water scarcity in Africa including South Africa 2030 (Fischer and Heilig, 1997).

In 1998, SA adopted a new water legislation that promoted equity, sustainability, representatively and efficiency through water management by decentralizing, new local and regional institutions; where registration and licencing is necessary. In SA, the Department of Water and Sanitation oversees all water related issues. It has a policy instrument known as the National Water Resource Strategy (NWRS) and its aim is to facilitate proper management of the nation's water resources, as well as provide a framework within which water resources can be protected, utilized, developed, conserved, managed and controlled (Pollard and Du Toit, 2008). This NWRS is also primarily

responsible for provision of a framework within which water will be managed at regional or catchment level in defined water management areas in the country (DWAF, 2004). The adoption of the legislation meant that water must be equally guaranteed for all, therefore water allocation can no longer be allocated to meet increased demand from agriculture, industry and other productive sectors. Water must also be allocated to satisfy the requirements for aquatic ecosystems and the ecological reserve; all of which meant that the responsibility for decision-making for water allocations would be decentralized to the capabilities of catchment management agencies (CMAs). In order to set sound guidelines for limiting the effects of economic or social impacts on biota, some measure of biological integrity or ecosystem health needs to be maintained (Dallas and Day, 2004). South Africa has a relatively strong history of water quantity management, with region-specific hydrology and systems models being developed that are routinely used in water resources management such as the Pitman and the Water Resources Modelling Platform (WReMP) systems models, modelling natural and human-altered flow respectively.

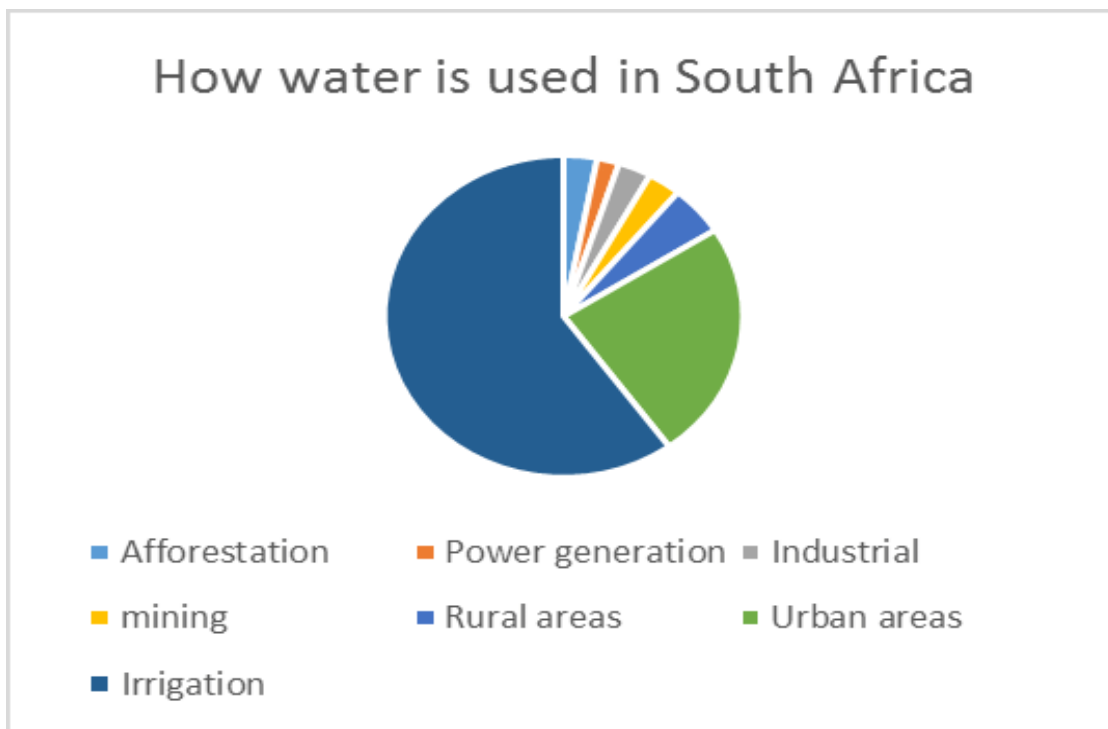


Figure 1-2: Water use in South Africa (Markus, 2018).

Ecological water requirements (EWR) quantify the water regime, in terms of quality, quantity and timing required for ensuring appropriate functioning and future persistence of water ecosystems; basically described, these are water regimes needed for supporting the ecological values of various water dependent ecosystems at a low levels of risk (VanLaarhoven *et al.*, 2004). The provision of water should be met after consideration of social, economic and ecological water requirements and may involve trade-offs between these requirements. In SA, EWR are sometimes

also referred to as ecological flow requirements. The South African Resource Directed Measures which were developed in 1999 in response to the National Water Act (Act 36 of 1998) have been consistently applied to different aquatic environments such as rivers in the country. The increasing competition between water users (Figure 1-2), decreasing water supply levels combined with increasing demand for freshwater are some of the major problems SA is facing (Hassan and Crafford, 2006). There is an anticipated rise in the demands on industrial and domestic water within countries and cities that are undergoing rapid economic growth; while the demand for power generation is also expected to grow (Bossa *et al.*, 2014)

Management of water quality requires attention and strict balance between protection of water resources and use of water resources (Karr, 1999). This balance leads to water usage being sustainable while taking the social, economic and environmental needs into consideration. Water quality monitoring requires that the chemical composition of effluent is measured and analyzed on a regular basis. The Department of Water Affairs and Forestry (DWAF, 1996a) set general as well as special standards for a selected range of variables which have to be met as end-of-pipe criteria, however there are limitations to this method because sampling of the water resource is on a monthly interval and therefore makes it difficult to accurately model concentration-duration trends. Taxonomic based approaches to biomonitoring compare the taxonomic assemblages of macroinvertebrate species such as composition, richness, diversity and abundance, and links them to environmental conditions (Culp *et al.*, 2011). Macroinvertebrate communities have been the most commonly used tool for making integrated assessments of water quality in rivers (Karr, 1999). Aquatic macroinvertebrate distribution patterns are the most frequently described in terms of taxonomic composition commonly expressed as the term community structure. Aquatic organisms may be able to tolerate these at low concentrations of toxic substances in the water, however it may be negatively affected when subjected to higher concentrations.

In SA, common biomonitoring approaches and tools have been developed to primarily focus on the assessment aquatic ecosystem structures through the analysis of the taxonomic structure of biota, such as the South African Scoring System version 5 by Dickens and Graham (2002) as well as the macroinvertebrate response assessment index by Thirion (2007). The linkage of trait responses to stressor gradients could advance the potential of assessments to identify the causes of pollution rather than to just identify the presence of pollution (Culp *et al.*, 2011). Trait Based Approaches (TBA) are also considered as more precise connectors of aquatic ecosystem structures and function (Doledec *et al.*, 1999). These TBAs might prove effective and extremely useful for improving ecosystem management and decision-making within the context of environmental change. South African rivers support a diverse and rich biota. However, the main focal point when dealing with topics of most aquatic studies; becomes specifically for the biodiversity, taxonomic

descriptions and the distribution of macroinvertebrate species (Statzner *et al.*, 2004). Effort should also be put towards developing realistic models using trait information to assess the structure and functioning of natural rivers since ecological information regarding macroinvertebrate traits is limited in the country; making this field and subject a necessary and fundamental part of research. Incorporating traits into other biomonitoring tools and methods can complement current approaches which address some of the challenges encountered by methods that rely only on taxonomic identification of biota (Van den Brink *et al.*, 2011). As mentioned, careful analysis of macroinvertebrate traits can also give reliable information on the ecosystem function of a given aquatic environment. Despite some TBAs in biomonitoring being applied in some areas of SA, the approach is not well established in the Mooi River catchment, North-West, South Africa. This project therefore aims to provide some scientifically based information with regards to the application of different macroinvertebrate traits within the aquatic ecosystem of the Mooi River catchment. The ecological impacts of land use on aquatic macroinvertebrates have been previously assessed by the application of Resource Directed Measures (RDM) tools such as the South African Scoring System (SASS 5) and the macroinvertebrate response assessment index (MIRAI). There is however, very limited information compiled on macroinvertebrate traits for the catchment.

1.2. Aim and objectives of the study

1.2.1. Aim

The aim of this study was to assess the macroinvertebrate responses in the Mooi River catchment using the macroinvertebrate response assessment index (MIRAI) and macroinvertebrate traits.

1.2.2. Objectives

The overall aim of the study was achieved through the following objectives:

1. To assess and evaluate the responses of the macroinvertebrate assemblages in the Mooi River catchment through the application of the Macroinvertebrate Response Assessment Index (MIRAI) (Thirion, 2007).
2. To assess and evaluate the functional assemblage structure responses of the macroinvertebrates through the application of traits in the Mooi River catchment.
3. To assess complementarity of MIRAI and macroinvertebrate trait responses in the Mooi River catchment.

4. To critically evaluate the complementarity of incorporating macroinvertebrate traits or Trait Based Approaches in ecological water requirements for the Mooi River catchment.

The above objectives were prompted by the following research questions:

- i. How do macroinvertebrate assemblages in the Mooi River catchment respond to disturbances?
- ii. How do macroinvertebrate functional assemblages in the Mooi River catchment respond to disturbances?
- iii. Will the responses of macroinvertebrate functional assemblages complement the responses from the MIRAI?
- iv. What value can be derived by using macroinvertebrate traits as a complementary approach in EWR?

1.3. Hypothesis

The macroinvertebrate assemblage responses and functional structures will reflect the presence of disturbances in the aquatic ecosystem of the Mooi River catchment.

1.4. Mini-dissertation structure

The application of the macroinvertebrate response assessment index (MIRAI), macroinvertebrate functional trait composition as well as interpretation thereof are the two main themes explored in this dissertation. The dissertation can further be divided into the following main parts:

Chapter 1: This provides a general introduction to the importance and initiation in the assessment of macroinvertebrate assemblage responses as well as the application of macroinvertebrate assemblages' functional information within Ecological Water Requirements (EWR) for biomonitoring of the Mooi River catchment.

Chapter 2: This provides reviews of existing literature for the scope of the study in a broad context. Subjects covered in the chapter are the water legislation, resource directed measures, resource quality objectives, water management areas, EWR, impacts in the Mooi River catchment, biomonitoring, and macroinvertebrate traits as applied in EWR.

Chapter 3: This chapter provides a detailed description of the study area including maps. The chapter describes sampling sites and sampling procedures. The methodologies used in the assessments and data analyses are also explained.

Chapter 4: This chapter provides the results of the assessments described in Chapter 3. The responses of the macroinvertebrate assemblages are captured from flow, habitat and water quality modification metrics and the Ecological Categories of the catchment are determined. The results of family-level traits data and their corresponding categories are expressed in the form of percentages within column charts.

Chapter 5: This chapter provides a discussion on the results in Chapter 4, namely the MIRAI and its applicability and sensitivity in defining ecological categories for impacted sites within the Mooi River catchment. Herein again, the use and examination of macroinvertebrate trait application for the impacted sites is discussed.

Chapter 6: This chapter provides conclusions and recommendations expressed from the study.

Chapter 7: All references used in the study are provided in this chapter.

CHAPTER 2: LITERATURE REVIEW

2.1. South African National Water Act (NWA) (Act No. 36 of 1998)

Human activities such as urbanization have had some significant contribution towards the impacts on the ecological environment with one such major alteration being the global hydrological cycle (Davies *et al*, 2010). Water resources require good management practices in order to become sustainable enough to promote social and economic development, while also sustainably maintaining aquatic fauna and flora. The National Water Act (Act No. 36 of 1998) governs all types of surface and groundwater resource usage in SA (DWAF, 1998). Behind the National Water Act (NWA) there are various other detailed legislation regarding the different uses of water in the country. Chapter 1 of the Act, and some of its fundamental principles are listed. These principles include the sustainability and equity in the use of all water resources which indicates the levels of protection, use, development, conservation, management and control of all water available water resources.

The NWA gives two rights to water, namely to basic human needs and towards the protection of aquatic ecosystems to secure ecologically sustainable development and use of the relevant water resource (DWAF, 1998). Chapter 2 Part 1 of the Act refers to strategies aimed at facilitating appropriate management of water resources. The ecosystem orientated objectives of the NWA are conceived in the National Water Resource Strategy 2 (NWRS2) (2013), which is improving on the first NWRS developed in 2004 to facilitate effective implementation of NWA, as it describes how the water resources of SA will be protected, used, developed, conserved, managed and controlled through compliance with the requirements of the policy and law (DWAF, 2004). Under NWRS2 there are two integrated water resource approached, namely, resource directed measures (RDM) and Source Directed Controls (SDC). The NWRS2 therefore aims to strike a balance between the use and protection of SA's water resources.

In the Act, the protection of the water resource is therefore legalized through the concepts of the Reserve, classification and resource quality objectives. The resource quality objectives (RQO) for a water resource are described and expressed as a numerical or descriptive statement of the conditions which should satisfy and meet the requirements of the water resource with regards to the quality. The RQOs encapsulate the ecological needs as well as the management class into gaugeable management goals, that are used to inform and direct resource managers in terms of how resource needs should be managed (DWAF, 1999).

The ecological reserve means the quantity and quality of water required for protection of aquatic ecosystems in order to ensure ecologically sustainable development and use of the relevant water resources (DWAF, 1998). The purpose of the RQOs according to the NWA is to set well-defined goals pertaining to the quality of the water resources. The NWA therefore brings to attention the importance of the balance between the need to protect and to use a water resource. Furthermore, NWA also expresses that upon determination of the class and RQOs of a water resource, they become obligatory on all authorities and institutions when exercising any power or performing any duty under this act (DWAF, 1998; Dickens *et al.*, 2011). The NWRS, section 3.1.2.3 states that resource quality objectives (RQOs) provide a descriptive and numerical narrative about the chemical, biological and physical characteristics, which take and consider the class and user requirements for a particular water resource (DWAF, 2004). The RQOs may therefore give an interpretation for the condition and character of the water quality, habitat, flow conditions and aquatic biota.

2.2. Resource Directed Measures (RDM) (DWAF, 1999)

The availability and use of water resources continues to hinder economic and societal development efforts due to scarcity. The earth's water resources are 97% salt water leaving only 3% remaining as freshwater which has uneven distribution (Kale, 2016). Only 1% of the available 3% is accessible for usage to the in the form rivers, lakes, and ponds (Davies and Day, 1998; Kale, 2016). The aim of RDM is to warrant that water resources are protected, by ensuring adequate ecosystem protection, functioning while also upholding a good state of health of aquatic and groundwater dependent ecosystems. The RDM manual (DWAF, 1999) is a document containing series of 15 volumes made up of: Resource Directed Measures for Protection of Water Resources in SA. Volume 3 of the manual focuses on RDM for River Ecosystems. The RDM are aimed at protection and using water resources in a sustainable manner with regards to water quality, ecological and riparian conditions (DWA, 2013).

The RDM is made up of the national water resource classification system, ecological reserve and the resource quality objectives (RQOs) (DWAF, 1999). Management classes of a water resource are allocated in the classification stage of the RDM process, where Classes I, II and III are assigned to a water resource according to the severity of human induced impacts on such a resource. Class I indicates a water resource that has minimal human impacts or pollution and Class II resources are those that are moderately impacted. Water resources placed in Class III are those that show the most serious changes from natural conditions (DWAF, 2008b; DWA, 2013). Water resources placed in Classes I and II are well managed in order to preserve their good state while Class III resources are adequately monitored to improve their deteriorated state based on

certain scenarios. The legal aspect of protection and quality, quantity and sustainability assessment of resources is placed on the reserve part of RDM. The reserve is the quantity and quality of water in a specific resource. The reserve must be assessed and monitored for excessive abstraction and regulation of flow as well as release of effluent discharge, however this may be difficult because flow-biota relationships may present limitations in deriving cause-effect relations of interacting variables (DWAF, 1999).

2.3. Resource Quality Objectives

The numerical or narrative objectives which are set for instream habitat and are also set according to the rules associated with each ecological management class, RQOs are legally binding. They also express the acceptance or unacceptance of pollution impacts and activities on a water resource. Furthermore, an RQO is a tool that may be able to give a steady time frame for decision making and planning for use of the resource (Dickens *et al.*, 2011). Qualitative and quantitative information about quality, size, habitat and living conditions of a water resource for sustainable use are obtained from RQO (Dickens *et al.*, 2011). Determination of the ecological reserve involves determination of present ecological state (PES) of that particular water resource. In order to determine the PES of a water resource, the biological, physical and chemical data is required. Information on macroinvertebrates, fish, riparian vegetation, geomorphology, hydrology and physico-chemical variables have to be collected.

As a means of safeguarding a certain desired level of protection, RQOs have to be determined for all significant water resources. Resource quality objectives as defined by the NWA are “clear goals relating to the quality of the relevant water resources”. These goals are scientifically derived criteria (Dickens *et al.*, 2011). There are steps which need to be followed in the process of determining RQOs as illustrated in Figure 2.1. There are additional steps by Dickens *et al.* (2011) which were incorporated in the process for implementation, monitoring and compliance as well as the review of RQOs. The steps were added so as to complete the modified management cycle of a water resource. The implementation portion involves decision making processes on the designated assignment of water resources to different users to support and implement the set RQOs. Management of a resource by means of applied RQOs is beneficial because focus is maintained mainly on managing numerous problems originating from various water demands placed on a particular resource. This approach is not only centered around the effect of individual discharges, but also on the overall effects from the diverse range of discharges. Overall limits of pollution variables are set to align with the required water use (Dickens *et al.*, 2011).

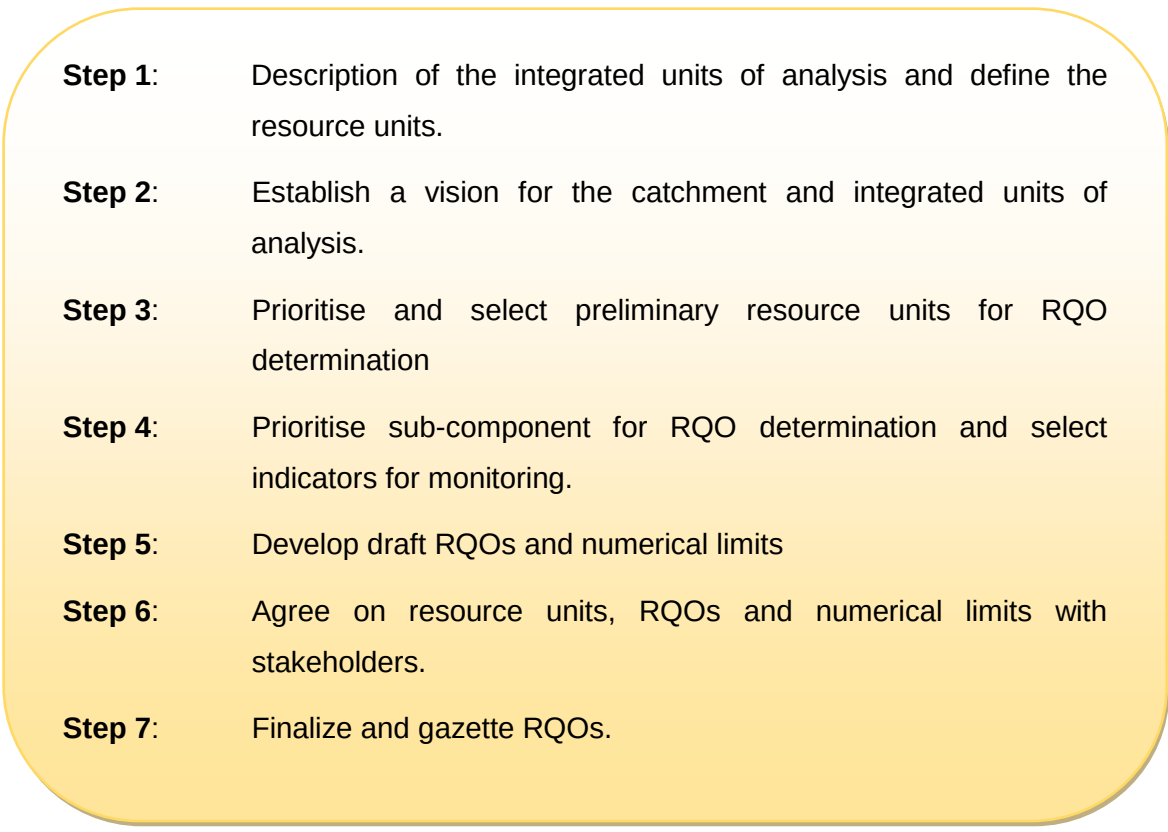
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- Step 1:** Description of the integrated units of analysis and define the resource units.
 - Step 2:** Establish a vision for the catchment and integrated units of analysis.
 - Step 3:** Prioritise and select preliminary resource units for RQO determination
 - Step 4:** Prioritise sub-component for RQO determination and select indicators for monitoring.
 - Step 5:** Develop draft RQOs and numerical limits
 - Step 6:** Agree on resource units, RQOs and numerical limits with stakeholders.
 - Step 7:** Finalize and gazette RQOs.

Figure 2-1: Seven steps for establishment of the RQO (Dickens *et al.*, 2011).

The extent of the available data could inform whether the RQO is numerical or descriptive and how the RQOs are applied is influenced by the level of confidence within which the specific RQO has been determined. The Mooi River catchment was divided into two resource units (Table 2-1), with their respective RQOs for water quality, riparian habitat and instream biota (DWAF, 1999). Extra steps taken in the determination of RQO are implementation, monitoring and compliance and review (Figure 2-2). The implementation part is the decision making on the assignment of water resources to various users to support and implement the RQO. The levels of monitoring and compliance depends on the type of use for the water resource. Finally, the review process involves the regular assessment of whether set RQO goals are being achieved or at least moving in that direction. According to Boyd *et al.* (2010), it would be beneficial to divide catchments into smaller more manageable units in ecosystems where there is different variation in water use. Therefore, each resource unit could be allocated its own RQOs and this could improve finer scale identification and management of pollution problems.

Water quality RQOs gazetted for the Mooi River include nutrients and salts (Table 2-1). Nutrient enrichment is a frequent problem in well-developed catchments (Davies and Day, 1998). As it is also indicated in the RQOs of the Mooi River catchment. An increase of nutrients in water is characterized by an increased production of algae and aquatic macrophytes, which may interfere

with numerous water uses. Nitrates and nitrites are normally used to indicate if water has been contaminated with discharge of treated sewage water (DWAF, 1996). Phosphorus is one of the controlling elements towards the degree of eutrophication in most catchments (Dallas and Day, 2004). Salinity (EC) refers to the concentration of salts in the water and it affects aquatic organisms, unnatural levels thereof may result in altered distribution patterns of species which affects the ecological health of ecosystems (Dallas and Day, 1998). For instream biota, specifically macroinvertebrates, the rating value for EC for D categories (DWS, 2016) has been set a limit of $\geq D$ (≥ 42).

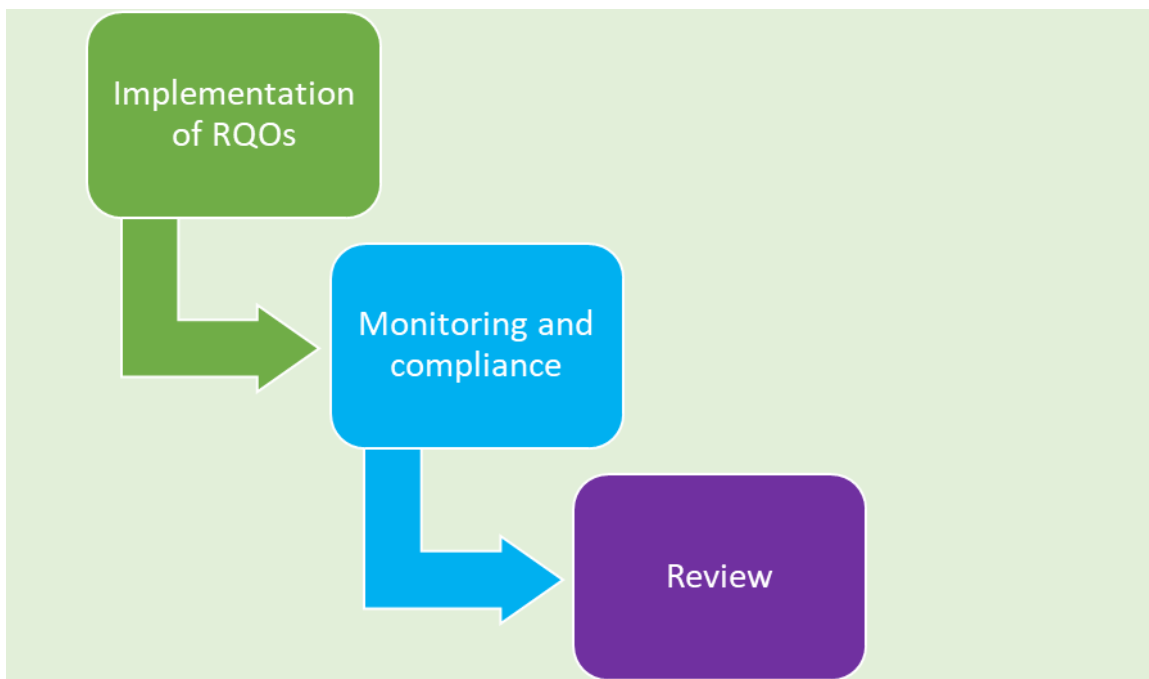


Figure 2-2: The three additional steps added for RQO determination for the implementation of modified management (adapted from Dickens *et al.*, 2011).

Table 2-1: Resource Quality Objectives (RQO) numerical limits set for Mooi River as gazette for the Upper Vaal catchment (DWS, 2016).

IUA	Class	RU	REC	RQO	Numerical Limits
Water quality	III	71	D	The nutrients should be improved to an acceptable state. Salts need to be improved to levels that do not threaten the ecosystem and to provide for users. The river water should not be toxic to aquatic organisms or be a threat to human health. Uranium concentrations need to be at acceptable levels.	≤ 0.125 mg/L (P) ≤ 4.00 mg/L (N) ≤ 111 mS/m (EC) F ≤ 3.0 mg/L, Al ≤ 150 μg/L, As ≤ 130 μg/L, Cd ≤ 5.0 μg/L, Cr ≤ 200 μg/L, Cu ≤ 8.0 μg/L, Hg ≤ 1.70 μg/L, Mn ≤ 1300 μg/L, Pb ≤ 13.00 μg/L, Se ≤ 30 μg/L, Zn ≤ 36 μg/L, Chlorine ≤ 5.0 μg/L, Uranium ≤ 15 μg/L
		73	D	The nutrients should be improved to an acceptable state Salts need to be improved to levels that do not threaten the ecosystem and to provide for users.	≤ 111 mS/m (EC) ≤ 0.125 mg/L (P) ≤ 500 mg/L (sulfates)

Table 2-1: Continued.

Riparian habitat	III	71	D	The riparian zone must be in a largely modified or better condition. Riparian vegetation must be in a largely modified or better condition. Low and high flows must be in a largely modified or better condition.	Riparian Zone Habitat Integrity category $\geq$ D ($\geq$ 42) Riparian EcoStatus category $\geq$ D ($\geq$ 42) Hydrological category $\geq$ D ($\geq$ 42)
	III	73	D	The riparian zone must be in a largely modified or better condition. Riparian vegetation must be in a largely modified or better condition. Low and high flows must be in a largely modified or better condition.	Riparian Zone Habitat Integrity category $\geq$ D ($\geq$ 42) Riparian EcoStatus category $\geq$ D ($\geq$ 42) Hydrological category $\geq$ D ($\geq$ 42)

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Table 2-1: Continued.

Biota	III	73	D	Instream habitat must be in a largely modified or better condition to support the ecosystem. Instream biota must be in largely modified or better condition. Flows must be in largely modified or better condition. Low flows must be suitable to support the ecosystem functions. Water quality: The nutrient concentrations must be decreased for ecosystem condition and other users. Salt concentrations must be at levels that do not threaten the ecosystem and are suitable for users.	Instream Habitat Integrity category $\geq$ D ($\geq$ 42) Fish ecological category $\geq$ D ($\geq$ 42) Macroinvertebrate ecological category $\geq$ D ($\geq$ 42) Instream EcoStatus category $\geq$ D ($\geq$ 42) Hydrological category $\geq$ D ($\geq$ 42) Water Quality category $\geq$ D ($\geq$ 42)
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The development of a system used in the classification of a water resource is described by the National Water Act (Act 36 of 1998) as the first step in preserving and managing a water resource (Dickens *et al.*, 2011). The indicators used for RQO may include chemical and physico-chemical, biological and hydro-geomorphological characteristics of the water resource, such as for Mooi River RQO (Table 2-1). The selection of an indicator is important as it must provide information regarding the bigger picture. It should be able to track a measureable change over time, without measuring everything. Criteria used to choose indicators for use as RQO are listed by Dickens *et al.* (2011). The Mooi River is a Management Class III rivers which means that it suffers from heavy impact of human use and is significantly changed from natural due to the human activities but still ecologically sustainable.

2.4. Water Management Areas (WMA) in South Africa

Strategic water source areas have the ability to support and sustain growth including the development needs of a country or region. In the context of SA, water management areas (WMA) are of particular importance because of their significance in enhancing downstream water quality and quantity. As has been established, the country's surface water resources have become extremely limited and SA is considered to be one of the driest countries (per capita), with 98 per cent of its surface water already developed however the country also has a growing water quality problem (Ashton, 2007). South Africa's national Department of Water Affairs previously divided the country into nine Water Management Areas (WMAs), each containing a large river system (NWRS, 2012).

The Vaal Water Management Area is subdivided into the upper, middle and lower regions, where the Mooi River catchment is located on the upper region of the WMA (Figure 2-3). The upper region of the WMA lies on the eastern central part of SA which includes the Vaal River, Klip River, Wilge River, Liebenbergsvlei River and Mooi River. It extends up until the confluence of the Mooi and Vaal Rivers. The WMA also includes reservoirs such as the Vaal Dam, Grootdraai Dam, Boskop Dam, Potchefstroom Dam and Sterkfontein Dam. The southern parts of the WMA extend over the Free State Province while the north-eastern parts are within Mpumalanga Province. Gauteng and North-West Provinces form the north and western parts of the WMA (DWAF, 2004; Labuschagne, 2017). Upper Vaal WMA is an important WMA to the economy of the country and for future development. The three main secondary catchments of the Upper Vaal WMA are all characterized by different types of development, and future growth in these regions. Presently, water use sectors in the WMA include the Ecological Reserve (environmental and in-stream requirements), domestic consumers (urban and rural), bulk water consumers (mines and coal-fired thermal power stations), agriculture (cultivation, livestock and game farms), afforestation, alien

vegetation and consumers involved in water transfers (Pitman and Lauchli, 2002). There are 15 integrated units of analysis (IUA) in the Upper Vaal region with the Mooi River found in Unit L (UL). The IUAs are placed categorically in terms of their degree of acceptable utilization and protection as either Class I which is indicative of high environmental protection and minimal utilization, Class II indicative of moderate protection and moderate utilization as well as Class III which indicates sustainable minimal protection and high utilization of the resource (DWS, 2016). At the end of the RQOs determination processes, RQOs are defined for each prioritized hydrological node for every IUA in terms of water quantity, quality, habitat as well as biota.

The Mooi River catchment is located in the North West Province and is a significant water resource forming part of the Upper Vaal WMA; water for the city of Potchefstroom is abstracted from the Boskop Dam for purification and domestic use (Annendale and Nealer, 2011). Mines were first introduced to the Mooi River catchment in 1887, however due to the numerous mining activities taking place on the West Rand and the far West Rand regions, the Mooi River has been subjected to high volumes of mining pollution (Winde and Wade, 2006). All information obtained at a biological level contributes immensely towards the determination of RQO. The determination of the class of water resources and RQO of the Upper Vaal WMA has been completed and gazetted (DWS, 2016) in terms of Section 13(1) and (B) of the National Water Act (Act 36 of 1998).

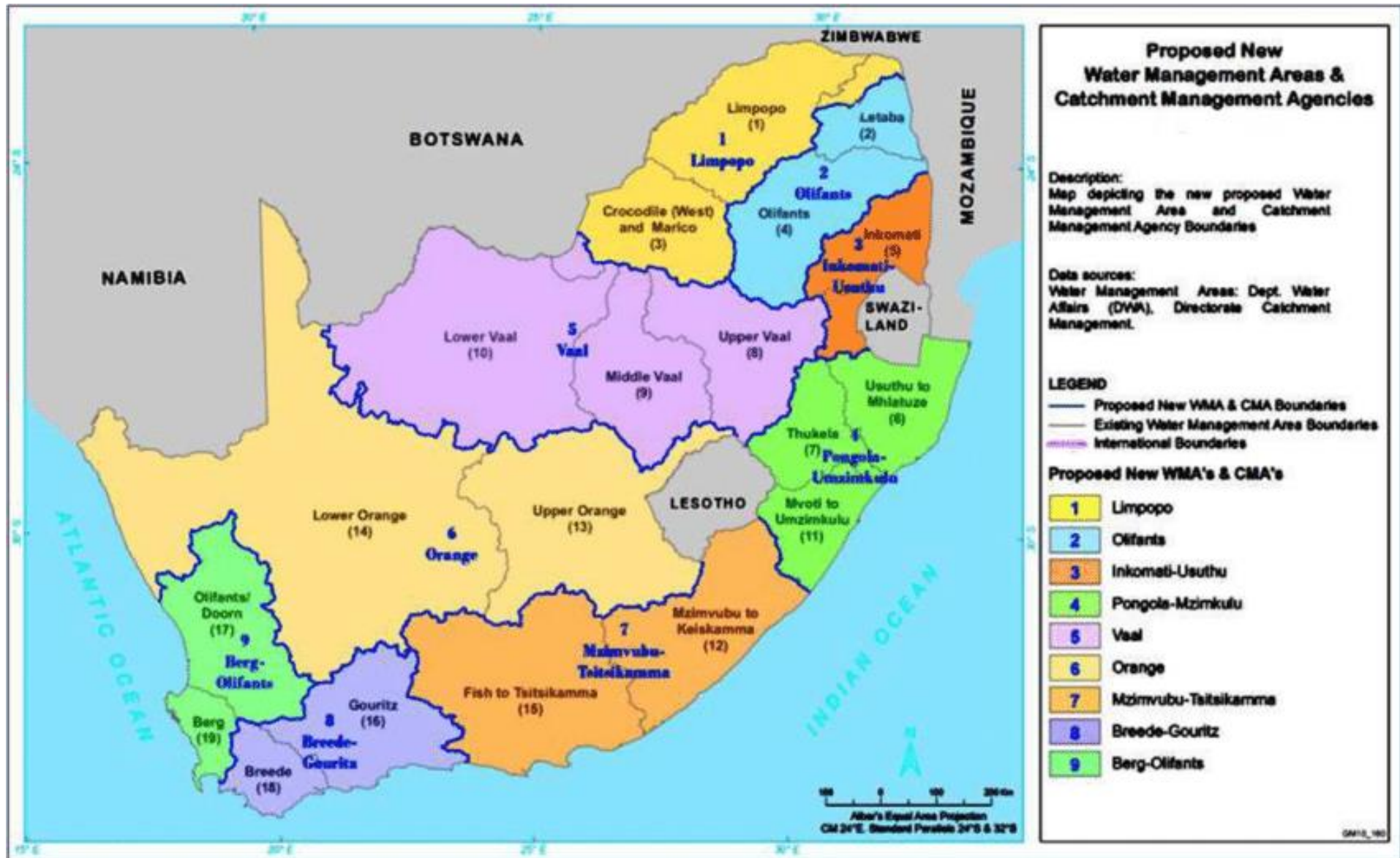


Figure 2-3: Water Management Areas in South Africa (NWRS, 2012).

2.5. Ecological Water Requirements (EWR)

The demand for freshwater is continually increasing with the growth of human populations around the world and rivers contribute 3% of the available freshwater, making them the main sources of freshwater. Societies benefit greatly from rivers. It is known that humans' existence depends greatly on water resources, as well as the various goods and services provided by these water resources (Karr, 1999). The goods and services supplied by river systems include water supply; wastewater transport; processing and dilution; natural resources, aquatic and riparian biodiversity conservation; flood control; and spaces of worship and rituals for surrounding communities. Ecosystem services were defined as a variety of benefits which people receive from the ecosystem (Millennium Ecosystem Assessment, 2005). The various benefits can therefore be used as a tool that informs or supports any decision making processes associated with human-environmental systems. According to Le Maitre *et al.* (2007), these services can range from products such as food, stabilizing and regulatory services as in disease control, and other life-enhancing functions such as recreational and spiritual environments. In the SA context, clear links have been established between biodiversity and human welfare in both commercial and subsistence sectors (Le Maitre *et al.*, 2007).

Ecological Water Requirements (EWR) are described as the optimal hydrological regime for maintaining valuable features and functions of aquatic ecosystems (Tharme, 2003). In RDM, the EWRs basically quantify the water regime in terms of quality, quantity and timing that is required to ensure the adequate functioning and future persistence of aquatic ecosystems. With reference to the reserve classification of the RDM, Step 3 requires that the EWRs of a catchment or study area be quantified. The main objective of this step in the WRCS is to provide necessary ecological and Reserve data which will inform and enable the determination of the Management Class (MC) of all significant water resources within the catchment or study area by means of quantifying the EWRs and describing all possible changes in non-water ecosystem goods, services as well as attributes at the established EWR sites and at the biophysical nodes to which the Reserve data can be extracted. Comprehensive EWR studies provide the highest level of confidence within the given water resources.

An underlying principle of the National Water Act (Act 36 of 1998) and the water resource strategy is the protection of the water resource in order to ensure long-term and sustainable use for people depending on that particular water resource. This therefore demonstrates a clear link between resource protection, sustainability and goods and services provided by the resource or catchment. With regards to water quality management, the National Water Act (Act 36 of 1998) states that the classification system for water resources may establish procedures which are designed to satisfy

the water quality requirements of water users as far as is reasonably possible, without significantly altering the natural water quality characteristics of the resource. The water quality should include all aspects of a water resource that is beyond quantitative and ecological aspects; and also inclusive of the physical, chemical and biological characteristics of the water (NWA, 1998).

2.6. Impacts on the Mooi River catchment

The Mooi River catchment is situated in western Gauteng and North-West Province of SA. The catchment has an area of 1800 km² and forms part of the Vaal River catchment area (van der Walt *et al.*, 2002; Tlokwe City Council, 2014). The Mooi River is a tributary of the Vaal River and according to Kleynhans *et al.* (2005), the river is located in Ecoregion 11, the Highveld ecoregion which is approximately 1400 m to 1800 m above sea level. The Mooi River consists of three major sub-catchments namely, the Wonderfontein Spruit on the north-eastern reach; the Mooi River proper on the northern reach as well as the Loop Spruit on the eastern reach. In the 1930s, large scale gold mining began in the Wonderfontein Spruit sub-catchment which is still evident in Krugersdorp, situated on the upper catchment side, and Carletonville in mid-catchment areas of the West Rand. This catchment is home to some of the richest gold mines in the world; water from the gold mines, industrial and urban areas as well as informal settlements drains into the Wonderfontein Spruit sub-catchment which contributes to the contamination of the water in the Mooi River. The geology of the catchment comprises mainly of dolomite which are divided into several compartments (van der Walt *et al.*, 2002). The Mooi River and its tributaries are recharged through several dolomitic eyes by the precipitation that ends up as ground water recharge (Winde and Van der Walt, 2004). The lower parts of the Wonderfontein Spruit are dominated by farming and mining activities. The confluence of the Mooi River and the Wonderfontein Spruit is situated upstream of the Boskop Dam where land use in the northern sub-catchment is predominantly crop and livestock farming with small scale diamond mining taking place in the stream channel between Klerkskraal and Boskop. The Mooi River State Water Scheme was established between the Boskop and Potchefstroom dams to supply water for irrigation to approximately 4750 ha of land.

The Loop Spruit sub-catchment (eastern) is also characterized by livestock and crop farming. This sub-catchment joins the Mooi River downstream of the city of Potchefstroom. Potchefstroom is located in between Potchefstroom Dam and the Mooi River-Loopspruit confluence. Since 1842, the Mooi River has been the main source of water for the town which currently has a population of around 179 604. (Statistics SA, 2016). An ecologically healthy Mooi River system is important for maintaining the quality of potable water of Potchefstroom and surrounding areas. However, this system is under constant threat from anthropogenic pollution arising from both agricultural and mining activities in its catchment (Venter *et al.*, 2013). River condition is assessed through a variety

of methods or techniques which indicate the general condition or health of a river as it is influenced by water quality. The Mooi River is currently classified as a class III water resource, which means that it is heavily impacted by human activity but still maintains a degree of ecological sustainability. The recommended ecological category for the Mooi River is C/D, indicating it is moderately to largely modified (DWA, 2016).

2.7. Macroinvertebrates in biomonitoring

Freshwater ecosystems are now tallied among some of the most endangered ecosystems in the world and this is further exacerbated by the decline in freshwater biodiversity which is extremely greater than in most affected terrestrial ecosystems (Mangadze *et al.*, 2019a). In the beginning biomonitoring was based mainly on chemical measure, however the incorporation of biological parameters soon followed (Bonada *et al.*, 2007). South Africa experiences unpredictable and variable rainfall distribution that can modify flow regimes and ecological conditions therefore also altering aquatic biota (Mantel *et al.*, 2010. Louw *et al.*, 2013). The lack of identification keys to species level within macroinvertebrate based biomonitoring indices in SA has led to development of keys that require only family level identification (O'Keeffe and Dickens, 2000). The successful management of river ecosystems and changes in river systems resulting from human or natural influences, need to be assessed and measured. Macroinvertebrates have been used extensively in bioassessments in SA, where assessment tools such as SASS5 (Dickens and Graham, 2002) and the Macroinvertebrate Response Assessment Index (MIRAI) (Thirion, 2007) are most common, however recently these tools have been applied in EWR studies as well (Ollis *et al.*, 2006).

According to Nel *et al.* (2018), sustainable utilization of our freshwater ecosystems is critical to developing emerging economies and the well-being of all citizens therefore biological monitoring programs have gained momentum in Southern African countries as an integrative approach for assessing effects of environmental stressors on aquatic ecosystems. In many developing countries, there is a rapidly growing and urgent need to characterize the diversity, structure, and function of freshwater ecosystems as a result of increasing pressure from population growth and other environmental impacts (Allan and Castillo, 2007). Macroinvertebrates make good candidates to assess aquatic ecosystem quality since they can respond in many ways to environmental stresses (Rosenberg and Resh, 1993). The challenge lies in mitigating trends and practices that cause harm to in order to improve the current condition of water resources (Masese *et al.*, 2013).

Taxonomic based approaches apply several metrics such as single metrics and indices and multi metric indices developed and used in biomonitoring based on macroinvertebrate community

structure. In Africa, a majority of macroinvertebrate based biomonitoring focuses on the family level taxonomic identification because of its cost effectiveness and availability of macroinvertebrate identification keys (Akamagwuna *et al.*, 2019). Biomonitoring uses various approaches, including the derivation of indices that reflect general ecological degradation such as the EPT index by Wallace *et al.* (1996). Other indices like the Hilsenhoff index are aimed at more specific types of stressor impacts therefore expressing the community response in relation to low oxygen levels that may come as a result of organic enrichment (Hilsenhoff, 1988). Ephemeroptera, Plecoptera and Trichoptera (EPT) taxa are frequently used in assessments because they represent one of the most diverse groups of macroinvertebrates occupying all types of habitat, have a wide range of sensitivities to stressors and their taxa richness is a widely used parameter for analysis (Lenat and Barbour, 1994). The EPT occupy almost all habitat and biotope types, can inhabit both fast-flowing and slow-flowing rivers of any size (Mereta *et al.*, 2013).

The use of family level data during rapid biomonitoring methods based on macroinvertebrates in rivers has been widely received because of its cost effectiveness, and ease (Marshall *et al.*, 2006). Adaptation and strengthening of any existing biotic indices as a reliable source of pollution identification is an important part of biomonitoring (Wallace *et al.*, 1996). In SA, the national program for assessing ecosystem status of rivers known as The River Eco-Status Monitoring Program (REMP) was designed and implemented in SA. The REMP is a component of the National Aquatic Ecosystem Health Monitoring Program (NAEHMP) of SA and it replaced the River Health Program (RHP) in 2016 (DWS, 2016). Large-scale river assessment programs are able to provide data in sufficient and specific detail, sample size, and scale to inform ecological knowledge (O’Keeffe and Dickens, 2000). In SA, the macroinvertebrate response assessment index (MIRAI) is one of the methods used as part of a group of models used in assessing ecological status (Thirion, 2007; Kleynhans *et al.*, 2008); the index also forms part of the REMP whose purpose is to monitor ecological conditions in river ecosystems as shown by instream and riparian drivers and responses.

In most biomonitoring assessments, the assessment of the ecological health and water quality of a stream tends to be biased towards the analysis of physical and chemical properties with less focus on biological monitoring (Bonada *et al.*, 2007). South African perspectives in river assessment still focuses mostly on the presence and/or absence of certain biota while also looking at the taxonomic analysis of these biota (Kleynhans *et al.*, 2008). Aquatic macroinvertebrates have a critical role in the assessment of river ecosystems in SA. Macroinvertebrate communities offer a good reflection on the existing flow regimes and water quality of a river. They are significant processors of different organic matter within rivers serving as water purifiers in the water. They provide a valuable source of food for larger animals within and even outside the river system (O’Keeffe and Dickens, 2000). The productivity of organisms within a stream is determined by, amongst others, the physical

structure, water quality, energy inputs as well as the flow regime of the stream. There are several different biomonitoring techniques currently available for application in river ecosystems. Selecting an appropriate technique depends on the different environmental issues being addressed and most significantly on the available resources. Biomonitoring methods include diversity indices, biotic indices, multi-metric approaches, and multivariate approaches. Trait Based Approaches are a promising area for the use of biomonitoring data in causal diagnosis by use of phenotypic characters of taxa in the area of traits analysis. The inclusion and incorporation of traits into already existing biomonitoring methods and in newly developed TBAs is perceived to enhance the predictive and diagnostic capabilities of biomonitoring tools therefore providing links between freshwater ecosystem structure and function (Doledec *et al.*, 1999).

2.8. Macroinvertebrate Response Assessment Index (MIRAI)

Aquatic macroinvertebrates have been used more commonly than any other group in the assessment of biological integrity of stream ecosystems. They form an integral part of a river ecosystem because their assemblages and communities offer a good reflection of the prevailing flow regime and water quality in a river (O' Keeffe and Dickens, 2000). There are four major components of a stream system's productivity required by macroinvertebrates, namely, flow regime, physical habitat structure, and water quality and energy inputs. Any interactions between these factors may result in the discontinuous or patchy distribution patterns of aquatic macroinvertebrate populations (Cummins *et al.*, 2005). As such aquatic macroinvertebrates are expected to respond to habitat changes or changes in driver conditions. The MIRAI is part of an EcoClassification process, developed by Thirion (2007). The approach uses macroinvertebrate abundance and presence, as well as macroinvertebrate preferences for flow modifications, habitat preferences and water quality when determining the Present Ecological Status (PES) of macroinvertebrates. The result is the Ecological Category (EC), which is a basic indication of the river condition as a percentage of what it should be or the expected.

In order to relate drivers to changes in the habitat and aquatic macroinvertebrate condition, two key elements are required. Firstly, habitat preferences and requirements for each taxon present should be obtained and from this point reference conditions can be established against which any response to drivers can be measured. Secondly, habitat features should be evaluated in terms of their suitability and requirements mentioned in the first point. This will result in expected and actual patterns that can be evaluated to achieve ecological category (EC) rating for the macroinvertebrates. Based on key requirements, the MIRAI provides an approach to deriving and interpreting aquatic macroinvertebrate response to driver changes (Thirion, 2007). Even though the MIRAI can be determined by using data and information collected during a standard SASS survey

(Dickens and Graham, 2002), it can also be determined using more detailed information. According to Thirion (2007), the following approach should be undertaken to relate drivers and the resultant habitat to the aquatic macroinvertebrate condition. Information on the habitat preferences and requirements of each of the taxa present should be obtained. A draft spreadsheet that includes a semi-quantitative rating of the intolerances based on SASS weights, habitat preferences and velocity preferences should be included in the MIRAI. In the case of limited or insufficient database, available literature and local experts should be consulted. Habitat features should be evaluated in terms of their suitability as well as the requirements of the aquatic macroinvertebrates inhabiting the region. Assessment of habitat integrity as well as that of the response of the macroinvertebrates based on the habitat template means that the MIRAI indirectly incorporates habitat integrity as part of the index. The MIRAI rating approach is composed of four different metric groups which measure deviation of the macroinvertebrate assemblage from the reference assemblage condition (Table 2-2).

The deviation is measured for flow, habitat and water quality modifications, as well as system connectivity and seasonality (Thirion, 2007). The four metric groups are combined to derive the macroinvertebrate EC. The metric group that will best represent the response of macroinvertebrates in a particular river or site is allocated a rank of 1 with a corresponding weight of 100%. The fourth metric group not mentioned above is system connectivity and seasonality. This metric is applied only when the reference taxa include species that are migratory as well as in situations where there are seasonal differences involved. This metric was therefore not included in the initial assessment; it should therefore receive a weight of 0%. The MIRAI model then automatically calculates the EC based on the percentage of reference. The flow regime is a significant factor in a river system 's ecology, because it influences most ecological processes and the presence of some macroinvertebrate species will depend on the flow range, because some species, like the Trichorythidae, are dependent on higher (>0.6m/s) flow rates . (Boulton and Brock, 1999, Thirion, 2007).

In Doleddec *et al.* (2017), highly fluctuating environments lead to higher levels of temporal variability in both taxonomic and trait compositions of benthic invertebrate assemblages that were linked to contrasting flow characteristics. In river ecosystems, flow variability is one of the main drivers of temporal variability of macroinvertebrate assemblages (Arthington *et al.*, 2006). Differences in physico-chemical parameters such as water turbidity, high conductivity, and high total dissolved solids (TDS) and low dissolved oxygen (DO) can be reflected by the longitudinal pollution gradient in the river (Matlou *et al.*, 2017). Macroinvertebrates therefore need the ability to survive in these various water quality conditions or they will not be present, therefore an important determining factor (Thirion, 2007). Anthropogenic stressors such as water pollution, flow modifications and

habitat degradation cause changes in hydrologic processes, and many other factors that closely affect the structure and function of stream ecosystems (Dudgeon *et al.*, 2006) Some macroinvertebrate species prefer the vegetation habitat, while others have preference for the cobbles habitat, which means that species composition also depends on the quality, quantity and type of habitat present (Chakona *et al.*, 2008; Louw *et al.*, 2013). The structure of macroinvertebrate assemblages is a function of large-scale variables that are measured at catchment levels and smaller-scale variables measured at site levels and habitat levels (Dallas, 2007).

Table 2-2: Present Ecological State (PES) and four MIRAI metric group rating systems (Thirion, 2007).

Metric	Categories	Scores
Present Ecological Status (PES)		0 - No change from reference 1 - Small change from reference 2 - Moderate change from reference 3 - Large change from reference 4 - Serious change from reference 5 - Extreme change from reference
Flow Modification	Very fast (>0.6 m/s) Moderate (0.3-0.6 m/s) Slow (0.1- 0.3 m/s) Very slow (<0.1 m/s)	0 - No preference 1 - Very small preference 2 - Small preference 3 - Moderate preference 4 - High preference 5 Very high preference

Table 2-2: Continued.

Habitat Modification	Bedrock	0 - No preference
	Cobbles	1 - Very small preference
	Vegetation	2 - Small preference
	Gravel, sand and mud	3 - Moderate preference
	Water column	4 - High preference
		5 - Very high preference
Water Quality	12-15	High requirement
Modification	7-11	Moderate requirement
(SASS Weights)	4-6	Low requirement
	1-3	Very low requirement

2.9. Trait Based Approaches (TBA)

Macroinvertebrates are also useful surrogates of ecosystem attributes, and the relative abundance of functional groups can potentially reflect anthropogenic impact (Merritt and Cummins, 2006). Family level taxonomic determinations in biomonitoring have been the focal point of most research but with lack in integrated taxonomic and trait based evaluations (Madikizela and Dye, 2010; (Akamagwuna *et al.*, 2019). As a result, taxonomy based descriptions are limited in their ability to define ecological responses to stress (Van den Brink *et al.*, 2011). According to Baird and Van den Brink (2007), if communities are grouped according to their trait characteristics and not according to species, it would yield a more functional and complete picture of ecosystem structure and function. The Trait Based Approaches (TBA) were developed from the habitat template concept (HTC) aimed to provide a framework for linking traits to environmental disturbances (Townsend and Hildrew, 1994). Taxonomic assessment approaches take a considerable amount of effort in analyzing organisms into correct taxonomic groups, but TBAs which focus more on functions are more useful in giving the ecological condition of a system (Cummins *et al.*, 2005). Even though TBAs have not gained popularity in SA, there are a number of studies on the application of the approach (Odume *et al.*, 2018).

Macroinvertebrate traits can be easily described as the characteristics that reflect an organism's adaptation to its environment. The determination of traits requires much less taxonomy expertise, so that it can be utilized where limited information is available, and/or for animal groups where taxonomy knowledge is limited (Doledec *et al.*, 1999). Traits therefore describe the physical

characteristics, ecological niche, and functional role of an organism within the ecosystem (Poff *et al.*, 2006). Since the state of a species traits are able to determine its role in the ecosystem it therefore means that traits may also be vital for prospective risk assessments (Doledec *et al.*, 1999). Most traits are predictable in the manner in which they will react to stress because trait response to disturbance can be put in context, but also possess discriminatory capabilities (Statzner *et al.*, 2004; Kuzmanovic *et al.*, 2017). There is a wide variety of traits used in ecosystem assessments and functional feeding classification of aquatic organisms is one of the commonly used because it enhances the knowledge of trophic dynamics in streams by simplifying the benthic community into trophic guilds functional feeding groups (FFGs) (Cummins *et al.*, 2005).

Feeding strategies are typical traits that reflect the adaptation of species to environmental conditions (Usseglio-Polatera *et al.*, 2000). The FFG can be used to show impacts of land use impacts such as in Fu *et al.* (2016) where the variance of the applied FFGs showed differences among the three land use types used in the study. In the Kenyan highlands, FFGs were used to assess anthropogenic effects on ecological condition Masese *et al.*, 2013). The group was able display assemblages according to richness, abundance and diversity of macroinvertebrates and showed that there was a diverse shredder assemblage that played an important role in organic matter processing and nutrient cycling in the Kenyan stream. If there is an unstable food dynamic or an imbalance in functional feeding groups within an ecosystem it will be reflected by stressed conditions, therefore trophic metrics are a substitute of complex processes such as trophic interaction, production and food source availability (Merritt *et al.*, 2017).

The complexity of the ecological dynamics found in aquatic ecosystems can be evaluated at many spatial scales, therefore macroinvertebrates with similar ecological and biological traits are expected to respond the same in specific environmental gradients (Usseglio-Polatera *et al.*, 2000). Richards *et al.* (1997) used physical properties found at reach and catchment scales within a mixed land use basin in order to predict behavioral traits of aquatic insects. It was concluded that species traits would show strong relationships to local environmental conditions because they are best suited to reach-scale physical features contrary to catchment features, especially geology influenced species through morphology and hydrology as land use effects were concealed by the geology. Findings in Bonada *et al.* (2007) showed that local habitat variabilities favors organisms with certain traits as others are constrained and may be affected by other large scale habitat characteristics. Due to drought induced changes in flow within riffle and pool habitat, habitat availability was also altered and in response, the macroinvertebrate community structure and traits were also altered. Macroinvertebrate richness as well as the EPT (Ephemeroptera, Plecoptera and Trichoptera) differed between the sites where distinct traits were observed in certain flow categories and some sites presented only a few traits which was attributed to habitat stability.

River restoration practices involve changes to the physical template of fluvial environments, with project aims often centered on promoting a range of habitats capable of supporting heterogeneous biotic assemblages (Palmer *et al.*, 2010). In Hughes *et al.* (2010), the responses of the macroinvertebrate assemblage of the River Odelouca, Portugal displayed gradients that describe physical impacts on the banks and channel as a result of land use change.

Ecological risk assessments for toxic substances in water utilizes the most sensitive indicator species theory because each species reacts differently to similar levels of being exposed to polluted environments (Baird and Van den Brink, 2007). Species sensitivity is widely used in environmental assessments because from the distribution patterns, variation may be estimated among species. Baird and Van den Brink (2007) used biological traits to predict species sensitivity to toxic substances with the hypothesis being that organisms' sensitivity to stress is a function of their biology and can therefore be predicted from morphology, feeding, physiology and life patterns. Four of the traits were then found to explain 71% of the variability in sensitivity to toxicants which were in a group of 12 and exposed to 15 different toxic substances. Sedimentation is widely acknowledged as a major cause of degradation to ecosystem ecology of rivers (Wood and Armitage, 1997). In Akamagwuna and Odume (2020), Ephemeroptera, Plecoptera and Trichoptera (EPT) traits were evaluated to indicate urban pollution and found that EPT predation and a preference for vegetation biotope were associated with the impacted sites and were also positively correlated with at least one physico-chemical indicator of increasing urban pollution. Oxygen availability in aquatic ecosystems affects the distribution of various freshwater communities (Dodds, 2006).

Dissolved oxygen (DO) is a parameter often used to analyze water quality on different aquatic ecosystems, as this parameter is strongly influenced by a combination of physical, chemical, and biological characteristics of streams of oxygen demanding substances (Chapman *et al.*, 2004). The dissolved oxygen concentration in water is generally the product of biological activities, such as photosynthesis by aquatic plants which increases DO levels during the day and decrease during the night (Davies and Day, 1998). The use of fertilizers and pesticides in agricultural activities increases the concentration of nutrients entering the aquatic ecosystem and this leads to a reduction in dissolved oxygen (Yakub *et al.*, 2002). Dos Reis Oliveira *et al.* (2019) assessed the impact of surrounding land use on the structure and functioning of lowland stream ecosystems in different land use types. Macroinvertebrate assemblages responded to low DO in crop lands and

wastewater treatment plants. It was concluded that the degree of tolerance of DO requirements vary among different taxa. Agricultural activities are causing increases in salinity of rivers and wetlands in semi-arid and arid areas of the world, including Australia and Southern Africa (Williams, 1987). The ions are expressed in terms of the capacity of the solution to conduct electricity and called electrical conductivity (EC); therefore, used as a measure of salinity (Davies and Day 1998, Kale, 2016). Poor irrigation management, minerals from rainwater runoff, and other discharges are main sources of EC in freshwater (Davies and Day, 1998). In Szocs *et al.* (2014), macroinvertebrate traits were applied to discriminate between saline and not-saline sites; where respiration by gills, shredders and life cycle duration responded strongly to salinization in the Werra River, Germany. Mining activity is another major source of salts entering the rivers. To correctly acclimate to salinity fluctuations, aquatic organisms must make adjustments in order to survive. Ovoviviparity, multivoltinism, aerial respiration and decrease in gill respiration are some of the macroinvertebrate responses favoured through increased levels of salinity (Botwe *et al.*, 2018). Rivers in SA currently have a wide salinity range, to which the maximum was recorded in the Sak River, Northern Cape (Dallas and Day, 1993). As one remedy to manage salinity, suggested by O'Keeffe and De Moor, (1988) was a transfer of water from non salinized rivers to dilute the salinized river, however this can have serious ecological, political and social consequences that need to be considered. In Velasco *et al.* (2006) the dilution of salinity allowed the colonization of species with low salinity tolerance, such Simuliidae, Ceratopogonidae and Tanypodinae.

CHAPTER 3: MACROINVERTEBRATE RESPONSE ASSESSMENT INDEX AND MACROINVERTEBRATE TRAITS METHODOLOGY

3.1. Study area

The Mooi River originates near Koster, which is a small farming town in the North-West Province. The river then flows south to form a confluence with the Vaal River between Orkney and Potchefstroom. The Mooi River catchment area is situated in the Upper Vaal Water Management Area (Merafong City Local Municipality, 2014) with an area of 1800 km². Mean temperatures in the catchment range from > 32 °C during the summer months to -1 °C in the winter with the common occurrence of frost during winter (Cilliers and Bredenkamp, 2000). The area has a flat topography, with elevations of between 1 520 m towards the north and 1 300 m towards the southwestern parts of the catchment (Van Veelen, 2009). The geology in the catchment consists mainly of an underlying dolomite, which has the characteristic to change the chemical properties of the Mooi River by causing an increase in pH and electrical conductivity levels, while also increasing calcium and magnesium concentrations (Henderson-Sellers, 1991).

The Mooi River has three sub-catchments, namely the Wonderfontein Spruit in the north-eastern reaches, the Loop Spruit in the eastern reaches and the Mooi River found in the northern reaches. There are four major dams within the catchment, namely the Boskop Dam, Klerkskraal Dam, Klipdrift Dam and the Potchefstroom Dam (van der Walt, *et al.*, 2002). Wonderfontein Spruit and Loop Spruit are the two main tributaries of the Mooi River, which are divided by the Gatsrand geological ridge. The ridge has been described as a steep, rocky ridge, containing some of the richest gold reserves in SA (Gauteng Department of Agriculture and Rural Development, 2011; Tlokwe City Council, 2014). Numerous goldmines are therefore situated along this ridge. The Mooi River flows into the Vaal River 20 km south of Potchefstroom (Tlokwe City Council, 2014). The Wonderfontein Spruit originates in the far West-Rand of Gauteng between Krugersdorp and Randfontein, around abandoned goldmines (Tlokwe City Council, 2014). The study was conducted as a desktop study where sites and aquatic macroinvertebrate data were extracted from biomonitoring assessments previously conducted in the Mooi River catchment within the North-West Province between 2014 and 2016. Data from 21 surveyed sites was extracted for the purpose of this study.

Ten sites were sampled in the Loop Spruit and Mooi River (Figure 3-1), while eleven sites were sampled in the Wonderfontein Spruit and Mooi River (Figure 3-2). It was noted from previous studies that site selection was based on the water availability, river accessibility, undisturbed natural areas as well as areas showing most impact from human activities such as mining,

agriculture and presence of sewage treatment facilities. Different types of biotopes also formed part of the criteria used in selecting the sites to ensure unbiased and sufficient representation of different river biotopes available within the river system. The detailed site information was extracted included GPS coordinates, biotopes and site descriptions. The sampled sites from which the macroinvertebrate data was extracted were grouped accordingly to form five distinct river reaches and were abbreviated from MR1 until MR5 (Figure 3-3). The following shows how the Mooi River reaches were represented:

MR1: Mooi River upstream of Wonderfontein Spruit

MR2: Wonderfontein Spruit

MR3: Mooi River between Wonderfontein Spruit and Loop Spruit confluence

MR4: Loop Spruit

MR5: Downstream of the Loop Spruit confluence with Mooi River

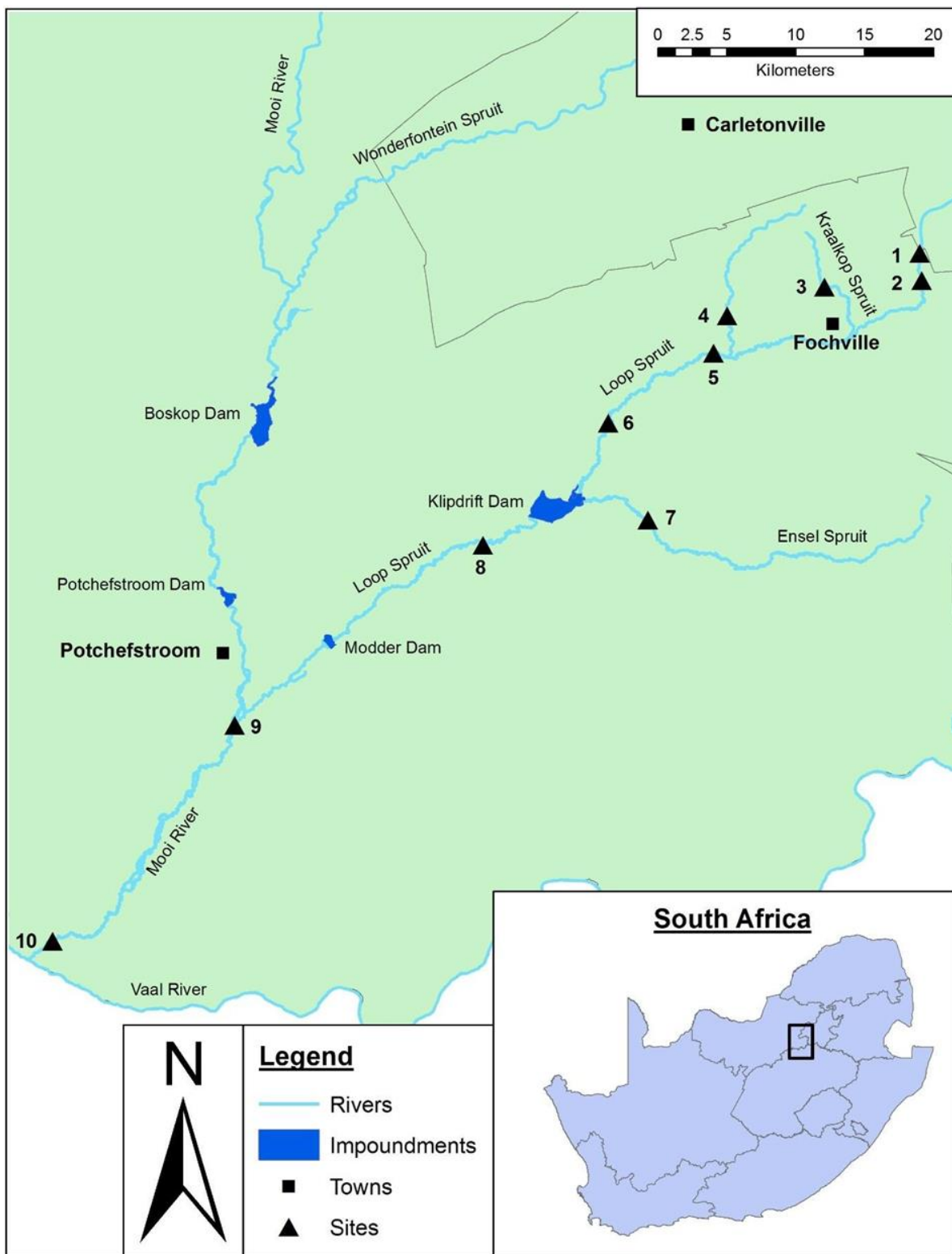


Figure 3-1: Sampling sites in the Loop Spruit and Mooi River as extracted from Erasmus (2017).

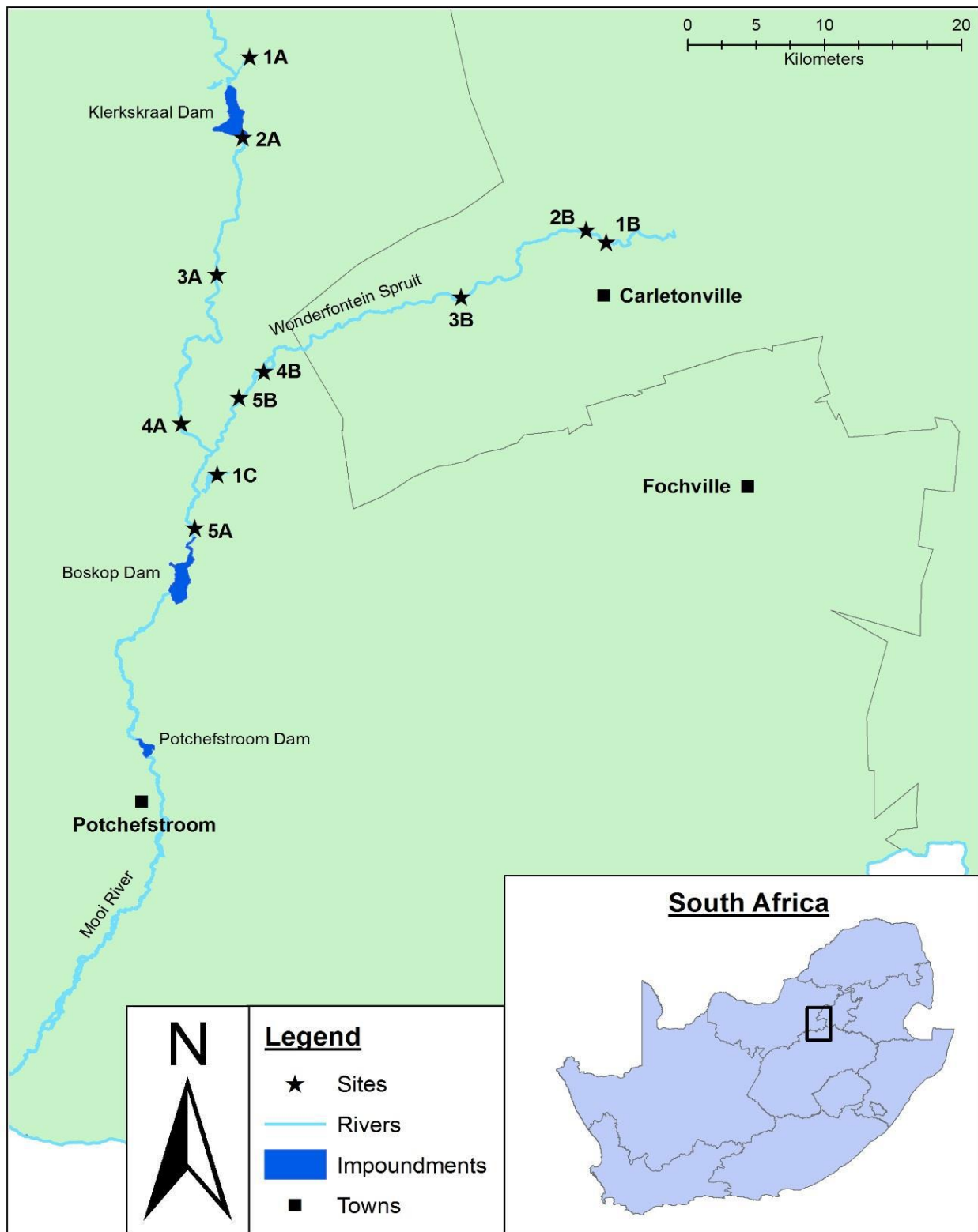


Figure 3-2: Sampling sites in the Wonderfontein Spruit and Mooi River as extracted from Pretorius (2017).

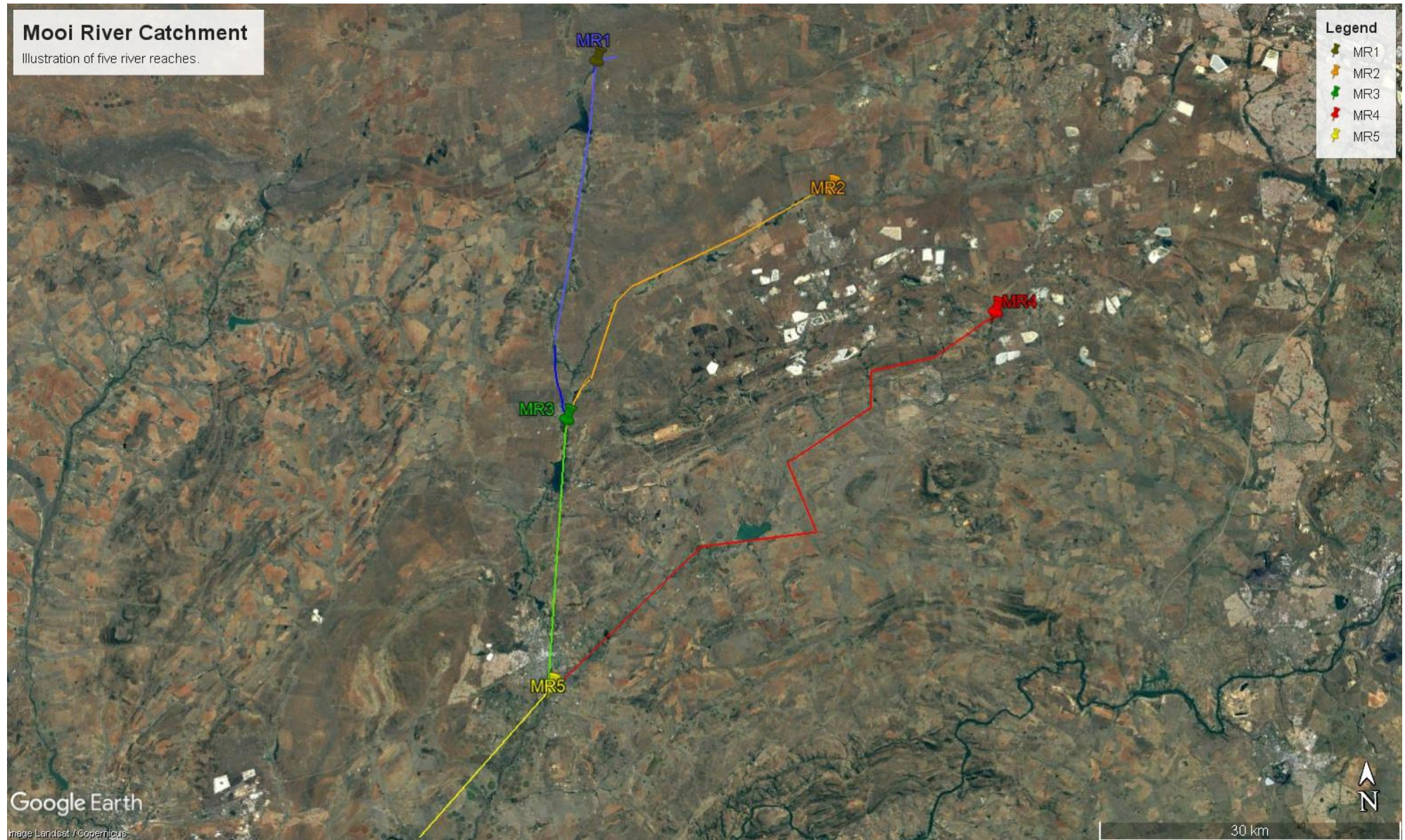


Figure 3-3: Map of the study area showing the Mooi River reaches. MR1 (blue), MR2 (orange), MR3 (green), MR4 (red) and MR5 (yellow).

Table 3-1: Physical characteristics of the study sites adopted from Erasmus (2017) and Pretorius (2017).

Reach	Sites	Location	Description	Biotopes
MR4	1	S26°25'49.3" E27°33'09.4"	On a farm with several springs feeding the Loop Spruit.	Sand, mud, riparian vegetation.
	2	S26°25'54.5" E27°33'08.7"	300 m downstream of Site 1.	Sand, vegetation, run biotope.
	3	S26°27'53.7" E27°29'30.5"	Kraalkop Spruit just north of Fochville before flowing into an impoundment. Livestock farming.	Tree canopy, sand, pool biotope.
	4	S26°28'41.7" E27°25'44.4"	Mining and agriculture.	Sand, trees, riparian vegetation, run and pool biotopes.
	5	S26°30'44.9" E27°25'38.9"	Water is abstracted for irrigational purposes.	Stones, riffle, run biotopes.
	6	S26°33'22.6" E27°20'31.5"	Upstream from Klipdrift Dam, agricultural activities.	Stones in current, riffle, run biotopes.
	7	S26°37'08.3" E27°22'16.2"	Crop farming and other agricultural activities.	Sand and mud with a pool biotope.
	8	S26°37'57.3" E27°15'15.1"	Dam for irrigation, agricultural activities.	Mud, a run biotope.
MR2	9	S26°19'04.9" E27°23'33.7"	One meter diameter pipeline which discharges water from the surrounding mines.	Mud, sand, stones, riffle, run biotopes.
	10	S26°18'57.4" S27°22'58.4"	Between Carletonville and Holfontein.	Mud, run and pool biotopes.
	11	S26°21'15.1" E27°18'05.8"	Downstream from the Abe Bailey Nature Reserve.	Stones, run, riffle, pool biotopes
	12	S26°23'46.2" E27°11'28.3"	Cattle farming.	Mud, pool biotope.

Table 3-1 Continued.

	13	S26°24'31.3" E27°10'39.6"	Cattle farming.	Stones, riparian vegetation, sand, pool biotope.
MR3	14	S26°28'44.8" E27°09'03.4"	The eye Gerhard Minnebron	Stones, sand, mud, pool, run biotope.
	21	S26°30'53.2" E27°07'28.4"	Inlet of Boskop Dam	Overhanging riparian vegetation, muddy substratum. Run and pool biotope.
MR5	15	S26°45'08.6" E27°06'01.2"	Mooi Loop Spruit confluences	Clay, run and pool biotopes.
	16	S26°52'50.2" E26°57'51.0"	Before the Mooi enters the Vaal River.	Sand, riffle and run biotopes.
MR1	17	S26°11'52.4" E27°09'52.5"	Springs that feed the MR	Stones with a pool biotope.
	18	S26°15'09.9" E 27°09'35.1"	Agricultural and various recreational activities.	Stones, riffle and run biotopes.
	19	S26°21'35.5" E27°08'20.1"	This site is downstream from the Klerkskraal Dam with agriculture being the main human activity.	Stones, sand and mud, run, riffle biotopes.
	20	S26°26'43.1" E27°07'06.5"	Cattle farming, small-scale cultivation.	Sandy, stones, riffle and run biotopes.

3.2. Methodology

The aquatic macroinvertebrate data was sourced from studies previously completed by Erasmus (2017) and Pretorius (2017) for their MSc dissertations with the North-West University (Potchefstroom Campus). The aquatic macroinvertebrate data were used as the primary information sources for macroinvertebrate species occurring in the Mooi River, Loop Spruit and Wonderfontein Spruit sub-catchments. Erasmus (2017) and Pretorius (2017), each conducted

three macroinvertebrate surveys over a period of two years (2014 to 2016) for 21 sites. Ten sites were sampled in the Loop Spruit and eleven in Wonderfontein Spruit. The locations of study sites are shown in Figures 3-1, 3-2 and 3-3, while site coordinates, brief habitat and biotope descriptions are also displayed in Table 3-1.

3.2.1. Sampling methodology

In Erasmus (2017) and in Pretorius (2017), macroinvertebrates were collected using a kick-stir sampling method with a D-frame net of 1 mm mesh in the dimensions of 30 cm x 30 cm x 30 cm. Samples were collected from gravel, sand, mud, stone and vegetation biotopes per sampling site and per sampling event. Sampling from each biotope type was done for approximately 2 minutes. Stones in current, out of current and bedrock were sampled. The contents of the net were emptied after sampling each biotope and contents stored and analyzed separately. Samples were then preserved in plastic containers containing 10% formaldehyde, transported back to the laboratory and identified, counted and recorded with the aid of a dissection microscope. The preserved macroinvertebrate specimens were identified up to family level using the Guides to Freshwater Invertebrates of Southern Africa (Davies and Day, 1998; Gerber and Gabriel, 2002a; Gerber and Gabriel, 2002b; Day *et al.*, 1999; Day and De Moor 2001; Day *et al.*, 2001; Day *et al.*, 2002; Day *et al.*, 2003; Day and De Moor 2002a; 2002b; De Moor *et al.*, 2003 as well as Stals and De Moor, 2007) compiled for the Water Research Commission in Pretoria.

3.2.2. MIRAI methodology (Thirion, 2007)

The macroinvertebrate response assessment index (MIRAI) approach or methodology was designed to provide a habitat-based cause-and-effect foundation aimed to interpret and provide an Ecological Category (EC) of instream conditions by assessing the deviation of aquatic macroinvertebrate assemblage from the reference condition. (Thirion, 2007). The approach uses a multi-criteria decision analyses Microsoft® Excel-based model composed of several macroinvertebrate attribute metrics for the evaluation of flow modifications, habitat suitability and diversity, water quality and connectivity as well as seasonality (Thirion, 2007). As stipulated in the Manual for EcoStatus Determination Module E: MIRAI (Thirion, 2007) as well as in the Manual for EcoStatus Determination (Kleynhans *et al.*, 2008), the MIRAI is one of six modelled indices developed for EcoClassification and EcoStatus determination. The MIRAI process consists of two integral parts, namely, determining reference conditions and deriving how the present ecological status (PES) actually deviates from the established reference conditions. The index uses four metric groups that is flow modification, habitat modification, water quality modification, and system connectivity and seasonality. Each of these metric group measures the deviation of the macroinvertebrate assemblages from the reference (expected) assemblage to current (observed)

macroinvertebrate assemblage found at each site. Macroinvertebrate data collected was subjected to MIRAI for determination of Ecological Categories (EC). However, the group metric for system connectivity and seasonality was not explored within this study. This was because the reference taxa did not include any migratory species and seasonal differences did not form part of the scope of the studies and were therefore not recorded. Due to these factors, the metric then received a weighting of 0%. For the purpose of this study the reference macroinvertebrate communities used, was derived from communities observed at the selected sampling sites. Demonstrating the relationship between changes in driver conditions such as change in habitat and the response of the macroinvertebrate assemblages required two key elements. Habitat preferences and requirements (reference conditions) for each macroinvertebrate taxa present were obtained. The reference conditions were established against which any responses to drivers were measured. Habitat features should be evaluated in terms of suitability and the requirements previously mentioned. This process resulted in expected and actual patterns, further evaluated to achieve an Ecological Category (EC) rating. The application of the MIRAI was therefore based on the three key requirements. This index provided an approach to deriving and interpreting macroinvertebrate responses to the driver changes. The index was applied to all the 21 sites following a methodology described by Thirion (2007). Aquatic macroinvertebrates expected at each point were derived for Thirion (2007), as well as from the PES/EIS database of the Department of Water and Sanitation (DWS, 2016) (Table 3-2).

Table 3-2: List of expected macroinvertebrate taxa in the Mooi River catchment (Thirion, 2007; DWS 2016).

Expected Taxa			
Porifera	Perlidae	Coenagrionidae	Nepidae
Coelenterata	Baetidae	Lestidae	Notonectidae
Turbellaria	Caenidae	Platycnemidae	Pleidae
Oligochaeta	Ephemeridae	Protoneuridae	Veliidae
Hirudinea	Heptageniidae	Aeshnidae	Corydalidae
Amphipoda	Leptophlebiidae	Corduliidae	Sialidae
Potamonautidae	Oligoneuridae	Gomphidae	Dipseudopsidae
Atyidae	Polymitarcyidae	Libellulidae	Ecnomidae
Paleomonidae	Prosoptomatidae	Pylalidae	Naucoridae
Hydracarina	Trichorythidae	Belostomatidae	Philopotamidae
Notonemouridae	Calopterygidae	Elmidae	Polycentropodidae
Corixidae	Chlorocyphidae	Gyrinidae	Psychomyiidae
Gerridae	Culicidae	Haliplidae	Calamoceratidae
Hydropsychidae	Dixidae	Hydroptilidae	Leptoceridae
Simuliidae	Empididae	Hydraenidae	Petrothrincidae

Table 3-2: Continued.

Syrphidae	Ephydriidae	Hydrophilidae	Pisuliidae
Tabanidae	Muscidae	Limnichidae	Dytiscidae
Tipulidae	Psychodidae	Psephenidae	Sphaeridae
Ancylidae	Hydrobiidae	Athericidae	
Bulinae	Lymnaeidae	Blepharoceridae	
Thiaridae	Physidae	Ceratopogonidae	
Viviparidae	Planorbinae	Chironomidae	
Corbiculidae	Corbiculidae	Unionidae	

3.2.2.1. Determination of the Ecological Category (EC)

The calculation of the ecological categories for the macroinvertebrate responses to flow, habitat and water quality modifications was done by totalling the weighted scores and expressing them as a percentage of the maximum (Thirion, 2007). This value indicated the percentage deviation away from the expected reference conditions and was subtracted from the 100 to arrive at the percentage value that represented the EC. This value was used to place the EC of that metric group in a particular category that ranges from A to F (Table 3-3) (Kleynhans *et al.*, 2008). The model then automatically calculated the EC based on the percentage deviation of reference conditions (Thirion, 2007)

Table 3-3: Classification system used to assess the macroinvertebrate community ecological category of the Mooi River catchment with a description of each class, adopted from Kleynhans *et al.* (2008).

Category	Description	Score
A	Unmodified, natural.	90-100
B	Largely natural with few modifications. A small change in natural habitats and biota may have taken place but the ecosystem functions are essentially unchanged.	80-90
C	Moderately modified. A loss and change of natural habitat and biota have occurred but the basic ecosystem functions are still predominantly unchanged.	60-79
D	Largely modified. A large loss of natural habitat, biota and basic ecosystem functions has occurred.	40-59
E	The loss of natural habitat, biota and basic ecosystem functions is extensive.	20-39
F	Modifications have reached a critical level and the lotic system has been modified completely with an almost complete loss of natural habitat and biota. In the worst instances the basic ecosystem functions have been destroyed and the changes are irreversible.	0

3.2.2.2 Macroinvertebrate trait selection

The traits selected for this study are relevant to Trait Based Approaches (TBA) and have a relationship with ecosystem disturbances. Their adaptive nature with regards to the organism was taken into account. The macroinvertebrate traits were compiled from the South African macroinvertebrates trait databases (Odume *et al.*, 2018) as well as from a review of literature (Usseglio-Polatera *et al.*, 2000; Bonada *et al.*, 2007).

Nine traits with 43 categories were assigned to each taxon through relevant literature. The selected traits included habitat preference, water quality preference (macroinvertebrate sensitivity), velocity preference, hydraulic habitat preference, functional feeding groups, respiration, body shape, body size as well as locomotion. (Table 3-4). To synthesize numerical data, the abundances of each category were tallied into relative abundance values.

Table 3-4: Selected macroinvertebrate traits and corresponding categories.

Functional traits	Category
Habitat Preference	Bedrock (B) Cobbles/stones (C) Vegetation (V) Gravel/sand/mud (GSM) Water column (W)
Water Quality Preference	Highly sensitive (12-15) Moderately sensitive (7-11) Moderately tolerant (4-6) Highly tolerant (1-3)
Velocity Preference	Very fast (>0.6 m/s) Moderately fast (0.3-0.6 m/s) Slow flow (0.1-0.3 m/s) Very slow (<0.1 m/s)
Hydraulic Habitat Preference	Riffles Pools Runs Rapid Indifferent

Table 3-4: Continued.

Functional Feeding Groups	Predators Filter feeders Deposit feeders Shredders Scrapers Grazers
Respiration	Gills Tegument/Cutaneous Aerial (spiracle, breathing tube, straps or other apparatus)
Body Shape	Streamlined Flattened Spherical Tubular/Cylindrical
Body Size	Very small (≤ 5) Small ($>5-10$) Medium ($>10-20$) Large ($>20-40$) Variable
Locomotion	Climber Crawler Sprawler Skater Swimmer Burrower Other

3.3. DATA ANALYSIS

The data for the study was collected from previous studies done on the Mooi River catchment (Erasmus, 2017 and Pretorius, 2017). In this study quantitative data analysis was integrated so as to interpret the data derived. The data was collected from 2014 to 2016. The MIRAI (Thirion, 2007) software was used to analyse data for macroinvertebrate ecological categories (EC) per reach (MR1, MR2, MR3, MR4 and MR5). The MIRAI was done in order to show differences between impacted and unimpacted reaches using macroinvertebrate responses to habitat, flow and water quality metrics (Table 4-2 to 4-6). The results compared the EC as well as the scores of the 3 metrics across five reaches (Table 4-7 to 4-11). The comparison of the ECs was presented in Figure 4-2 and that of the metric scores was shown in Figure 4-3. For functional trait analysis, the macroinvertebrate data were classified into traits and their respective categories based on the classification by Odume *et al.* (2018). The abundance for each category was determined by adding up the abundances of all taxa belonging to that specific category (Table 3-5, 3-7, 3-9, 3-11 and 3-13). This data was then used to calculate each category's relative abundance score. The relative abundance of the categories at the above stated reaches was computed by dividing the total abundance of macroinvertebrates belonging to a specific category by the total abundance of macroinvertebrates found in that reach, the value was then multiplied by 100. This was done by means of the statistical function in Microsoft Excel®. The data was presented in Table 3-6, 3-8, 3-10, 3-12 and 3-14. Observed functional differences among the reaches were presented in the form of histograms (Figure 4-4 to 4-12).

Table 3-5: Macroinvertebrate trait categories assigned in MR1.

Taxa in MR1	Abundance	FFG	RES	HHP	BSIZE	BSHAPE	LOCO	Velocity	Habitat	WQ
Aeshnidae	19	P	G	P	L	O	CL	S	C	MS
Atyidae	444	DF	G	I	S	O	SW	VS	V	MS
Baetidae	1195	DF	G	RI	S	ST	SP	MF	C	HS
Belostomatidae	17	P	A	P	S	FL	CR	VS	V	HT
Caenidae	640	DF	G	RI	S	ST	CR	VF	GSM	MT
Ceratopogonidae	13	GR	G	I	VS	C/T	CR	VF	C	MT
Chaoboridae	12	P	T/C	P	S	C/T	B	VS	GSM	MS
Chironomidae	934	P	G	I	V	C/T	SW	S	B	MS
Chrysomelidae	1	GR	A	I	S	O	CR	VS	V	MS
Coenagrionidae	913	P	G	P	M	FL	CL	MF	V	MS
Corbiculidae	57	FF	G	RA	S	O	B	S	GSM	MT
Corixidae	15	P	A	I	S	O	SW	S	GSM	MT
Crambidae	5	GR	T/C	P	V	CT	CR	VS	V	HS
Culicidae	20	FF	A	I	S	CT	SP	VS	W	HT
Curculionidae	3	GR	A	P	V	O	CR	VS	V	HT
Cypridoidea	1	DF	T/C	P	S	O	SW	VS	V	HT
Daphniidae	68	FF	G	P	S	O	SW	VS	GSM	HS
Dixidae	26	FF	A	P	S	CT	CR	VS	W	MS
Dolichopodidae	1	P	A	P	S	CT	CR	VS	W	MS
Dytiscidae	53	P	A	P	S	O	SW	VS	V	MT
Ecnomidae	9	DF	G	P	M	CT	SW	S	C	MS
Elmidae	82	SC	A	RI	S	O	CR	MF	C	MS
Empididae	5	P	A	I	V	CT	B	MF	C	MS
Ephyridae	1	SC	A	I	VS	CT	SP	VS	GSM	HT
Gerridae	4	P	A	P	S	O	SK	VS	W	MS
Glossiphonidae	12	P	T/C	P	V	CT	O	S	C	HT
Gomphidae	2	P	G	P	L	O	B	MF	GSM	MT
Gyrinidae	176	P	A	I	S	O	SW	VF	W	MT
Haliplidae	2	GR	A	P	VS	O	CR	S	V	MT
Hydrachnidae	11	P	T/C	P	VS	SP	SW	VS	V	HS
Hydraenidae	33	SC	A	P	VS	O	CR	MF	V	MS
Hydridae	63	P	T/C	P	S	TC	O	S	C	MS
Hydrophilidae	4	SC	A	P	S	O	CR	VS	V	MT
Hydropsychidae	167	P	G	RA	S	CT	SW	VF	C	MS
Hydroptilidae	1	DF	G	RA	VS	CT	SW	S	V	MT
Hygrobatidae	1	P	T/C	P	VS	SP	SW	VS	V	HS
Libellulidae	41	P	G	P	M	FL	CR	MF	B	MT
Lymnaeidae	4	DF	G	P	S	O	CR	VS	V	HT
Mesoveliidae	6	P	A	P	S	O	SK	VS	V	MS
Muscidae	43	P	A	I	VS	CT	SP	VF	W	VL
Naucoridae	5	P	A	P	S	O	SW	MF	W	MT

Table 3-5: Continued.

Nepidae	1	P	A	P	M	FL	CL	VS	V	HT
Notonectidae	2	P	A	P	M	O	SW	VS	W	HT
Paraphrynoveliidae	4	P	A	RA	S	O	SK	VF	C	HT
Physidae	276	SC	A	I	M	O	CR	VS	V	HT
Planorbidae	495	SC	A	I	S	O	CR	S	V	HT
Pleidae	5	P	A	P	VS	O	SW	VS	V	MT
Polymitarcyidae	2	FF	G	P	M	CT	B	VS	GSM	MS
Potamonautidae	43	DF	G	I	L	FL	W	MF	C	HT
Rhabdocoela	22	P	T/C	I	VS	FL	O	S	W	MS
Simuliidae	391	FF	A	I	S	CT	SP	VF	C	MT
Sphaeriidae	42	FF	G	I	S	O	B	S	GSM	HT
Stratiomyidae	1	DF	A	I	S	CT	SP	VS	V	HT
Tabanidae	3	P	A	I	S	CT	CR	S	GSM	MT
Tipulidae	2	P	A	I	M	CT	O	S	GSM	MT
Tubellaria	51	P	T/C	I	VS	FL	O	S	W	VL
Tubificidae	200	GR	T/C	P	V	CT	B	VS	GSM	HT
Veliidae	13	P	A	P	S	O	SK	VS	W	MS
Total	6662									

Table 3-6: Macroinvertebrate trait relative abundance in MR1.

Trait	Category	Relative abundance (%)
Habitat preference	B-bedrock	14,64
	C-cobbles	30,06
	V-vegetation	34,18
	GSM-gravel,sand.mud	15,67
	W-water	5,45
Water quality preference	HS-highly sensitive	19,21
	MS-moderately sensitive	41,37
	MT-moderately tolerant	21,16
	HT-highly tolerant	18,25
Velocity preference	VF-very fast	21,53
	MF-moderately fast	34,81
	S-slow	25,92
	VS-very slow	17,74
Hydraulic habitat preference	P-pools	23,09
	RI-riffles	28,78
	RA-rapids	3,44
	I-indiffrent	4,47
FFG	P- predator	39,07
	DF-deposit feeder	35,09
	FF-filter feeder	9,1
	SC-scraper	13,37
	GR-grazer	3,36
Respiration	G-Gills	68,99
	A-Aerial	25,37
	T/C- tegument/cutaneous	5,67
Body shape	ST-steamlined	9,61
	FL-flatterned	16,33
	T/C-tubular/cylindrical	28,29
	SP-spherical	0,18
	O-variable	27,26
Body size	VS-very small	2,75
	S-small	60,19
	M-medium	1,87
	L-large	0,96
	V-variable	1,74
Locomotion	CR-crawler	24,71
	CL-climber	14
	SP-sprawler	24,78
	SW-swimmer	28,4
	O-other	0
	B- burrower	4,19
	SK- skater	0,4

Table 3-7: Macroinvertebrate trait categories assigned in MR2.

Taxa in MR2	Abundance	FFG	RES	HHP	BSIZE	BSHAPE	LOCO	Velocity	Habitat	WQ
Aeshnidae	16	P	G	P	L	O	CL	S	C	MS
Atyidae	47	DF	G	I	S	O	SW	VS	V	MS
Baetidae	520	DF	G	RI	S	ST	SP	MF	C	HS
Belostomatidae	43	P	A	P	S	FL	CR	VS	V	HT
Caenidae	15	DF	G	RI	S	ST	CR	VF	GSM	MT
Ceratopogonidae	19	G	G	I	VS	CT	CR	VF	C	MT
Chironomidae	1002	O	G	I	V	CT	SW	S	B	MS
Coenagrionidae	163	P	G	I	M	FL	CL	MF	V	MS
Corbiculidae	18	FF	G	RA	S	O	B	S	GSM	MT
Corixidae	455	P	A	I	S	O	SW	S	GSM	MT
Crambidae	1	G	T	P	V	CT	CR	VS	V	HS
Culicidae	14	FF	A	I	S	CT	SP	VS	W	HT
Curculionidae	24	G	A	P	V	O	CR	VS	V	HT
Cyclopidae	22	P	T/C	I	S	O	SW	VS	GSM	HS
Daphniidae	2793	FF	G	P	S	O	SW	VS	GSM	HS
Dolichopodidae	1	P	A	P	S	CT	CR	VS	W	MS
Dytiscidae	29	P	A	P	S	O	SW	VS	V	MT
Ecnomidae	1	DF	G	P	M	CT	SW	S	C	MS
Elmidae	2	SC	A	RI	S	O	CR	MF	C	MS
Ephydriidae	22	SC	A	I	VS	CT	SP	VS	GSM	HT
Eylaidae	1	P	T/C	P	V	O	SW	VS	V	HS
Gerridae	1	P	A	P	S	O	SK	VS	W	MS
Glossiphoniidae	612	P	T	P	V	CT	O	S	C	HT
Gomphidae	3	P	G	P	L	O	B	MF	GSM	MT
Gyrinidae	95	P	A	I	S	O	SW	VF	W	MT
Haliplidae	1	G	A	P	VS	O	CR	S	V	MT
Hydraenidae	18	SC	A	P	VS	O	CR	MF	V	MS
Hydriidae	298	P	T	P	S	CT	O	S	C	MS
Hydrophilidae	6	SC	A	P	S	O	CR	VS	V	MT
Hydropsychidae	145	P	G	RA	S	CT	SW	VF	C	MS
Hydroptilidae	109	DF	G	RA	VS	CT	SW	S	V	MT
Libellulidae	16	P	G	P	M	FL	CR	MF	B	MT
Lymnaeidae	48	DF	G	P	S	O	CR	VS	V	HT
Mesoveliidae	11	P	A	P	S	O	SK	VS	V	MS
Muscidae	41	P	A	I	VS	CT	SP	VF	W	HT
Naucoridae	69	P	A	P	S	O	SW	MF	W	MT
Nepidae	3	P	A	P	M	FL	CL	VS	V	HT
Notonectidae	10	P	A	P	M	O	SW	VS	W	HT
Physidae	225	SC	A	I	M	O	CR	VS	V	HT
Planorbidae	564	SC	A	I	S	O	CR	S	V	HT
Pleidae	30	P	A	P	VS	O	SW	VS	V	MT
Potamonautidae	10	DF	G	I	L	FL	W	MF	C	HT

Table 3-7: Continued.

Psephenidae	1	SC	G	RU	S	FL	CR	VF	C	MS
Psychodidae	1	DF	A	I	VS	CT	SP	VS	W	HT
Rhabdocoela	116	P	T	I	VS	FL	O	S	W	MS
Scirtidae	3	FF	A	RI	V	O	SW	S	W	MS
Simuliidae	630	FF	A	I	S	CT	SP	VF	C	MT
Sphaeriidae	15	FF	G	I	S	O	B	S	GSM	HT
Stratiomyidae	8	DF	A	I	S	CT	SP	VS	V	HT
Tabanidae	1	P	A	I	S	CT	CR	S	GSM	MT
Tipulidae	4	P	A	I	M	CT	O	S	GSM	MT
Tubificidae	697	G	T	P	V	CT	B	VS	GSM	HT
Veliidae	1	P	A	P	S	O	SK	VS	W	MS
Total	9000									

Table 3-8: Macroinvertebrate trait relative abundance in MR2.

Trait	Category	Relative abundance (%)
Habitat preference	B-bedrock	11,31
	C-cobbles	25,04
	V-vegetation	14,79
	GSM-gravel,sand.mud	44,94
	W-water	3,91
Water quality preference	HS-highly sensitive	37,08
	MS-moderately sensitive	20,29
	MT-moderately tolerant	16,67
	HT-highly tolerant	25,97
Velocity preference	VF-very fast	10,51
	MF-moderately fast	8,9
	S-slow	35,72
	VS-very slow	44,87
Hydraulic habitat preference	P-pools	44,82
	RI-riffles	0,6
	RA-rapids	3,02
	I-indiffrent	38,41
FFG	P- predator	24,29
	DF-deposit feeder	8,43
	FF-filter feeder	38,59
	SC-scraper	9,31
	GR-grazer	8,24
Respiration	G-Gills	54,9
	A-Aerial	25,69
	T/C- tegument/cutaneous	19,41
Body shape	ST-steamlined	5,94
	FL-flattered	3,91
	T/C-tubular/cylindrical	40,07
	SP-spherical	0
	O-variable	50,08
Body size	VS-very small	3,97
	S-small	65,02
	M-medium	4,69
	L-large	0,32
	V-variable	26
Locomotion	CR-crawler	10,94
	CL-climber	2,02
	SP-sprawler	13,73
	SW-swimmer	53,46
	O-other	11,44
	B- burrower	8,14
	SK- skater	0,14

Table 3-9: Macroinvertebrate trait categories assigned in MR3.

Taxa in MR3	Abundance	FFG	RES	HHP	BSIZE	BSHAPE	LOCO	Velocity	Habitat	WQ
Aeshnidae	3	P	G	P	L	O	CL	S	C	MS
Atyidae	851	DF	G	I	S	O	SW	VS	V	MS
Baetidae	584	DF	G	RI	S	ST	SP	MF	C	HS
Belostomatidae	11	P	A	P	S	FL	CR	VS	V	HT
Caenidae	133	DF	G	RI	S	ST	CR	VF	GSM	MT
Ceratopogonidae	17	G	G	I	VS	CT	CR	VF	C	MT
Chaoboridae	1	P	T/C	P	S	CT	B	VS	GSM	MS
Chironomidae	118	P	G	I	V	CT	SW	S	B	MS
Chlorocyphidae	1	P	G	I	M	FL	CL	S	W	HT
Chrysomelidae	1	G	A	I	S	O	CR	VS	V	MS
Coenagrionidae	63	P	G	P	M	FL	CL	MF	V	MS
Corixidae	11	P	A	I	S	O	SW	S	GSM	MT
Crambidae	3	G	T/C	P	V	CT	CR	VS	V	HS
Culicidae	1	FF	A	I	S	CT	SP	VS	W	HT
Curculionidae	1	G	A	P	V	O	CR	VS	V	HT
Dixidae	4	FF	A	P	S	CT	CR	VS	W	MS
Dytiscidae	7	P	A	P	S	O	SW	VS	V	MT
Ecnomidae	13	DF	G	P	M	CT	SW	S	C	MS
Elmidae	3	SC	A	RI	S	O	CR	MF	C	MS
Empididae	1	P	A	I	V	CT	B	MF	C	MS
Ephydriidae	1	SC	A	I	VS	CT	SP	VS	GSM	HT
Gerridae	5	P	A	P	S	O	SK	VS	W	MS
Gomphidae	17	P	G	P	L	O	B	MF	GSM	MT
Gyrinidae	13	P	A	I	S	O	SW	VF	W	MT
Hydraenidae	5	SC	A	P	VS	O	CR	MF	V	MS
Hydrophilidae	6	SC	A	P	S	O	CR	VS	V	MT
Hydropsychidae	48	P	G	RA	S	CT	SW	VF	C	MS
Hydroptilidae	32	DF	G	RA	VS	CT	SW	S	V	MT
Libellulidae	6	P	G	P	M	FL	CR	MF	B	MT
Lymnaeidae	10	DF	G	P	S	O	CR	VS	V	HT
Muscidae	3	P	A	I	VS	CT	SP	VF	W	HT
Naucoridae	29	P	A	P	S	O	SW	MF	W	MT
Nepidae	1	P	A	P	M	FL	CL	VS	V	HT
Notonectidae	1	P	A	P	M	O	SW	VS	W	HT
Planorbidae	102	SC	A	I	S	O	CR	S	V	HT
Potamonautidae	16	DF	G	I	L	FL	W	MF	C	HT
Protoneuridae	1	P	G	P	M	FL	SP	S	V	MS
Rhabdocoela	5	P	T/C	I	VS	FL	O	S	W	MS
Simuliidae	91	FF	A	I	S	CT	SP	VF	C	MT
Sphaeriidae	171	FF	G	I	S	O	B	S	GSM	HT
Tubificidae	26	G	T/C	P	V	CT	B	VS	GSM	HT
Total	2416									

Table 3-10: Macroinvertebrate trait relative abundance in MR3.

Trait	Category	Relative abundance (%)
Habitat preference	B-bedrock	5,13
	C-cobbles	32,12
	V-vegetation	45,28
	GSM-gravel,sand.mud	14,9
	W-water	2,57
Water quality preference	HS-highly sensitive	2,43
	MS-moderately sensitive	46,44
	MT-moderately tolerant	14,98
	HT-highly tolerant	14,28
Velocity preference	VF-very fast	12,62
	MF-moderately fast	29,97
	S-slow	18,92
	VS-very slow	38,49
Hydraulic habitat preference	P-pools	8,81
	RI-riffles	29,8
	RA-rapids	3,31
	I-indifferent	58,07
FFG	P- predator	14,28
	DF-deposit feeder	67,84
	FF-filter feeder	11,05
	SC-scraper	4,84
	GR-grazer	1,99
Respiration	G-Gills	98,68
	A-Aerial	12,29
	T/C- tegument/cutaneous	1,45
Body shape	ST-steamlined	29,68
	FL-flattened	4,3
	T/C-tubular/cylindrical	14,74
	SP-spherical	0
	O-variable	51,28
Body size	VS-very small	2,61
	S-small	86,18
	M-medium	3,56
	L-large	1,49
	V-variable	6,17
Locomotion	CR-crawler	1,25
	CL-climber	2,81
	SP-sprawler	28,19
	SW-swimmer	46,48
	O-other	0,21
	B- burrower	8,94
	SK- skater	0,21

Table 3-11: Macroinvertebrate trait categories assigned in MR4.

Taxa in MR4	Abundance	FFG	RES	HHP	BSIZE	BSHAPE	LOCO	Velocity	Habitat	WQ
Aeshnidae	21	P	G	P	L	O	CL	S	C	MS
Athericidae	5	P	A	RA	V	CT	SW	S	C	MS
Atyidae	58	DF	G	I	S	O	SW	VS	V	MS
Baetidae	1499	DF	G	RI	S	ST	SP	MF	C	HS
Belostomatidae	13	P	A	P	S	FL	CR	VS	V	HT
Blephariceridae	2	SC	A	RA	V	O	SW	VF	C	HS
Branchipodidae	9	FF	G	P	S	O	CR	VS	C	HS
Caenidae	532	DF	G	RI	S	ST	CR	VF	GSM	MT
Ceratopogonidae	83	G	G	I	VS	CT	CR	VF	C	MT
Chironomidae	5058	P	G	I	V	CT	SW	S	B	MS
Chlorocyphidae	11	P	G	I	M	FL	CL	S	W	HT
Chrysomelidae	27	G	A	I	S	O	CR	VS	V	MS
Coenagrionidae	414	P	G	P	M	FL	CL	MF	V	MS
Corbiculidae	8	FF	G	RA	S	O	B	S	GSM	MT
Corixidae	1235	P	A	I	S	O	SW	S	GSM	MT
Crambidae	1	G	TC	P	V	CT	CR	VS	V	HS
Culicidae	43	FF	A	I	S	CT	SP	VS	W	HT
Curculionidae	1	G	A	P	V	O	CR	VS	V	HT
Cypridoidea	162	DF	TC	P	S	O	SW	VS	V	HT
Daphniidae	1328	FF	G	P	S	O	SW	VS	GSM	HS
Dixidae	2	FF	A	P	S	CT	CR	VS	W	MS
Dolichopodidae	9	P	A	P	S	CT	CR	VS	W	MS
Dytiscidae	307	P	A	P	S	O	SW	VS	V	MT
Ecnomidae	8	DF	G	P	M	CT	SW	S	C	MS
Elmidae	38	SC	A	RI	S	O	CR	MF	C	MS
Empididae	1	P	A	I	VS	CT	B	MF	C	MS
Ephydriidae	43	SC	A	I	VS	CT	SP	VS	GSM	HT
Gerridae	23	P	A	P	S	O	SK	VS	W	MS
Glossiphoniidae	1163	P	TC	P	V	CT	O	S	C	HT
Gomphidae	55	P	G	P	L	O	B	MF	GSM	MT
Gyrinidae	194	P	A	I	S	O	SW	VF	W	MT
Haliplidae	11	G	A	P	VS	O	CR	S	V	MT
Hydrachnidae	1	P	TC	P	VS	SP	SW	VS	V	HS
Hydraenidae	274	SC	A	P	VS	O	CR	MF	V	MS
Hydroida	46	P	T/C	P	V	O	O	VS	W	HT
Hydrophilidae	20	SC	A	P	S	O	CR	VS	V	MT
Hydropsychidae	337	P	G	RA	S	CT	SW	VF	C	MS
Hydroptilidae	104	DF	G	RA	VS	CT	SW	S	V	MT
Hygrobatidae	3	P	T/C	P	VS	SP	SW	VS	V	HS
Isotomidae	2	DF	A	P	VS	O	O	MF	W	MS
Lestidae	1	P	G	P	M	O	SP	VS	V	MS
Libellulidae	37	P	G	P	M	FL	CR	MF	B	MT

Table 3-11: Continued.

Limnesiidae	13	P	A	P	VS	O	SW	VS	V	HS
Limnichidae	3	G	A	RI	S	O	B	S	GSM	MS
Lymnaeidae	35	DF	G	P	S	O	CR	VS	V	HT
Mesoveliidae	5	P	A	P	S	O	SK	VS	V	MS
Muscidae	81	P	A	I	VS	CT	SP	VF	W	HT
Nepidae	3	P	A	P	M	FL	CL	VS	V	HT
Notonectidae	98	P	A	P	M	O	SW	VS	W	HT
Perlidae	1	SH	G	RI	S	FL	CR	VF	C	HS
Physidae	570	SC	A	I	M	O	CR	VS	V	HT
Planariidae	9	P	T/C	P	V	FL	O	S	W	MS
Planorbidae	496	SC	A	I	S	O	CR	S	V	HT
Pleidae	27	P	A	P	VS	O	SW	VS	V	MT
Potamonautidae	7	DF	G	I	L	FL	W	MF	C	HT
Protoneuridae	12	P	G	P	M	FL	SP	S	V	MS
Psychodidae	5	DF	A	I	VS	CT	SP	VS	W	HT
Rhabdocoela	19	P	T	I	VS	FL	O	S	W	MS
Sciomyzidae	8	P	A	P	S	CT	SP	VS	GSM	HT
Scirtidae	2	FF	A	RI	V	O	SW	S	W	MS
Simuliidae	1629	FF	A	I	S	CT	SP	VF	C	MT
Spercheidae	1	FF	A	P	S	O	W	VS	W	MS
Sphaeriidae	430	FF	G	I	S	O	B	S	GSM	HT
Sphaeriusidae	1	G	A	RA	S	O	CR	VS	GSM	HT
Stratiomyidae	3	DF	A	I	S	CT	SP	VS	V	HT
Tabanidae	13	P	A	I	S	CT	CR	S	GSM	MT
Teratothyasidae	3	P	T/C	P	VS	O	W	VS	V	HS
Tipulidae	15	P	A	I	M	CT	O	S	GSM	MT
Tubellaria	8	P	TC	I	VS	FL	O	S	W	HT
Tubificidae	2100	G	TC	P	V	CT	B	VS	GSM	HT
Veliidae	10	P	A	P	S	O	SK	VS	W	MS
Total	18796									

Table 3-12: Macroinvertebrate trait relative abundance in MR4.

Trait	Category	Relative abundance (%)
Habitat preference	B-bedrock	27,11
	C-cobbles	25,55
	V-vegetation	13,64
	GSM-gravel,sand.mud	30,7
	W-water	2,1
Water quality preference	HS-highly sensitive	15,22
	MS-moderately sensitive	33,73
	MT-moderately tolerant	22,72
	HT-highly tolerant	28,34
Velocity preference	VF-very fast	15,21
	MF-moderately fast	12,38
	S-slow	45,92
	VS-very slow	26,49
Hydraulic habitat preference	P-pools	33,17
	RI-riffles	11,04
	RA-rapids	2,43
	I-indifferent	53,36
FFG	P- predator	49,26
	DF-deposit feeder	12,85
	FF-filter feeder	18,37
	SC-scraper	7,68
	GR-grazer	11,85
Respiration	G-Gills	53,46
	A-Aerial	26,38
	T/C- tegument/cutaneous	20,16
Body shape	ST-steamlined	10,81
	FL-flattened	28,4
	T/C-tubular/cylindrical	56,99
	SP-spherical	0,02
	O-variable	29,35
Body size	VS-very small	3,61
	S-small	45,11
	M-medium	6,22
	L-large	0,44
	V-variable	44,62
Locomotion	CR-crawler	11,56
	CL-climber	2,39
	SP-sprawler	17,68
	SW-swimmer	47,63
	O-other	6,71
	B- burrower	13,82
	SK- skater	0,2

Table 3-13: Macroinvertebrate trait categories assigned in MR5.

Taxa in MR5	Abundance	FFG	RESP	HHP	BSIZE	BSHAPE	Locomotion	Velocity	Habitat	WQ
Atyidae	113	DF	G	I	S	O	SW	VS	V	MS
Baetidae	389	DF	G	RI	S	ST	SP	MF	C	HS
Belostomatidae	5	P	A	P	S	FL	CR	VS	V	HT
Branchipodidae	3	FF	G	P	S	O	CR	VS	C	HS
Caenidae	137	DF	G	RI	S	ST	CR	VF	GSM	MT
Ceratopogonidae	25	GR	G	I	VS	T/C	CR	VF	C	MT
Chironomidae	728	P	G	I	V	T/C	SW	S	W	HT
Coenagrionidae	161	P	G	P	M	FL	CL	MF	V	MT
Corbiculidae	53	FF	G	RA	S	O	B	S	GSM	MT
Corixidae	363	P	A	I	S	O	SW	S	W	HT
Culicidae	50	FF	A	I	S	T/C	SP	VS	W	HT
Daphniidae	42	FF	G	P	S	O	SW	VS	GSM	HS
Dytiscidae	160	P	A	P	S	O	SW	VS	V	MT
Elmidae	2	SC	A	RI	S	O	CR	MF	C	MS
Ephyridae	3	SC	A	I	VS	T/C	SP	VS	GSM	HT
Glossiphoniidae	43	P	T/C	P	V	T/C	O	S	C	HT
Gomphidae	1	P	G	P	L	O	B	MF	GSM	MT
Gyrinidae	147	P	A	I	S	O	SW	VF	W	MT
Hydrachnidae	1	P	T/C	P	VS	SP	SW	VS	V	HS
Hydraenidae	9	SC	A	P	VS	O	CR	MF	V	MS
Hydroida	48	P	T/C	P	V	O	O	VS	W	HT
Hydrophilidae	1	SC	A	P	S	O	CR	VS	V	MT
Hydropsychidae	3	P	G	RA	S	T/C	SW	VF	C	MS
Hydroptilidae	10	DF	G	RA	VS	T/C	SW	S	V	MT
Isotomidae	2	DP	A	P	VS	O	O	MF	W	MS
Libellulidae	2	P	G	P	M	FL	CR	MF	B	MT
Lymnaeidae	1	DF	G	P	S	O	CR	VS	V	HT
Muscidae	5	P	A	I	VS	T/C	SP	VF	W	HT
Notonectidae	29	P	A	P	M	O	SW	VS	W	HT
Physidae	76	SC	A	I	M	O	CR	VS	V	HT
Planorbidae	50	SC	A	I	S	O	CR	S	V	HT
Potamonautilidae	8	DF	G	I	L	FL	W	MF	C	HT
Rhabdocoela	21	P	T/C	I	VS	FL	O	S	W	MS
Salifidae	5	P	T/C	P	S	T/C	O	S	C	HT
Simuliidae	18	FF	A	I	S	T/C	SP	S	C	MT
Sphaeriidae	24	FF	G	I	S	O	B	S	GSM	HT
Stratiomyidae	3	DF	A	I	S	T/C	SP	VS	V	HT
Tabanidae	1	P	A	I	S	T/C	CR	S	GSM	MT
Tubificidae	797	GR	T/C	P	V	T/C	B	VS	GSM	HT
TOTAL	3539									

Table 3-14: Macroinvertebrate trait relative abundance in MR5.

Trait	Category	Relative abundance (%)
Habitat preference	B-bedrock	0,06
	C-cobbles	14,02
	V-vegetation	16,67
	GSM-gravel,sand.mud	22,9
	W-water	39,36
Water quality preference	HS-highly sensitive	12,29
	MS-moderately sensitive	4,24
	MT-moderately tolerant	20,23
	HT-highly tolerant	63,24
Velocity preference	VF-very fast	8,96
	MF-moderately fast	16,22
	S-slow	37,19
	VS-very slow	37,64
Hydraulic habitat preference	P-pools	37,02
	RI-riffles	14,92
	RA-rapids	1,86
	I-indiffrent	46,2
FFG	P- predator	48,69
	DF-deposit feeder	18,73
	FF-filter feeder	5,37
	SC-scraper	3,98
	GR-grazer	23,23
Respiration	G-Gills	48,04
	A-Aerial	26,12
	T/C- tegument/cutaneous	25,84
Body shape	ST-steamlined	14,86
	FL-flattered	5,57
	T/C-tubular/cylindrical	47,7
	SP-spherical	0,03
	O-variable	31,76
Body size	VS-very small	2,15
	S-small	44,36
	M-medium	7,57
	L-large	0,25
	V-variable	45,66
Locomotion	CR-crawler	8,82
	CL-climber	4,55
	SP-sprawler	13,22
	SW-swimmer	42,22
	O-other	3,36
	B- burrower	27,2

CHAPTER 4: RESULTS

4.1. Introduction

The following chapter contains the results of the analysis of macroinvertebrate communities in the Mooi River catchment using the Macroinvertebrate Response Assessment Index (MIRAI) and application of macroinvertebrate traits. The results will be presented as taxa lists for each Mooi River reach. The analyses of the EC and flow, habitat and water quality metrics will be presented in tables for each reach. Traits will be presented in graphs where each reach's data will be represented. In general, macroinvertebrate data were subjected to MIRAI and trait analyses to explore whether metrics could provide further ecological information that may have the potential to enhance the understanding of macroinvertebrate responses in the catchment.

4.2. Macroinvertebrate abundance

Throughout the study, a total of 40 413 macroinvertebrate individuals from 83 taxa were collected and identified (Erasmus, 2017 and Pretorius, 2017). The macroinvertebrate abundance from the five reaches are shown in Figure 4-1, where MR4 had the highest abundance (18 796) during the sampling period of 2014 to 2016.

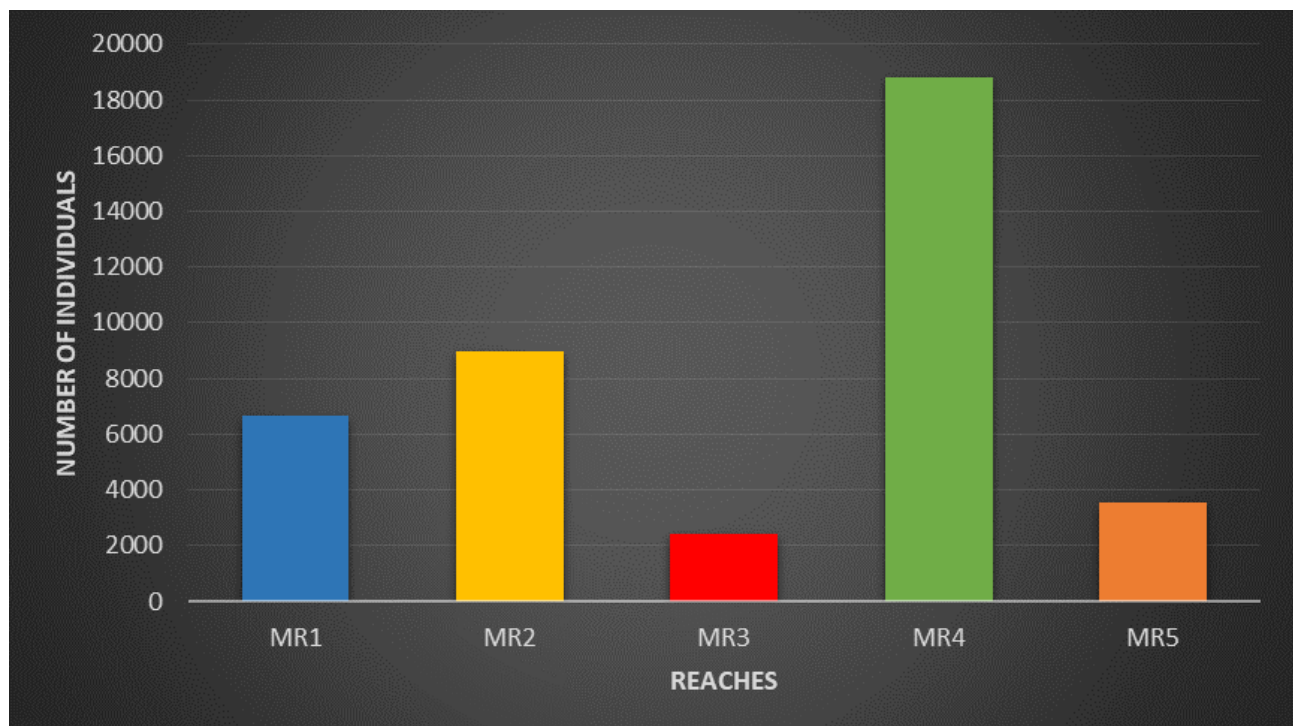


Figure 4-1: Macroinvertebrate assemblage abundance of the Mooi River catchment.

Table 4-1: Mooi River reaches and their respective number of taxa.

Reaches	No.of taxa	No. of individuals
MR1	41	6 662
MR2	38	9 000
MR3	33	2 416
MR4	47	18 796
MR5	26	3 539

A total of 6662 individuals from 41 taxa were recorded in MR1 (Table 4-1). Taxa such as Baetidae (1 194), Chironomidae (934) and Coenagrionidae (913) had the highest abundance (Table 4-2). In MR2, 9 000 individuals were recorded from 38 taxa where the most abundant taxa were Daphniidae (2 793) and Chironomidae (1 002) (Table 4-3). A total of 2 416 individuals was recorded in MR3 from 33 taxa where Atyidae (851) and Baetidae (584) had the highest abundance (Table 4-5). The highest number of recorded individuals was in MR4, where 18 796 were found from 47 taxa; taxa that had the highest abundances were Chironomidae (5058), Naididae (2 100), Simuliidae (1 629), Baetidae (1 499), Daphniidae (1 328) and Glossiphonidae (1 163) (Table 4-7). In MR5, 3 539 individuals were recorded from 26 taxa and taxa that had the highest abundance were Naididae (797), Chironomidae (728), Baetidae (389) and Corixidae (363) (Table 4-9).

Table 4-2: Macroinvertebrate taxa and MIRAI metrics collected in MR1.

Macroinvertebrates in MR1	Abundance	Velocity preference categories				Habitat preference categories				Water quality requirements
		<0.1	0.1-0.3	0.3-0.6	>0.6	COBBLES	VEG	GSM	WATER	
Aeshnidae	19	2,5	3,5	4	2,5	4	3	3	0	MODERATE
Atyidae	444	4	3,5	0,5	0	1	4,5	0,5	0	MODERATE
Baetidae	1 195	3	3,5	4	4	4	4	4	0	LOW
Belostomatidae	17	4	1	0	0	0	4,5	0,5	0	VERY LOW
Caenidae	640	4,5	3,5	3	3	3	3	4,5	0	LOW
Ceratopogonidae	13	4,5	3	2,5	4,5	3,5	2	4	0	LOW
Chaoboridae	12									
Chironomidae	934	4,5	4,5	4,5	4,5	3,5	3	3,5	0	VERY LOW
Chrysomelidae	1									
Coenagrionidae	913	4,5	3,5	2	2	0,5	4,5	0,5	0	LOW
Corbiculidae	57	4	4	3,5	3	3	1	4,5	0	LOW
Corixidae	15	4,5	3	1,5	1	3	2,5	3,5	2	VERY LOW
Crambidae	5									
Culicidae	20	4,5	2	0	0	0	4	0	3,5	VERY LOW
Curculionidae	3									
Cypridoidea	1									
Daphniidae	68									
Dixidae	26	4	3	2	0	0	2,5	0	4,5	MODERATE
Dolichopodidae	1									
Dytiscidae	53	4,5	1,5	0,5	0	2	4	3,5	0	LOW
Ecnomidae	9	2	3,5	3,5	1,5	4	1	1,5	0	MODERATE
Elmidae	82	1,5	3	4	4,5	4	1	3,5	0	MODERATE
Empididae	5	0	1	4	3	4,5	2	0	0	LOW
Ephydriidae	1	4,5	1	0	0	0,5	2	4	0	VERY LOW
Gerridae	4	4	3,5	2,5	0	1	3	0	4	LOW
Glossiphonidae	12									
Gomphidae	2	4,5	4	3	2,5	2,5	1	4,5	0	LOW

Table 4-2: Continued.

Gyrinidae	176	3,5	3,5	3,5	3,5	3	3,5	2	4	LOW
Haliplidae	2	4,5	1	0	0	4	3,5	2	0	LOW
Hydrachnidae	11									
Hydraenidae	33	1	1,5	3	4	4	3	1,5	3	MODERATE
Hydridae	63									
Hydrophilidae	4	3,5	3,5	3,5	3,5	2,5	4,5	1,5	1	LOW
Hydropsychidae	167	1	2,5	4	4,5	4,5	1	1,5	0	LOW
Hydroptilidae	1	3,5	4	4,5	3	3,8	4	1,5	0	LOW
Hygrobatidae	1									
Libellulidae	41	3	3,5	4	3,5	4,5	3,5	2,5	0	LOW
Lymnaeidae	4	4,5	2	1	0,5	1	4,5	4	0	VERY LOW
Mesoveliidae	6									
Muscidae	43	4,5	1	0	0	0,5	2,5	3,5	4	VERY LOW
Naucoridae	5	3	4	3	1,5	3,5	3,5	3,5	3	LOW
Nepidae	1	4,5	0,5	0	0	0	5	0	0	VERY LOW
Notonectidae	2	4	3	0,5	0	0	4	0	3,5	VERY LOW
Paraphrynoveliidae	4									
Physidae	276	4,5	2	1	0,5	1	4,5	4	0	VERY LOW
Planorbidae	495									
Pleidae	5	4,5	1	0	0	1	4,5	0,5	1	LOW
Polymitarcyidae	2	4,5	1	0	0	0,5	0,5	5	0	MODERATE
Potamonautidae	43	4	4,5	4,5	4,5	4,5	0,5	4	0	VERY LOW
Rhabdocoela	22									
Simuliidae	391	1,5	2	3,5	4,5	4,5	1,5	0,5	0	LOW
Sphaeriidae	42	4,5	4,5	4	3,5	4	0,5	4,5	0	VERY LOW
Stratiomyidae	1									
Tabanidae	3	1	4,5	4	2,5	4	1	3	0	LOW
Tipulidae	2	2,5	4	4	4	3,5	0,5	4	0	LOW
Tubellaria	51	2	4	4,5	4	4	1	3	0	VERY LOW
Naididae	200									
Veliidae	13	4	2,5	2	2	2,5	3,5	1,5	4,5	LOW
TOTAL	6 662									

Table 4-3: Macroinvertebrate taxa and MIRAI metrics collected in MR2.

Macroinvertebrates in MR2	Abundance	Velocity preference metric				Habitat preference metric				Water quality requirements metric
		<0.1	0.1-0.3	0.3-0.6	>0.6	COBBLES	VEG	GSM	WATER	
Aeshnidae	16	2,5	3,5	4	2,5	4	3	3	0	MODERATE
Atyidae	47	4	3,5	0,5	0	1	4,5	0,5	0	MODERATE
Baetidae	520	3	3,5	4	4	4	4	4	0	LOW
Belostomatidae	43	4	1	0	0	0	4,5	0,5	0	VERY LOW
Caenidae	15	4,5	3,5	3	3	3	3	4,5	0	LOW
Ceratopogonidae	19	4,5	3	2,5	4,5	3,5	2	4	0	LOW
Chironomidae	1 002	4,5	4,5	4,5	4,5	3,5	3	3,5	0	VERY LOW
Coenagrionidae	163	4,5	3,5	2	2	0,5	4,5	0,5	0	LOW
Corbiculidae	18	4	4	3,5	3	3	1	4,5	0	LOW
Corixidae	455	4,5	3	1,5	1	3	2,5	3,5	2	VERY LOW
Crambidae	1									
Culicidae	14	4,5	2	0	0	0	4	0	3,5	VERY LOW
Curculionidae	24									
Cyclopidae	22									
Daphniidae	2793									
Dolichopodidae	1									
Dytiscidae	29	4,5	1,5	0,5	0	2	4	3,5	0	LOW
Ecnomidae	1	2	3,5	3,5	1,5	4	1	1,5	0	MODERATE
Elmidae	2	1,5	3	4	4,5	4	1	3,5	0	MODERATE
Ephydriidae	22	4,5	1	0	0	0,5	2	4	0	VERY LOW
Eylaidae	1									
Gerridae	1	4	3,5	2,5	0	1	3	0	4	LOW
Glossiphoniidae	612									
Gomphidae	3	4,5	4	3	2,5	2,5	1	4,5	0	LOW
Gyrinidae	95	3,5	3,5	3,5	3,5	3	3,5	2	4	LOW
Haliplidae	1	4,5	1	0	0	4	3,5	2	0	LOW
Hydraenidae	18	1	1,5	3	4	4	3	1,5	3	MODERATE

Table 4-3: Continued.

Hydridae	298									
Hydroptilidae	109	3,5	4	4,5	3	3,8	4	1,5	0	LOW
Hydrophilidae	6	3,5	3,5	3,5	3,5	2,5	4,5	1,5	1	LOW
Hydropsychidae	145	1	2,5	4	4,5	4,5	1	1,5	0	LOW
Libellulidae	16	3	3,5	4	3,5	4,5	3,5	2,5	0	LOW
Lymnaeidae	48	4,5	2	1	0,5	1	4,5	4	0	VERY LOW
Mesoveliidae	11									
Muscidae	41	4,5	1	0	0	0,5	2,5	3,5	4	VERY LOW
Naucoridae	69	3	4	3	1,5	3,5	3,5	3,5	3	LOW
Nepidae	3	4,5	0,5	0	0	0	5	0	0	VERY LOW
Notonectidae	10	4	3	0,5	0	0	4	0	3,5	VERY LOW
Physidae	225	4,5	2	1	0,5	1	4,5	4	0	VERY LOW
Planorbidae	564									
Pleidae	30	4,5	1	0	0	1	4,5	0,5	1	LOW
Potamonautidae	10	4	4,5	4,5	4,5	4,5	0,5	4	0	VERY LOW
Psephenidae	1	2,5	3,5	4,5	4	4,5	0,5	1	0	MODERATE
Psychodidae	1	0,5	4,5	4	0	3,5	3,5	3,5	3	VERY LOW
Rhabdocoela	116									
Scirtidae	3									
Simuliidae	630	1,5	2	3,5	4,5	4,5	1,5	0,5	0	LOW
Sphaeriidae	15	4,5	4,5	4	3,5	4	0,5	4,5	0	VERY LOW
Stratiomyidae	8									
Tabanidae	1	1	4,5	4	2,5	4	1	3	0	LOW
Tipulidae	4	2,5	4	4	4	3,5	0,5	4	0	LOW
Naididae	697									
Veliidae	1	4	2,5	2	2	2,5	3,5	1,5	4,5	LOW
TOTAL	9 000									

Table 4-4: Macroinvertebrate taxa and MIRAI metrics collected in MR3.

Macroinvertebrates in MR3	Abundance	Velocity preference categories				Habitat preference categories				Water quality requirements
		<0.1	0.1-0.3	0.3-0.6	>0.6	COBBLES	VEG	GSM	WATER	
Aeshnidae	3	2,5	3,5	4	2,5	4	3	3	0	MODERATE
Atyidae	851	4	3,5	0,5	0	1	4,5	0,5	0	MODERATE
Baetidae	584	3	3,5	4	4	4	4	4	0	LOW
Belostomatidae	11	4	1	0	0	0	4,5	0,5	0	VERY LOW
Caenidae	133	4,5	3,5	3	3	3	3	4,5	0	LOW
Ceratopogonidae	17	4,5	3	2,5	4,5	3,5	2	4	0	LOW
Chaoboridae	1									
Chironomidae	118	4,5	4,5	4,5	4,5	3,5	3	3,5	0	VERY LOW
Chlorocyphidae	1	3	4	3	1	4,5	3	1,5	0	MODERATE
Chrysomelidae	1									
Coenagrionidae	63	4,5	3,5	2	2	0,5	4,5	0,5	0	LOW
Corixidae	11	4,5	3	1,5	1	3	2,5	3,5	2	VERY LOW
Crambidae	3									
Culicidae	1	4,5	2	0	0	0	4	0	3,5	VERY LOW
Curculionidae	1									
Dixidae	4	4	3	2	0	0	2,5	0	4,5	MODERATE
Dytiscidae	7	4,5	1,5	0,5	0	2	4	3,5	0	LOW
Ecnomidae	13	2	3,5	3,5	1,5	4	1	1,5	0	MODERATE
Elmidae	3	1,5	3	4	4,5	4	1	3,5	0	MODERATE
Empididae	1	0	1	4	3	4,5	2	0	0	LOW
Ephydriidae	1	4,5	1	0	0	0,5	2	4	0	VERY LOW
Gerridae	5	4	3,5	2,5	0	1	3	0	4	LOW
Gomphidae	17	4,5	4	3	2,5	2,5	1	4,5	0	LOW
Gyrinidae	13	3,5	3,5	3,5	3,5	3	3,5	2	4	LOW
Hydraenidae	5	1	1,5	3	4	4	3	1,5	3	MODERATE
Hydrophilidae	6	3,5	3,5	3,5	3,5	2,5	4,5	1,5	1	LOW
Hydropsychidae	48	1	2,5	4	4,5	4,5	1	1,5	0	LOW
Hydroptilidae	32	3,5	4	4,5	3	3,8	4	1,5	0	LOW

Table 4-4 Continued.

Libellulidae	6	3	3,5	4	3,5	4,5	3,5	2,5	0	LOW
Lymnaeidae	10	4,5	2	1	0,5	1	4,5	4	0	VERY LOW
Muscidae	3	4,5	1	0	0	0,5	2,5	3,5	4	VERY LOW
Naucoridae	29	3	4	3	1,5	3,5	3,5	3,5	3	LOW
Nepidae	1	4,5	0,5	0	0	0	5	0	0	VERY LOW
Notonectidae	1	4	3	0,5	0	0	4	0	3,5	VERY LOW
Planorbidae	102									
Potamonautidae	16	4	4,5	4,5	4,5	4,5	0,5	4	0	VERY LOW
Protoneuridae	1	2	3	1	1	2	4	1	0	MODERATE
Rhabdocoela	5									
Simuliidae	91	1,5	2	3,5	4,5	4,5	1,5	0,5	0	LOW
Sphaeriidae	171	4,5	4,5	4	3,5	4	0,5	4,5	0	VERY LOW
Naididae	26									
TOTAL	2 416									

Table 4-5: Macroinvertebrate taxa and MIRAI metrics collected in MR4.

Macroinvertebrates in MR4	Abundance	Velocity preference categories				Habitat preference categories				Water quality requirements
		<0.1	0.1-0.3	0.3-0.6	>0.6	COBBLES	VEG	GSM	WATER	
Aeshnidae	21	2,5	3,5	4	2,5	4	3	3	0	MODERATE
Athericidae	5	3,5	4,5	4	3,5	4	3	3	0	MODERATE
Atyidae	58	4	3,5	0,5	0	1	4,5	0,5	0	MODERATE
Baetidae	1 499	3	3,5	4	4	4	4	4	0	LOW
Belostomatidae	13	4	1	0	0	0	4,5	0,5	0	VERY LOW
Blepharoceridae	2	0	0,5	1	4,5	5	0,5	0	0	HIGH
Branchipodidae	9									
Caenidae	532	4,5	3,5	3	3	3	3	4,5	0	LOW
Ceratopogonidae	83	4,5	3	2,5	4,5	3,5	2	4	0	LOW
Chironomidae	5 058	4,5	4,5	4,5	4,5	3,5	3	3,5	0	VERY LOW
Chlorocyphidae	11	3	4	3	1	4,5	3	1,5	0	MODERATE
Chrysomelidae	27									
Coenagrionidae	414	4,5	3,5	2	2	0,5	4,5	0,5	0	LOW
Corbiculidae	8	4	4	3,5	3	3	1	4,5	0	LOW
Corixidae	1 235	4,5	3	1,5	1	3	2,5	3,5	2	VERY LOW
Crambidae	1									
Culicidae	43	4,5	2	0	0	0	4	0	3,5	VERY LOW
Curculionidae	1									
Cypridoidea	162									
Daphniidae	1 328									
Dixidae	2	4	3	2	0	0	2,5	0	4,5	MODERATE
Dolichopodidae	9									
Dytiscidae	307	4,5	1,5	0,5	0	2	4	3,5	0	LOW
Ecnomidae	8	2	3,5	3,5	1,5	4	1	1,5	0	MODERATE
Elmidae	38	1,5	3	4	4,5	4	1	3,5	0	MODERATE
Empididae	1	0	1	4	3	4,5	2	0	0	LOW
Ephydriidae	43	4,5	1	0	0	0,5	2	4	0	VERY LOW
Gerridae	23	4	3,5	2,5	0	1	3	0	4	LOW

Table 4-5: Continued.

Glossiphoniidae	1 163									
Gomphidae	55	4,5	4	3	2,5	2,5	1	4,5	0	LOW
Gyrinidae	194	3,5	3,5	3,5	3,5	3	3,5	2	4	LOW
Haliplidae	11	4,5	1	0	0	4	3,5	2	0	LOW
Hydrachnidae	1									
Hydraenidae	274	1	1,5	3	4	4	3	1,5	3	MODERATE
Hydroida	46									
Hydrophilidae	20	3,5	3,5	3,5	3,5	2,5	4,5	1,5	1	LOW
Hydropsychidae	337	1	2,5	4	4,5	4,5	1	1,5	0	LOW
Hydroptilidae	104	3,5	4	4,5	3	3,8	4	1,5	0	LOW
Hygrobatidae	3									
Isotomidae	2									
Lestidae	1									
Libellulidae	37	3	3,5	4	3,5	4,5	3,5	2,5	0	LOW
Limnésiidae	13									
Limnichidae	3	4	2	1,5	0	0,5	1	4	0	MODERATE
Lymnaeidae	35	4,5	2	1	0,5	1	4,5	4	0	VERY LOW
Mesoveliidae	5									
Muscidae	81	4,5	1	0	0	0,5	2,5	3,5	4	VERY LOW
Nepidae	3	4,5	0,5	0	0	0	5	0	0	VERY LOW
Notonectidae	98	4	3	0,5	0	0	4	0	3,5	VERY LOW
Perlidae	1	0,5	3	4	3,5	4	0,5	1,5	0	HIGH
Physidae	570	4,5	2	1	0,5	1	4,5	4	0	VERY LOW
Planariidae	9									
Planorbidae	496									
Pleidae	27	4,5	1	0	0	1	4,5	0,5	1	LOW
Potamonautidae	7	4	4,5	4,5	4,5	4,5	0,5	4	0	VERY LOW
Protoneuridae	12	2	3	1	1	2	4	1	0	MODERATE
Psychodidae	5	0,5	4,5	4	0	3,5	3,5	3,5	3	VERY LOW
Rhabdocoela	19									
Sciomyzidae	8									
Scirtidae	2									
Simuliidae	1 629	1,5	2	3,5	4,5	4,5	1,5	0,5	0	LOW
Spercheidae	1									

Table 4-5: Continued.

Sphaeriidae	430	4,5	4,5	4	3,5	4	0,5	4,5	0	VERY LOW
Sphaeriusidae	1									
Stratiomyidae	3									
Tabanidae	13	1	4,5	4	2,5	4	1	3	0	LOW
Teratothyasidae	3									
Tipulidae	15	2,5	4	4	4	3,5	0,5	4	0	LOW
Tubellaria	8	2	4	4,5	4	4	1	3	0	VERY LOW
Naididae	2 100									
Veliidae	10	4	2,5	2	2	2,5	3,5	1,5	4,5	LOW
TOTAL	18 796									

Table 4-6: Macroinvertebrate taxa and MIRAI metrics collected in MR5.

Macroinvertebrates in MR5	Abundance	Velocity preference categories				Habitat preference categories				Water quality requirements
		<0.1	0.1-0.3	0.3-0.6	>0.6	COBBLES	VEG	GSM	WATER	
Atyidae	113	4	3,5	0,5	0	1	4,5	0,5	0	MODERATE
Baetidae	389	3	3,5	4	4	4	4	4	0	LOW
Belostomatidae	5	4	1	0	0	0	4,5	0,5	0	VERY LOW
Branchipodidae	3									
Caenidae	137	4,5	3,5	3	3	3	3	4,5	0	LOW
Ceratopogonidae	25	4,5	3	2,5	4,5	3,5	2	4	0	LOW
Chironomidae	728	4,5	4,5	4,5	4,5	3,5	3	3,5	0	VERY LOW
Coenagrionidae	161	4,5	3,5	2	2	0,5	4,5	0,5	0	LOW
Corbiculidae	53	4	4	3,5	3	3	1	4,5	0	LOW
Corixidae	363	4,5	3	1,5	1	3	2,5	3,5	2	VERY LOW
Culicidae	50	4,5	2	0	0	0	4	0	3,5	VERY LOW
Daphniidae	42									
Dytiscidae	160	4,5	1,5	0,5	0	2	4	3,5	0	LOW
Elmidae	2	1,5	3	4	4,5	4	1	3,5	0	MODERATE
Ephydriidae	3	4,5	1	0	0	0,5	2	4	0	VERY LOW
Glossiphoniidae	43									
Gomphidae	1	4,5	4	3	2,5	2,5	1	4,5	0	LOW
Gyrinidae	147	3,5	3,5	3,5	3,5	3	3,5	2	4	LOW
Hydrachnidae	1									
Hydraenidae	9	1	1,5	3	4	4	3	1,5	3	MODERATE
Hydroida	48									
Hydrophilidae	1	3,5	3,5	3,5	3,5	2,5	4,5	1,5	1	LOW
Hydropsychidae	3	1	2,5	4	4,5	4,5	1	1,5	0	LOW
Hydroptilidae	10	3,5	4	4,5	3	3,8	4	1,5	0	LOW
Isotomidae	2									
Libellulidae	2	3	3,5	4	3,5	4,5	3,5	2,5	0	LOW
Lymnaeidae	1	4,5	2	1	0,5	1	4,5	4	0	VERY LOW
Muscidae	5	4,5	1	0	0	0,5	2,5	3,5	4	VERY LOW

Table 4-6: Continued.

Planorbidae	50									
Physidae	76	4,5	2	1	0,5	1	4,5	4	0	VERY LOW
Notonectidae	29	4	3	0,5	0	0	4	0	3,5	VERY LOW
Potamonautidae	8	4	4,5	4,5	4,5	4,5	0,5	4	0	VERY LOW
Rhabdocoela	21									
Salifidae	5									
Simuliidae	18	1,5	2	3,5	4,5	4,5	1,5	0,5	0	LOW
Sphaeriidae	24	4,5	4,5	4	3,5	4	0,5	4,5	0	VERY LOW
Stratiomyidae	3									
Tabanidae	1	1	4,5	4	2,5	4	1	3	0	LOW
Naididae	797									
TOTAL	3 539									

4.3 Macroinvertebrate Ecological Categories (EC)

Table 4-7 illustrates the results of the MIRAI for macroinvertebrate assemblages collected in MR1. The results are presented to illustrate the flow modification, habitat modification and water quality metrics as well as the ecological category (EC) of the macroinvertebrate assemblages in MR1. The flow modification metric was 58.7%, habitat modification was 51.1% and the water quality metric was 32.6%. The overall ecological class score for MR1 was 46.73% placed in Ecological Category D. The MR1 was largely modified (Table 3-3).

Table 4-7: MIRAI score sheet for MR1.

Which measures will best indicate macroinvertebrate response (at this site)						
INVERTEBRATE EC						
INVERTEBRATE EC METRIC GROUP		METRIC GROUP CALCULATED SCORE	CALCULATED WEIGHT	WEIGHTED SCORE OF GROUP	RANK OF METRIC GROUP	%WEIGHT FOR METRIC GROUP
FLOW MODIFICATION	FM	58,7	0,309	18,1466	3	85
HABITAT	H	51,1	0,327	16,7392	2	90
WATER QUALITY	WQ	32,6	0,364	11,8442	1	100
CONNECTIVITY & SEASONALITY	CS	0,0	0,000	0	0	
						275
INVERTEBRATE EC				46,73		
INVERTEBRATE EC CATEGORY				D		
>89=A; 80-89=B; 60-79=C; 40-59=D; 20-39=E; <20=F						
Guidelines for ranking of metric groups. Which of the Metric Groups will best indicate the response of invertebrates at this site or reach/invertebrate habitat segment. Considering the range from 5 to 0 of each of these metric groups, which one would most affect overall Invertebrate Response (PES) if it changed from 0 to 5? (irrespective of the rating). This metric group is ranked as 1, the next most responsive, ranked as 2, etc.						
Guidelines for weighting of metric groups. Give 100% to rank 1, then say how big the impact of each of the others is as a % of that (irrespective of the rating).						

Table 4-8 illustrates the results of the MIRAI for macroinvertebrate assemblages collected in MR2. The results are presented to illustrate the flow modification, habitat modification and water quality metrics as well as the EC of the macroinvertebrate assemblages in MR2. The flow modification metric was 55.7%, habitat modification was 51.6% and the water quality metric was 32.2%. The overall EC score for MR2 was 45.5% placed in Ecological Category D. The MR2 was largely modified (Table 3-3).

Table 4-8: MIRAI score sheet for MR2.

Which measures will best indicate responses of macroinvertebrates (at this site)						
INVERTEBRATE EC						
INVERTEBRATE EC METRIC GROUP		METRIC GROUP CALCULATED SCORE	CALCULATED WEIGHT	WEIGHTED SCORE OF GROUP	RANK OF METRIC GROUP	%WEIGHT FOR METRIC GROUP
FLOW MODIFICATION	FM	55,7	0,302	16,8078	3	80
HABITAT	H	51,6	0,321	16,5551	2	85
WATER QUALITY	WQ	32,2	0,377	12,1411	1	100
CONNECTIVITY & SEASONALITY	CS	0,0	0,000	0		
						265
INVERTEBRATE EC				45,5039		
INVERTEBRATE EC CATEGORY				D		
>89=A; 80-89=B; 60-79=C; 40-59=D; 20-39=E; <20=F						
<u>Guidelines for ranking of metric groups.</u>						
Which of the Metric Groups will best indicate the response of invertebrates at this site or reach/invertebrate habitat segment.						
Considering the range from 5 to 0 of each of these metric groups, which one would most affect overall Invertebrate Response (PES) if it changed from 0 to 5? (irrespective of the rating). This metric group is ranked as 1, the next most responsive, ranked as 2, etc.						
<u>Guidelines for weighting of metric groups.</u>						
Give 100% to rank 1, then say how big the impact of each of the others is as a % of that (irrespective of the rating).						

Table 4-9 illustrates the results of the MIRAI for macroinvertebrate assemblages collected in MR3. The results are presented to illustrate the flow modification, habitat modification and water quality metrics as well as the EC of the macroinvertebrate assemblages in MR3. The flow modification metric was 54.7%, habitat modification was 50.5% and the water quality metric was 31.3%. The overall EC score for MR3 was 44.64% placed in Ecological Category D. The MR3 was largely modified (Table 3-3).

Table 4-9: MIRAI score sheet for MR3.

Which measures will best indicate macroinvertebrate responses (at this site)						
		INVERTEBRATE EC				
INVERTEBRATE EC METRIC GROUP		METRIC GROUP CALCULATED SCORE	CALCULATED WEIGHT	WEIGHTED SCORE OF GROUP	RANK OF METRIC GROUP	%WEIGHT FOR METRIC GROUP
FLOW MODIFICATION	FM	54,7	0,296	16,2074	3	80
HABITAT	H	50,5	0,333	16,8333	2	90
WATER QUALITY	WQ	31,3	0,370	11,5926	1	100
CONNECTIVITY & SEASONALITY	CS	0,0	0,000	0	0	0
						270
INVERTEBRATE EC				44,6366		
INVERTEBRATE EC CATEGORY				D		
>89=A; 80-89=B; 60-79=C; 40-59=D; 20-39=E; <20=F						
Guidelines for ranking of metric groups. Which of the Metric Groups will best indicate the response of invertebrates at this site or reach/invertebrate habitat segment. Considering the range from 5 to 0 of each of these metric groups, which one would most affect overall Invertebrate Response (PES) if it changed from 0 to 5? (irrespective of the rating). This metric group is ranked as 1, the next most responsive, ranked as 2, etc.						
Guidelines for weighting of metric groups. Give 100% to rank 1, then say how big the impact of each of the others is as a % of that (irrespective of the rating).						

Table 4-10 illustrates the results of the MIRAI for macroinvertebrate assemblages collected in MR4. The results are presented to illustrate the flow modification, habitat modification and water quality metrics as well as the EC of the macroinvertebrate assemblages in MR4. The flow modification metric was 54%, habitat modification was 61.2% and the water quality metric was 43.4%. The overall EC score for MR4 was 52.23% in Ecological Category D. The MR4 was largely modified (Table 3-3).

Table 4-10: MIRAI score sheet for MR4.

Which measures will best indicate macroinvertebrate responses (at this site)						
		INVERTEBRATE EC				
INVERTEBRATE EC METRIC GROUP		METRIC GROUP CALCULATED SCORE	CALCULATED WEIGHT	WEIGHTED SCORE OF GROUP	RANK OF METRIC GROUP	%WEIGHT FOR METRIC GROUP
FLOW MODIFICATION	FM	54,0	0,333	18,01	2	90
HABITAT	H	61,2	0,296	18,1316	3	80
WATER QUALITY	WQ	43,4	0,370	16,0847	1	100
CONNECTIVITY & SEASONALITY	CS	0,0	0,000	0		
						270
INVERTEBRATE EC				52,2262		
INVERTEBRATE EC CATEGORY				D		
>89=A; 80-89=B; 60-79=C; 40-59=D; 20-39=E; <20=F						
<u>Guidelines for ranking of metric groups.</u>						
Which of the Metric Groups will best indicate the response of invertebrates at this site or reach/invertebrate habitat segment.						
Considering the range from 5 to 0 of each of these metric groups, which one would most affect overall Invertebrate Response (PES) if it changed from 0 to 5? (irrespective of the rating). This metric group is ranked as 1, the next most responsive, ranked as 2, etc.						
<u>Guidelines for weighting of metric groups.</u>						
Give 100% to rank 1, then say how big the impact of each of the others is as a % of that (irrespective of the rating).						

Table 4-11 illustrates the results of the MIRAI for macroinvertebrate assemblages collected in MR5. The results are presented to illustrate the flow modification, habitat modification and water quality metrics as well as the EC of the macroinvertebrate assemblages in MR5. The flow modification metric was 41.5%, habitat modification was 43.4% and the water quality metric was 41.2%. The overall EC score for MR5 was 41.94% in Ecological Category D/E. The MR5 was largely modified and bordered on becoming seriously modified (Table 3-3).

Table 4-11: MIRAI score sheet for MR5.

Which measures will best indicate responses of macroinvertebrates (at this site)						
		INVERTEBRATE EC				
INVERTEBRATE EC METRIC GROUP		METRIC GROUP CALCULATED SCORE	CALCULATED WEIGHT	WEIGHTED SCORE OF GROUP	RANK OF METRIC GROUP	%WEIGHT FOR METRIC GROUP
FLOW MODIFICATION	FM	41,2	0,296	12,211	3	80
HABITAT	H	43,4	0,333	14,4762	2	90
WATER QUALITY	WQ	41,2	0,370	15,2505	1	100
CONNECTIVITY & SEASONALITY	CS	0,0	0,000	0		
						270
INVERTEBRATE EC				41,9377		
INVERTEBRATE EC CATEGORY				D/E		
>89=A; 80-89=B; 60-79=C; 40-59=D; 20-39=E; <20=F						
<u>Guidelines for ranking of metric groups.</u>						
Which of the Metric Groups will best indicate the response of invertebrates at this site or reach/invertebrate habitat segment.						
Considering the range from 5 to 0 of each of these metric groups, which one would most affect overall Invertebrate Response (PES) if it changed from 0 to 5? (irrespective of the rating). This metric group is ranked as 1, the next most responsive, ranked as 2, etc.						
<u>Guidelines for weighting of metric groups.</u>						
Give 100% to rank 1, then say how big the impact of each of the others is as a % of that (irrespective of the rating).						

A summary of the Ecological Category (EC) for the reaches are shown in Figure 4-2, where MR4 had the highest EC (52.23%), followed by MR1 (46.73%), MR2 (45.5%), MR3 (44.64%) and finally MR5 (41.94%). The summary of the metric group scores for the five reaches are illustrated in Figure 4-3, where MR1 had the highest flow modification metric (58.7%), MR4 had the highest habitat preference metric (61.2%) and the highest water quality metric was in MR4 (43.4%). The reaches with the highest metrics and EC showed the closest degree to those of the reference conditions. The reaches which displayed the highest deviation from the reference conditions were MR5, where the ecological class of the flow modification metric was the lowest at 41.2%. The habitat preference metric was also the lowest in MR5 (43.4%) and the lowest water quality metric was found in MR3 (31.3%).

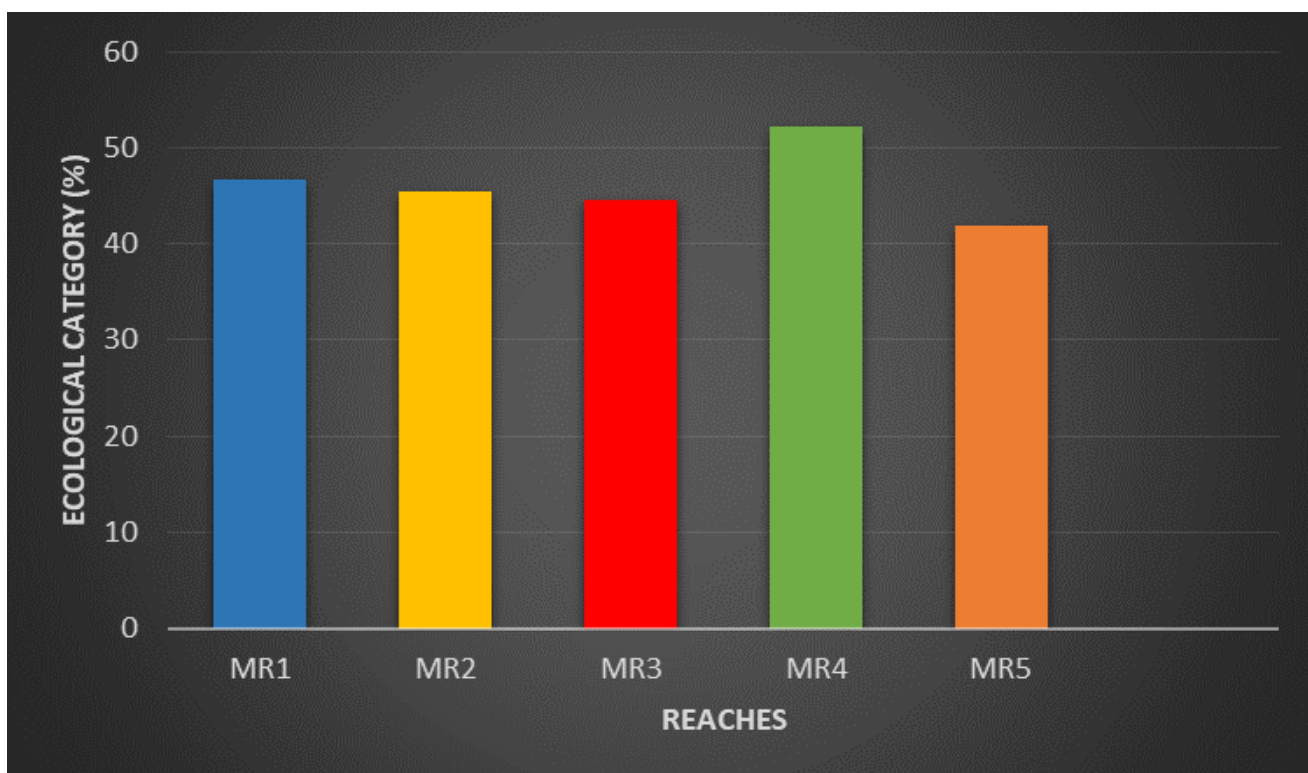


Figure 4-2: A summary of the ecological category (EC) scores of the Mooi River macroinvertebrate assemblages.



Figure 4-3: A summary of the metric group scores of the Mooi River macroinvertebrate assemblages; flow modification (FM), habitat preference (HP) and water quality (WQ).

4.4. Macroinvertebrate traits

The results of all the assessed macroinvertebrate traits are recorded below. There were nine traits applied and analyzed in this study with a total of 43 categories for analysis of assemblage trait structure (total abundance percentage), a 100% stacked column was used to compare the different traits along the five Mooi River reaches. Based upon the results, there were visible differences in assemblage composition amongst the five river reaches.

4.4.1. Habitat preference

The habitat preferences of the macroinvertebrate assemblages for the five reaches are displayed in Figure 4-4. Biotopes selected for the scope of the study were bedrock, cobbles/stones, vegetation, gravel, sand and mud (GSM) as well as water column. An analysis of the Mooi River catchment showed that taxa that prefer the GSM biotope had an overall abundance of 26.24%. Taxa that prefer the cobble/stone biotope had an overall abundance of 25.77%, followed by taxa with a preference for vegetation with 25.31%. Taxa that prefer the bedrock biotope had an overall abundance of 11.84% and finally the taxa that prefer the water column had an overall abundance of 10.85%. At reach level, the GSM preferring taxa had the highest abundance in MR2 (44.94%) and lowest abundance in MR3 (14.9%). Macroinvertebrate taxa with a preference for the cobble/stones biotope had the highest abundance in MR1 (30.06%) and had the lowest abundance in MR5 (14.02%), while taxa that prefer vegetation had the highest abundance in MR3 (45.28%) and the lowest abundance was found in MR4 (13.64%). Taxa that prefer bedrock biotope had the highest abundance in MR4 (27.11%) and had the lowest in MR5 (0.06%). Taxa that prefer the water column had the highest abundance in MR5 (39.36%) and the lowest abundance was in MR4 (2.1%).

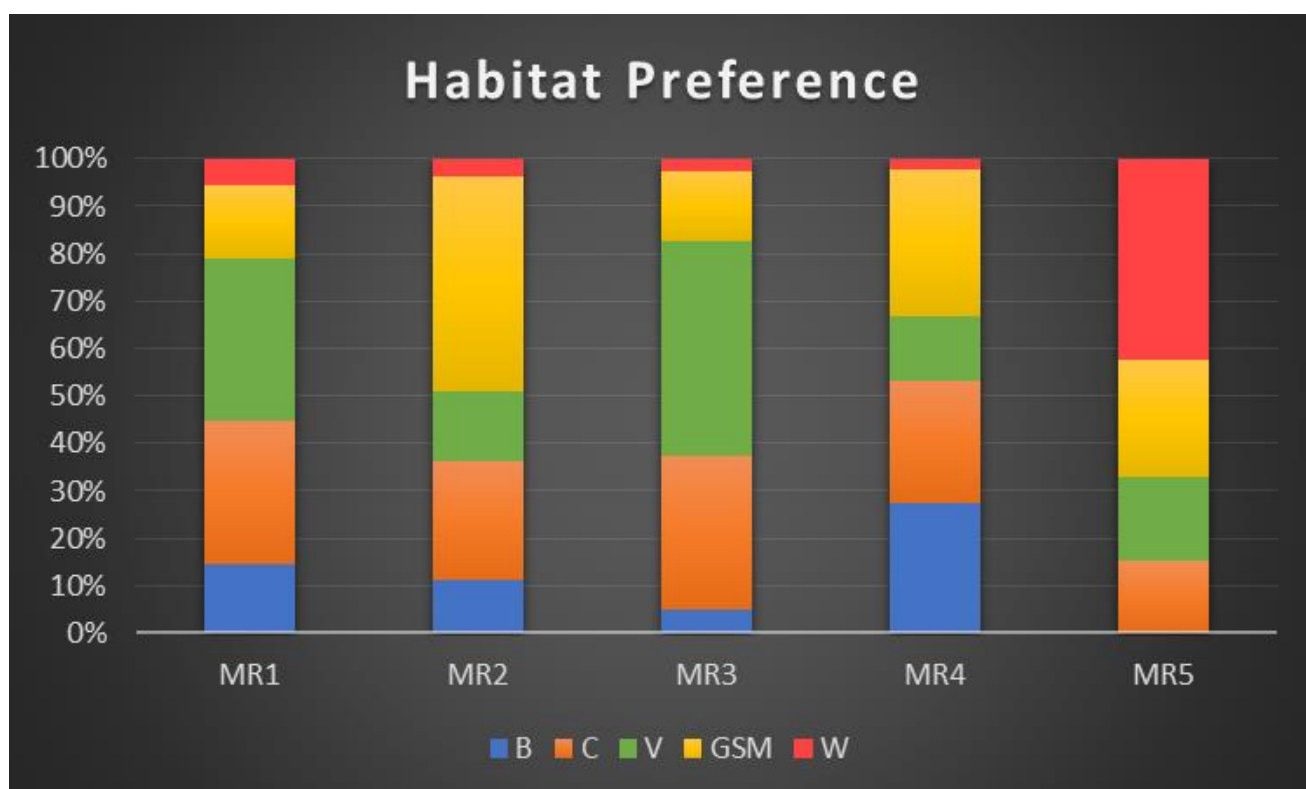


Figure 4-4: Macroinvertebrate habitat preference of the Mooi River macroinvertebrate assemblages; bedrock biotope (B) cobbles/stones biotope (C), vegetation (V), gravel, sand and mud biotope (GSM) and water column (W).

4.4.2. Water quality preference

The water quality preferences of the macroinvertebrate assemblages for the five reaches are displayed in Figure 4-5. The selected sensitivity categories for the scope of the study were highly sensitive (HS), moderately sensitive (MS), moderately tolerant (MT), and highly tolerant (HT) based on Dickens and Graham (2002). The overall analysis of the Mooi River catchment showed that taxa that are highly tolerant had an overall abundance of 31.39%. Moderately sensitive taxa had an overall abundance of 30.55%. The moderately tolerant taxa had an overall abundance of 20.03% and the highly sensitive taxa had an overall abundance of 18.03%. At reach level, the highly tolerant taxa had the highest abundance in MR5 (63.24%), the second highest abundance was in MR4 (28.34%) and had the lowest abundance of HT taxa was in MR3 (14.28%). The moderately sensitive taxa had the highest abundance in MR3 (46.44%) and had the lowest in MR5 (4.24%). The moderately tolerant taxa had the highest abundance in MR4 (22.72%) and had the lowest abundance in MR3 (14.98%). The highly sensitive taxa had the highest abundance in MR2 (37.08%) and had the lowest abundance in MR3 (2.43%). The sensitivity of macroinvertebrates to disturbances varies (Rosenberg and Resh, 1993), some macroinvertebrates are tolerant to

deteriorating water quality such as Oligochaeta and Culicidae. Some sensitive taxa like Caenidae were found in the study.

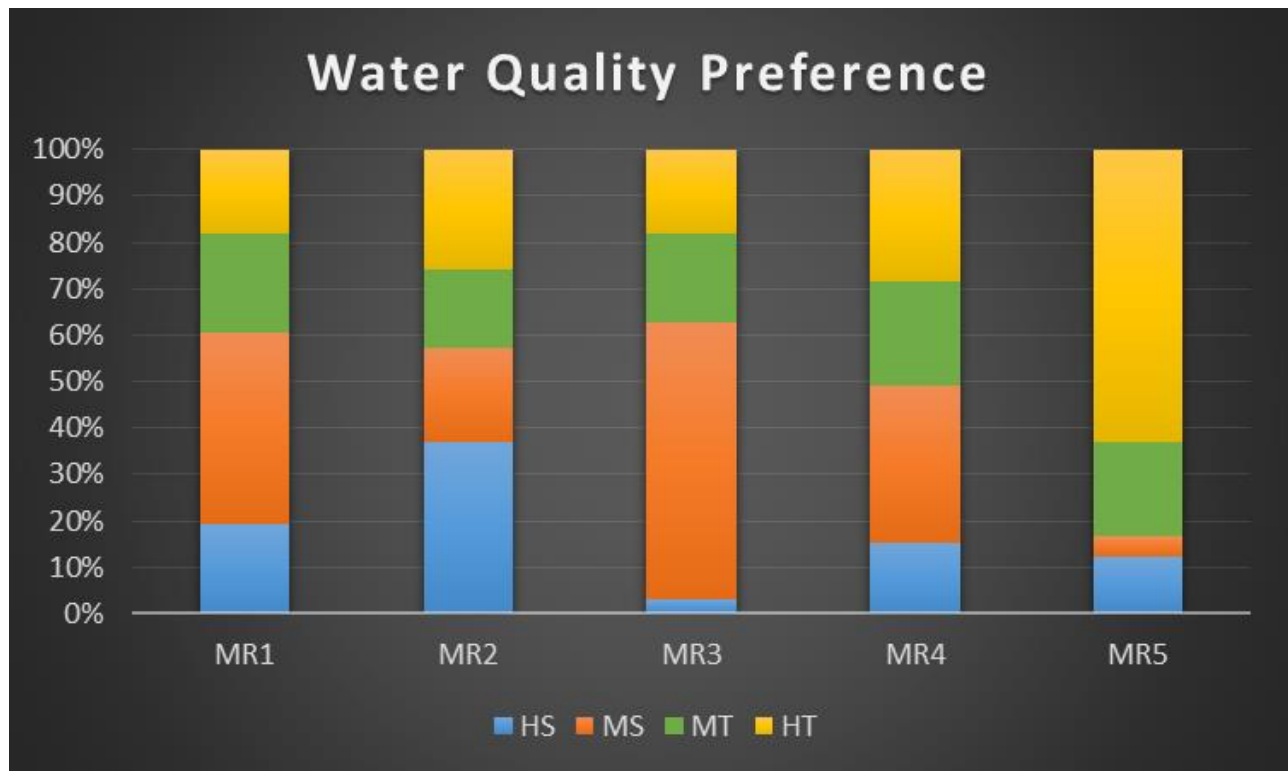


Figure 4-5: Water quality preference of the Mooi River macroinvertebrate assemblages; highly sensitive taxa (HS), moderately sensitive taxa (MS), moderately tolerant taxa (MT), and highly tolerant taxa (HT).

4.4.3. Velocity preference

The velocity preferences of the macroinvertebrate assemblages for the five reaches are displayed in Figure 4-6. The selected velocity categories for the scope of the study were the very fast (VF), moderately fast (MF), slow (S), and very slow (VS) water flows. The overall analysis of the Mooi River catchment showed that taxa who prefer very slow water flow had an overall abundance of 33.05%. Taxa with preference for slow flowing water had an overall abundance of 32.73%. Taxa with preference for water that has a moderate flow had an overall abundance of 20.46%. Taxa with preference for very fast water flow had an overall abundance of 13.77%. At reach level, taxa with preference for water with a very slow flow had the highest abundance in MR2 (44.87%) and had the lowest abundance in MR1 (17.74%). Taxa with preference for moderately flowing water had the highest abundance in MR1 (34.81%) and had the lowest abundance in MR2 (8.9%). Taxa with preference for water that has very fast flow had the highest abundance in MR1 (21.53%) and had the lowest abundance in MR5 (8.96%). Taxa with preference for slow flowing water had the highest abundance in MR4 (45.92%) and had the lowest abundance in MR3 (18.92%). Families such as

Baetidae that have a preference for moderate flows had the highest number of individuals (584) recorded in MR3. The lowest abundance of taxa that prefer very fast water flow was recorded in MR5 (8.96%). Some of these taxa at MR5 included Caenidae and Gyrinidae that had 137 and 147 recorded individuals, respectively (Table 4-6). The lowest abundance of taxa with a preference for moderate water flow taxa was found in MR2 (8.9%).

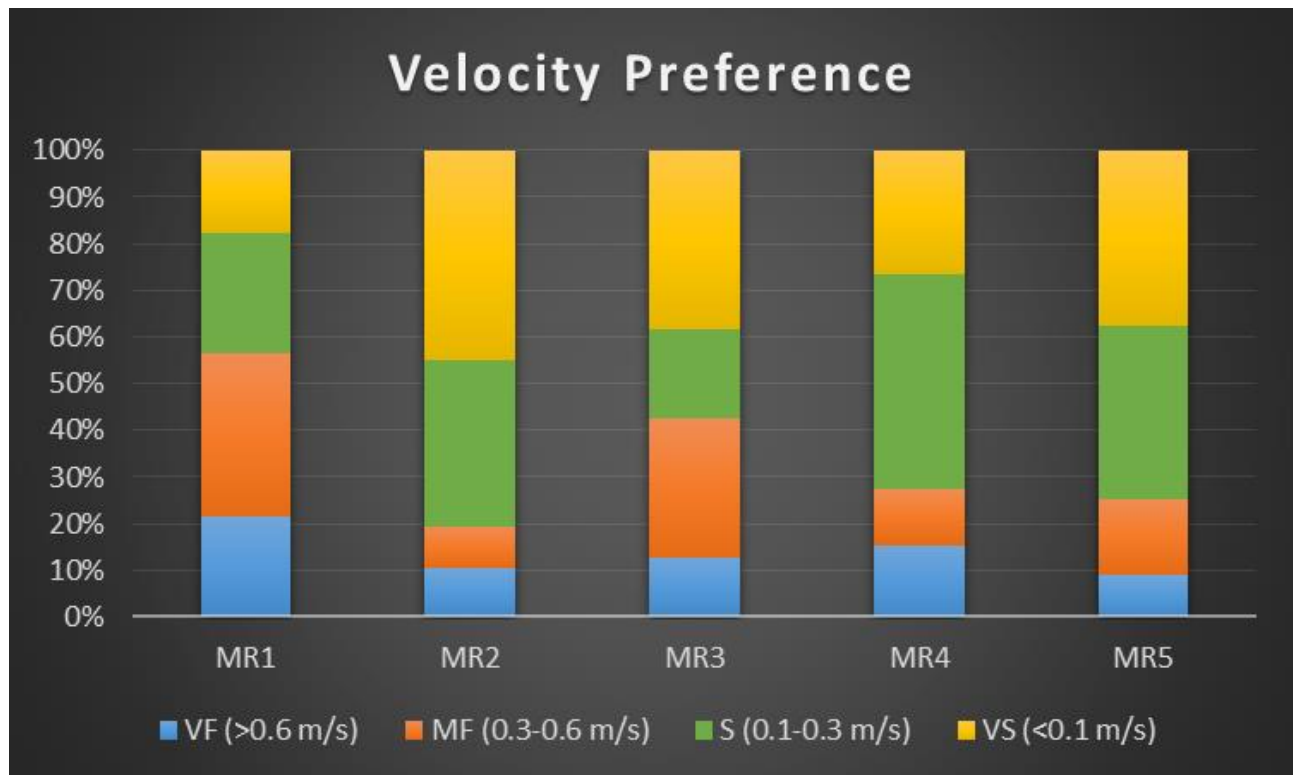


Figure 4-6: Macroinvertebrate velocity preference of the Mooi River macroinvertebrate assemblages; very fast flow (VF), moderately fast flow (MF), slow flow (S), very slow flow (VS).

4.4.4. Hydraulic habitat preference

The hydraulic habitat preferences of the macroinvertebrate assemblages for the five reaches are displayed in Figure 4-7. The selected hydraulic habitat categories for the scope of the study were the riffles (RI), pools (P), runs (RU), rapids (RA), and taxa that does not show preference to a specific hydraulic habitat was described as being indifferent (IND). The overall analysis of the Mooi River catchment showed that taxa that are indifferent to hydraulic habitat conditions were dominant in the catchment and had an overall abundance of 49.45% followed by taxa with a preference for pools with an overall abundance of 30.18%. Taxa with a preference for riffle habitats had an overall abundance of 17.5% and taxa that prefer rapids had 2.9%. Taxa with a preference for runs were absent in the catchment during the survey period. At reach level, the highest abundance of taxa

that were indifferent to hydraulic habitats was in MR3 (58.07%) where taxa such as Chironomidae and Sphaeriidae were found, the lowest abundance of these taxa was recorded in MR2 (38.41%). The highest abundance of taxa with a preference for pool habitats was in MR2 (44.83%) and the lowest abundance for the taxa was in MR3 (8.81%). The highest abundance of taxa that prefer riffles habitats was in MR3 (29.8%) and the lowest abundance was in MR2 (0.6%). Taxa such as Caenidae and Baetidae who thrive in riffle habitats were well represented in MR3 (Table 4-4). The highest abundance of taxa that have a preference for rapids habitat was found in MR1 (3.44%) and the lowest abundance was in MR5 (1.86%).

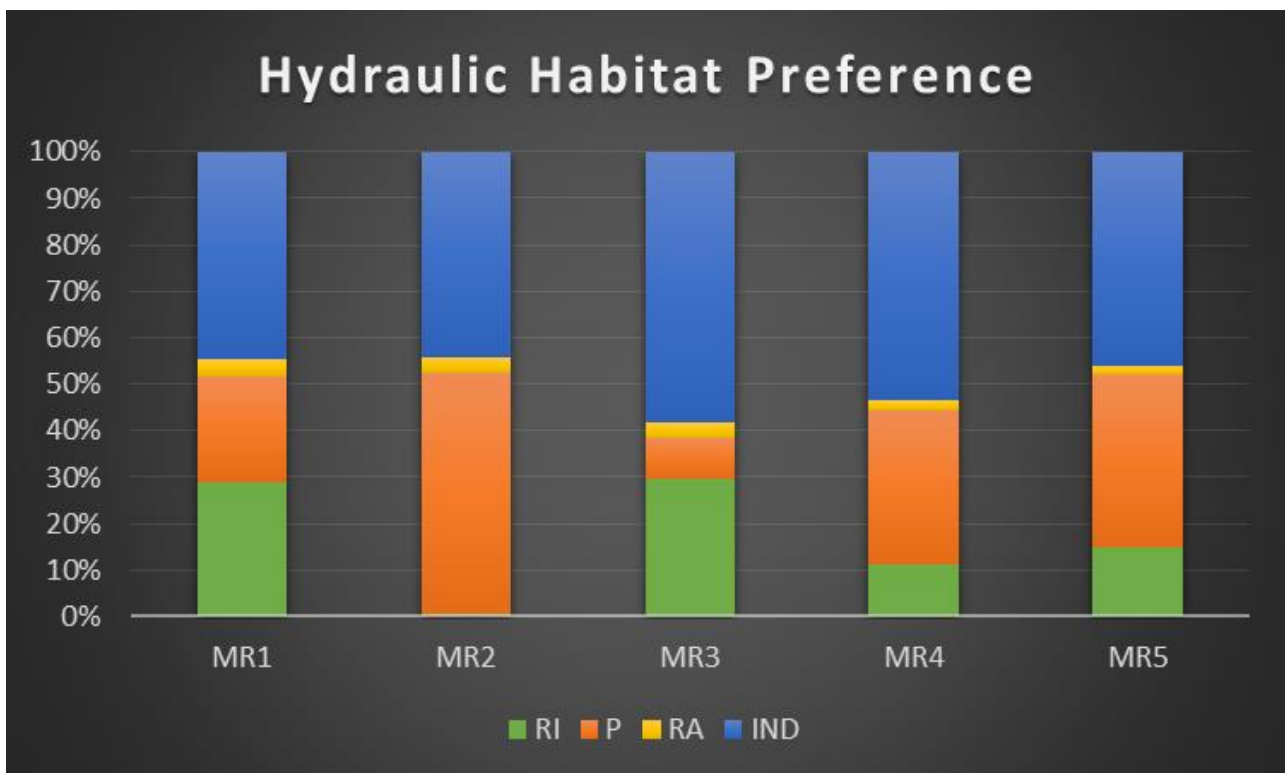


Figure 4-7: Hydraulic habitat preference of the Mooi River macroinvertebrate assemblages; riffles biotope (RI), pools biotope (P), rapids biotope (RA), and indifferent taxa (IND).

4.4.5. Functional feeding groups (FFG)

The functional feeding groups of the macroinvertebrate assemblages for the five reaches are displayed in Figure 4-8. The selected feeding categories for the scope of the study were predator (P), deposit feeder (DF), scraper (SC) filter feeder (FF) and grazer (GR). The overall analysis of the Mooi River catchment showed that macroinvertebrate taxa that are predators had the highest overall abundance (35.94%) in the catchment. Taxa that are deposit feeders had the second highest overall abundance of 29.24%. Deposit feeders, also referred to as collectors or collector-gatherers are macroinvertebrates that have modified mouth parts to sieve or collect small particles which accumulate at the bottom of the stream (Cummins *et al.*, 2005). Filter feeders, scrapers and

grazers had overall abundances of 16.87%, 9.96% and 8.01% respectively in the catchment. At reach level, taxa that feed by means of predation had the highest abundance in MR4 (49.26%) and MR5 (48.69%). Predator taxa had the lowest abundance in MR3 (14.28%). Deposit feeders had the highest abundance in MR3 (67.84%) and had the lowest abundance in MR2 (8.42%). Taxa that are filter feeders had the highest abundance in MR2 (38.59%) and had the lowest in MR5 (5.37%). Taxa that feed by means of grazing had the highest abundance in MR5 (23.23%) and had their lowest abundance in MR3 (1.99%). Scrapers had the highest abundance in MR1 (13.37%) and had the lowest abundance in MR5 (3.98%).

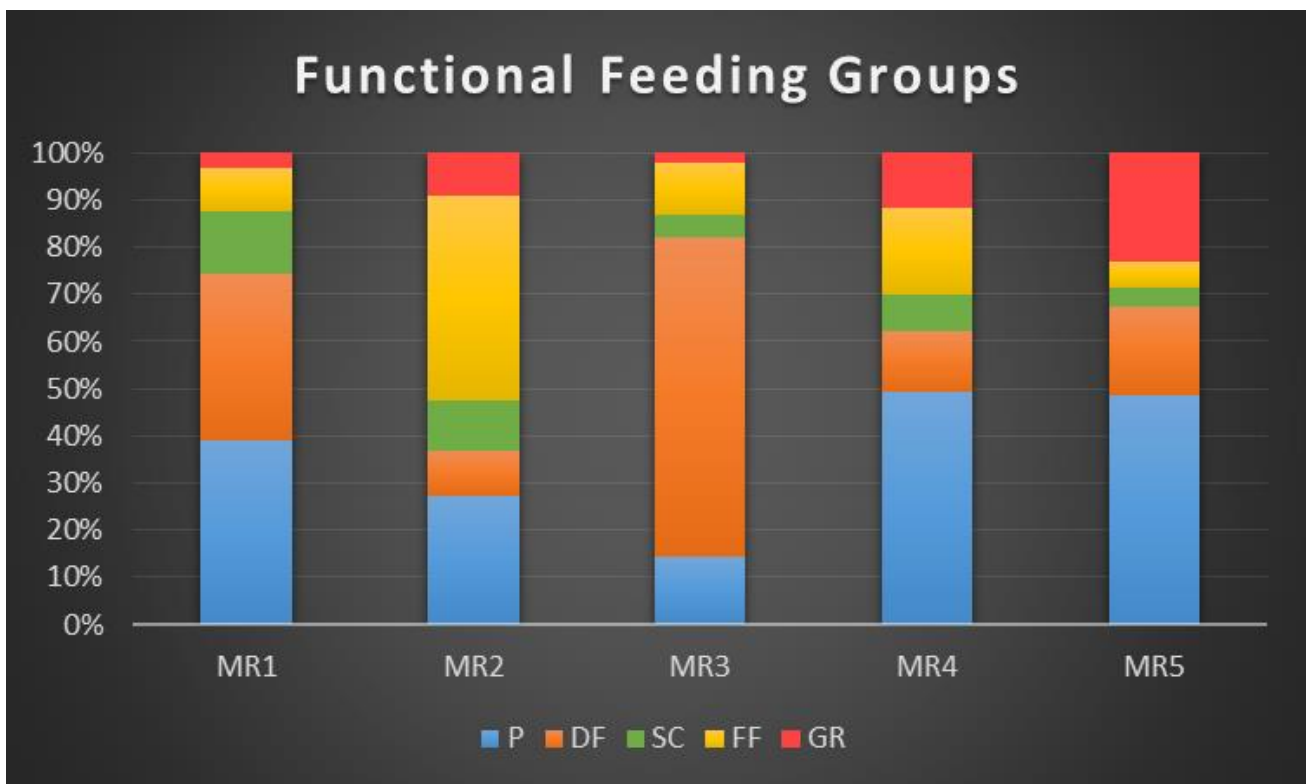


Figure 4-8: Functional feeding groups of the Mooi River macroinvertebrate assemblages; predator (P), deposit feeder (DF), scraper (SC) filter feeder (FF), and grazer (GR).

4.4.6. Respiration

The modes of respiration for the macroinvertebrate assemblages in the five reaches are displayed in Figure 4-9. The selected respiratory mode categories for the scope of the study were tegument or cutaneous breathers (T/C), gills breathers (G), aerial breathers (A). In the study, taxa that breathe by means of a lung, plastron and as well as other apparatus were all included under the category of aerial breathers. The overall analysis of the Mooi River catchment showed that taxa that are gill breathers had the highest overall abundance (63.24%), followed by aerial breathers (22.61%) and lastly the tegument breathers (14.16%). At reach level, the highest abundance of gill

breathers was in MR3 (98.68%) and the lowest abundance was in MR5 (48.04%). According to the results of the Ecological Category of MR3 which was found to be a D (Table 4-9) and the water quality metric of the reach was the lowest in comparison to the rest of the catchment, it would be expected that gill breathers would have a lower abundance in this reach. The highest abundance of aerial breathers was in MR4 (26.38%) and the lowest abundance was in MR3 (12.29%). The highest abundance of tegument breathers was in MR5 (20.85%) and the lowest abundance was in MR3 (1.45%).



Figure 4-9: Modes of respiration of the Mooi River macroinvertebrate assemblages; tegument/cutaneous breathers (T/C), gill breathers (G), aerial: lungs, plastron and other apparatus (A).

4.4.7. Body shape

The body shape trait and categories for the macroinvertebrate assemblages in the five reaches are displayed in Figure 4-10. The selected categories for the scope of the study were the streamlined body shape (ST), flattened body shape (FL), spherical body shape (SP), tubular or cylindrical body shape (T/C). Macroinvertebrate body shapes that did not conform to the shapes categories listed were recorded under the category as 'variable' (V). The overall analysis of the Mooi River catchment showed that other body shapes had the highest overall abundance of 37.38%, closely followed by the tubular or cylindrical body shapes with 37.08%. The third highest overall abundance was for the streamlined macroinvertebrates (13.97%), then the flattened shape was

11.53% and the spherical body shape had an overall abundance of 0.045%. At reach level, body shape under the category 'variable' had the highest abundance in MR2 (50.08%) and had the lowest in MR1 (27.26%). The tubular or cylindrical body shape macroinvertebrates had the highest abundance in MR4 (56.99%) and had the lowest in MR3 (14.74%). Streamlined macroinvertebrate shapes had the highest abundance in MR3 (29.68%) and had the lowest abundance in MR2 (5.94%). The flattened macroinvertebrate shapes had the highest abundance in MR4 (28.4%) and had the lowest abundance in MR2 (3.91%). The spherical body shape had the highest abundance in MR1 (0.18%) and had the lowest in MR4 (0.02%).

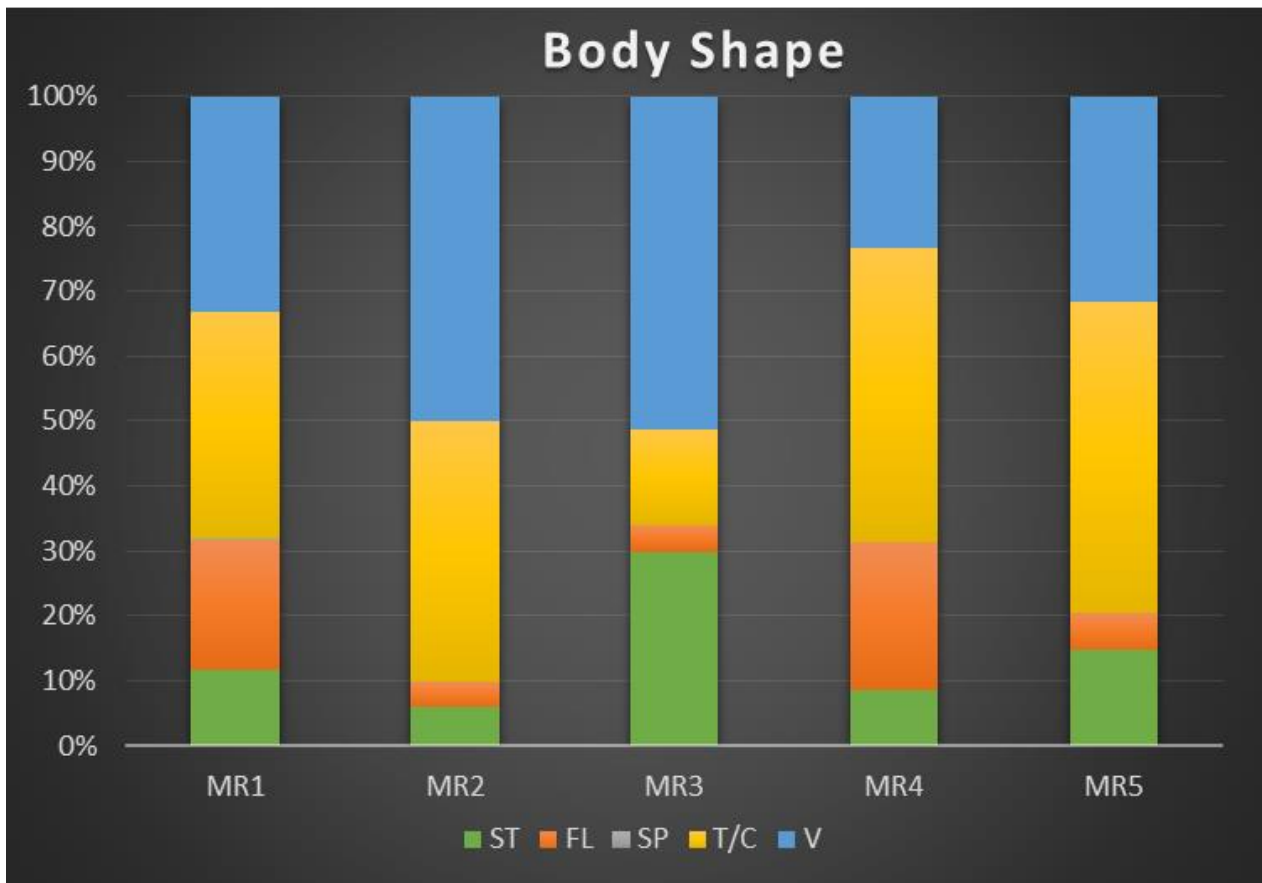


Figure 4-10: Body shape trait of the Mooi River macroinvertebrate assemblages; streamlined body (ST), flattened body (FL), tubular/cylindrical body (T/C), spherical body (SP) and variable taxa (V).

4.4.8. Body size

The body size trait and categories for the macroinvertebrate assemblages in the five reaches are displayed in Figure 4-11. The body size traits were categorized into five attributes: <5 mm (very small), >5 -10 mm (small), >10 -20 mm (medium), >20-40 mm (large) as well as a variable body size (V) category where macroinvertebrate that had a variable body size were recorded. The overall analysis of the Mooi River catchment showed that macroinvertebrates with a small body

size had the highest overall abundance of 64.35%, followed by taxa with variable body sizes that showed a 26.56% abundance. Macroinvertebrates of medium size had the third highest abundance of 5.11%, taxa with a very small body size as well as those with a large body had 3.23% and 0.74%, respectively. At reach level, taxa with a small body size had the highest abundance in MR3 (86.18%) and had the lowest in MR5 (44.36%). Taxa with variable body sizes had the highest abundance in MR5 (45.66%) and had the lowest in MR1 (1.74%). Macroinvertebrate taxa with a medium body size had the highest abundance in MR5 (7.57%) and the lowest in MR1 (1.87%). Taxa that have a very small body size had the highest abundance in MR2 (3.97%) and had the lowest in MR5 (2.15%). Taxa with a large body size had the highest abundance in MR3 (1.49%) and had the lowest in MR5 (0.25%).

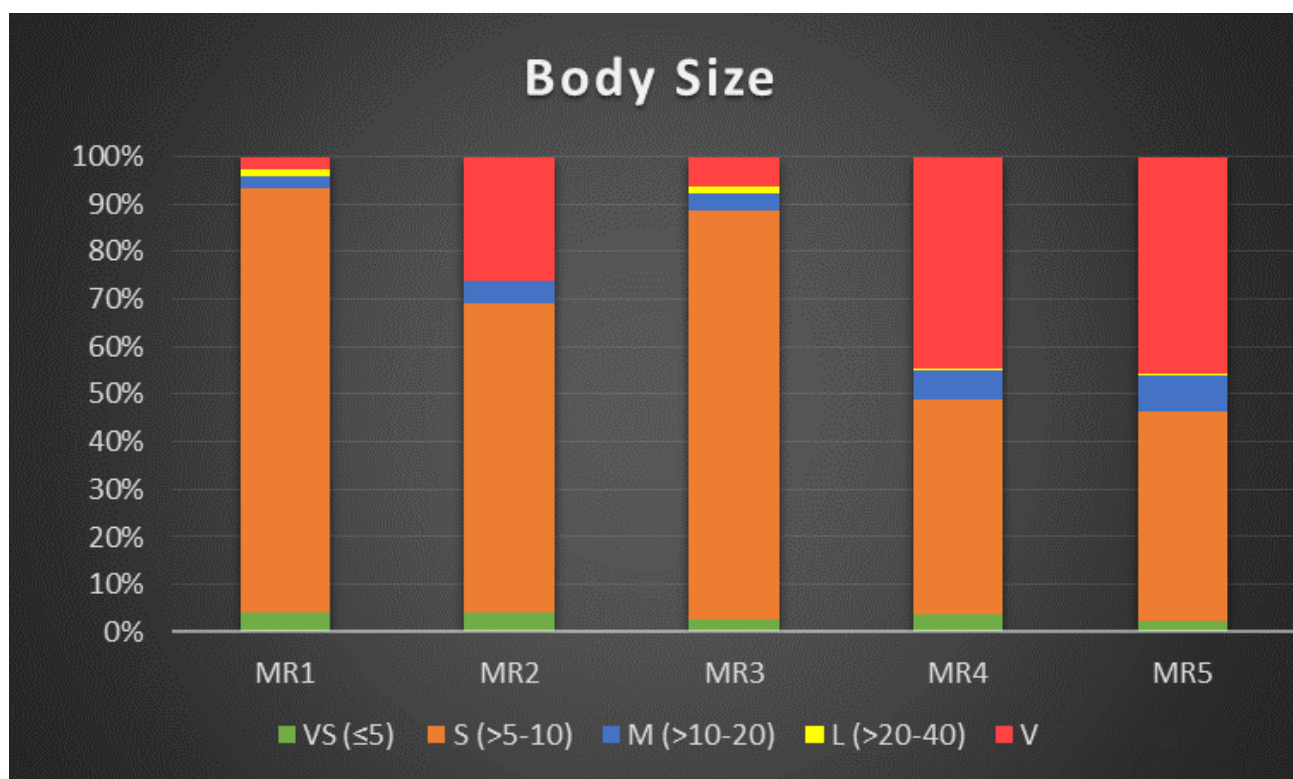


Figure 4-11: Body size trait of the Mooi River macroinvertebrate assemblages; very small body (VS), small body (S), medium body (M), large body (L), variable body size (V).

4.4.9. Locomotion

The mobility categories for the macroinvertebrate assemblages in the five reaches are displayed in Figure 4-12. The selected categories for the scope of the study were climber (CL), crawler (CR), sprawler (SP), skater (SK), swimmer (SW), burrower (B). Macroinvertebrate mobility modes that did not fit into the selected categories were recorded under the category as 'variable'. The overall analysis of the Mooi River catchment showed that the swimmers had the highest overall

abundance of 45.1%. Macroinvertebrates that move by means of sprawling had an overall abundance of 20.17% followed by the burrowing macroinvertebrates with 12.88%. Crawling macroinvertebrates had an overall abundance of 11.84%. The macroinvertebrate taxa that are climbers had an overall abundance of 5.33%. Macroinvertebrate taxa that utilize other forms of mobility had an overall abundance of 4.49% and the skating taxa had 0.2%. At reach level, swimmers had the highest abundance in MR2 (53.46%) and had the lowest abundance in MR1 (28.4%). Sprawlers had the highest abundance in MR3 (28.19%) and had the lowest in MR5 (13.22%). The burrowers had the highest abundance in MR5 (27.2%) and had the lowest abundance in MR1 (4.19%). Climbers had the highest abundance in MR1 (14%) and had the lowest abundance in MR2 (2.02%). Macroinvertebrates taxa that use other forms of mobility had the highest abundance in MR2 (11.44%) and had the lowest in MR3 (0.21%) but it was noted that none of this category were found in MR1 (0%). Skaters had the highest abundance in MR3 (0.21%) and the lowest was in MR2 (0.14%) and none were recorded in MR5 (0%).

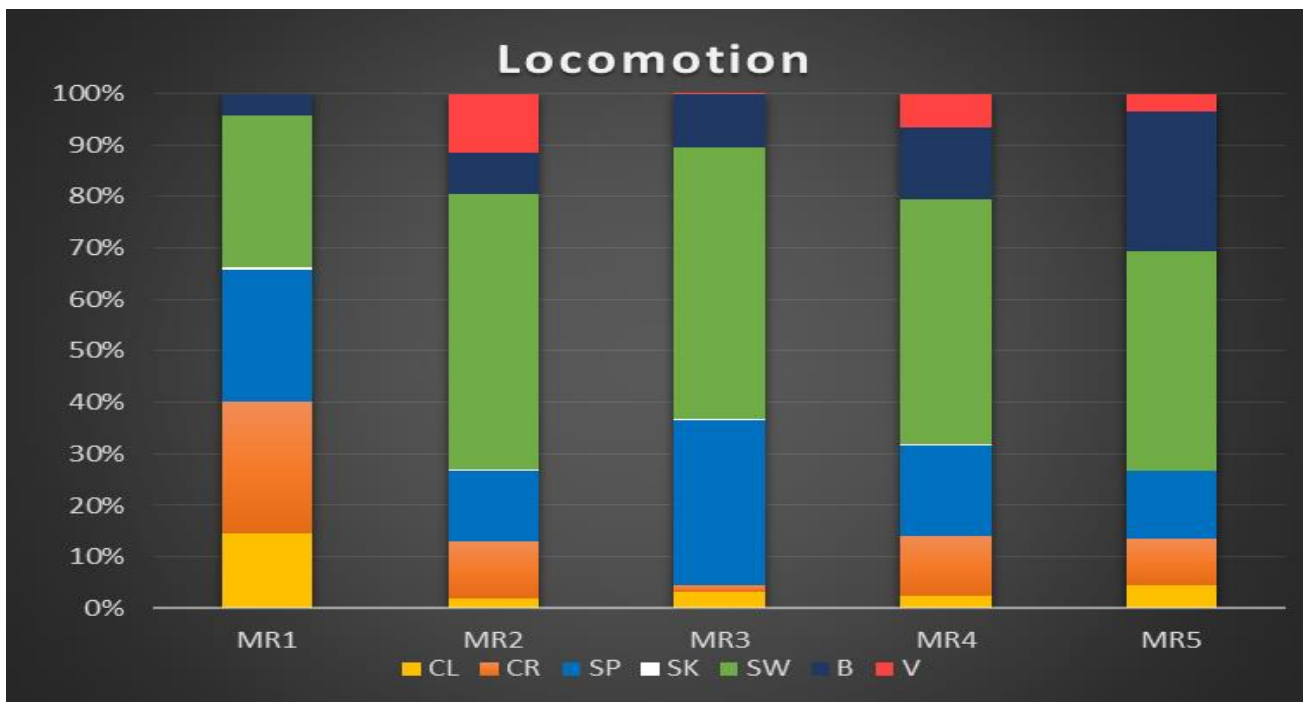


Figure 4-12: Modes of locomotion of the Mooi River macroinvertebrate assemblages; where climber (CL), crawler (CR), sprawler (SP), skater (SK), swimmer (SW), burrower (B), variable (V).

CHAPTER 5: DISCUSSION

Ecological water requirements (EWR) form a vital part of water resource management in SA (Tharme, 2003). Current EWR methods used in perennial rivers in SA involve the use of macroinvertebrates, fish and riparian vegetation as the biotic components of assessment. Macroinvertebrate based biomonitoring provides a holistic picture of the water quality and their trait information is useful in characterizing ecosystem function and structure while assessing ecological condition (Louw *et al.*, 2013). This study aimed to show the effectiveness of using macroinvertebrate traits in combination with current EWR invertebrate assessments. The Mooi River catchment, suffers from numerous disturbances due to anthropological activities. The MIRAI and traits were used to indicate such disturbances in the catchment.

The measurement of physico-chemical variables is important for ecosystem assessment (Akamagwuna *et al.*, 2019). In this study the assessment of macroinvertebrate responses indicated that water quality influenced the assemblage structure and distribution across the five river reaches. The water quality metrics from the MIRAI assessments showed the most impact through the responses of the macroinvertebrate assemblages. The results indicated that the most impacted reaches with a deteriorated water quality were MR3 (Mooi River between Wonderfontein Spruit and Loop Spruit) where the water quality metric was 31.3%; MR2 (Wonderfontein Spruit) (32.2%) and MR1 (Mooi River upstream of Wonderfontein Spruit) (32.6%). The Wonderfontein area is characterized by mining activities as well as other human activities such as irrigation, livestock and crop farming activities that have an impact on the water. The sub-catchment is also characterized by a one meter diameter pipeline into which the river flows for approximately 32 km and discharges near the Carletonville area (Tlokwe City Council, 2014). The purpose of this was to prevent the recirculation of water coming from the dewatered underground compartments (Hamman, 2012). The pipe may be viewed as a cause of both quantitative and qualitative impacts. It may be considered as a flow hindrance for the river therefore interfering with the quantity of water available. This may cause some parts of the sub-catchment to be drier than others.

According to the findings of Dabrowski *et al.* (2014), water quality can deteriorate during droughts and cause high levels of dissolved salts especially potassium, sodium, chlorine and total alkalinity. A qualitative aspect of the impacts is the deteriorated water quality from the water being pumped from the underground mine workings directly to the surface. Hamman (2012) found that the concentrations of cobalt, selenium, nickel, gold, uranium, cadmium, lead and zinc were higher in the Wonderfontein Spruit compared to the Mooi River, which suggested that they could have been as a result of gold mining activities. Both of the authors' findings may support the reasons behind the deteriorated water quality found in MR1, MR2 and MR3. Macroinvertebrates are sensitive towards extensive organic pollution, changes in habitat as well as physico-chemical factors such

as EC, turbidity, flow, pH and temperature (Dallas and Day, 2004). Ephemeroptera, Plecoptera, and Trichoptera (EPT) are macroinvertebrate orders that are considered as an essential taxonomic group for monitoring in freshwater ecosystems because of their sensitivity to pollution (Wallace *et al.*, 1996; Barbour *et al.* 1999). In urban rivers the macroinvertebrate assemblages have been reported to change due to urban pollution and as a response, sensitive taxa such as species of EPT decrease in abundance, richness and density, while those of tolerant taxa increase in urban polluted rivers (Davies *et al.*, 2010). The low abundance of taxa such as Caenidae (Ephemeroptera), Perlidae (Plecoptera) and Hydropsychidae (Trichoptera) at MR1 and MR3 could indicate the deteriorated water quality. The highest abundance of Chironomidae was in MR4. Chironomidae are tolerant and able survive in highly polluted water conditions (Jun *et al.*, 2016.) According to Matlou *et al.* (2017), the presence of sensitive taxa is an indication of good habitat and water quality. This is in contrast with the findings of the study because although MR2 had the highest abundance of highly sensitive taxa (Figure 4-5), it still had a low water quality metric score. The high abundance of the sensitive taxa may be attributed to other factors such as conducive habitat conditions. Another factor may be that the taxa are tolerant to the compounds affecting the water quality. In MR2 the flow and habitat metrics were 55.7% and 51.6% ,respectively, which could be considered as showing moderate deviation from reference conditions and therefore capable of sustaining a small number of highly sensitive taxa.

Ephemeroptera are also associated with high oxygen concentrations and fast flowing waters (Jun *et al.*, 2016; Rasifudi *et al.*, 2018). The MR3 reach showed the highest water quality deviation from natural conditions that may be as a result of an increase in the concentration of pollutants flowing into this reach because both MR1 and MR2 flow directly into MR3 (Table 4-9). In MR1, the recreational and farming activities as well as the springs may be the contributing factors for downstream water quality deterioration (MR3). The contribution of pollution from MR2 into MR3 may come from the discharge originating from the underground gold mine works through the pipeline as well as farming activities in the area (Table 3-1). These findings may be corroborated by those of Matlou *et al.* (2017) where changes in the macroinvertebrate abundance and diversity reflected the longitudinal pollution gradient in the Steelpoort River. The macroinvertebrate assemblages in the studied catchment also showed that the highest number of taxa and individuals were recorded in MR4 (Table 4-1) where there was good representation of different tolerant groups such as Chironomidae and Simuliidae (Table 4-5). This could be attributed to good biotope diversity which offers higher habitat heterogeneity as this site was characterized by GSM, pool, riffle, run, stones, trees and riparian vegetation. The high abundance of Simuliidae in MR4 could be due to the presence of the Klipdrift Dam, as their abundance is positively linked to reservoir outflows and are reported to have high presence below impoundments (Marchetti, 2014; Rasifudi *et al.*, 2018).

The diversity of macroinvertebrates is considered to be variable in rivers in response to disturbances, resources and habitat availability; a decrease in diversity with corresponding increase in abundance of few taxa may indicate community disturbance (Morphin-Kani and Murugesan, 2014). The MR4 reach had the highest macroinvertebrate abundance. The low macroinvertebrate abundance found in MR3 could be due to the high water flows resulting in less favourable conditions for macroinvertebrates to thrive. In the study, flow modification metric in MIRAI showed the highest deviation from natural conditions in MR5 (Table 4-11) and velocity preference (Figure 4-6) of the macroinvertebrate assemblages showed that taxa with a preference for very slow water velocity had a higher abundance when compared to other flow categories in this reach. Flow and water quality are closely linked factors in aquatic ecology. In the study by Horrigan and Baird (2008), flow reductions were found to be a result of shifts from a lotic macroinvertebrate assemblage toward becoming dominated by lentic macroinvertebrate assemblages. Water quality is bound to change as flow regimes change. This may be due to various reasons one being that the dilution capacity of the system has most likely been altered. This is in accordance with the findings as the water quality metric was similar to the flow metric for MR5.

Water abstraction for domestic and agricultural use takes place at the Mooi River State Water Scheme, situated between the Boskop and Potchefstroom Dams (Van der Walt *et al.*, 2002). The MR5 reach was situated in close proximity to the confluences of the Loop Spruit and Mooi River as well as the confluence of the Mooi River and Vaal River. The closeness thereof could be associated with an increased hydraulic disturbance in MR5 with scouring flows and the increased interaction between the main river and the tributary, leading to reduced macroinvertebrate biodiversity in MR5; their response was the high abundance of taxa with a preference for very slow water flows in this reach. The results from this study were similar to those of Eady *et al.* (2014) where a disappearance of flow-dependant taxa was observed and more non-flow dependant taxa emerged due to changing flow conditions and reduced mean daily flows. The habitat metric showed the lowest deviation from natural conditions in MR4, which indicated that the available habitat was the closest to natural conditions when compared to habitat metrics of other reaches. Contrary to the study's findings, the abundance of Odonata families such as Aeshnidae, Coenagrionidae and Libellulidae were not high in MR4. Even though families of Odonata are widespread, the group is sensitive to habitat disturbances and pollution, and are found to have a positive correlation to electrical conductivity; however, it responds more to habitat form and structure than to acidity and nutrient levels (Agboola *et al.*, 2019).

Flow alteration to streams that receive groundwater recharge may be associated with increased salinity and may filter macroinvertebrates with traits that allow resistance or resilience to high or low levels of salinity and flow (Botwe *et al.*, 2018). Several springs are located along the Mooi

River catchment in MR1 and MR4 (Table 3-1) which feed the Mooi River and Loop Spruit with groundwater and the Gerhard Minnebron eye drains into the Wonderfontein Spruit. When groundwater recharges surface water, there is that potential to increase the salinity of surface water. In the study by Botwe *et al.* (2018), streamlined body shape and gill respiration were found to decrease during low flows while crawling rate and aerial respiration increased. Therefore, flow may be the reason that the highest abundance of crawlers was found in MR1. Saline conditions lead to substantial declines in the proportions of gill breathers as opposed to the tolerance of tegument or cutaneous breathers which survive even at high concentrations (Zhao *et al.*, 2018). This may also suggest that there is an increase in salinity in MR1 because the second highest abundance of gill breathers was recorded in this reach.

Dallas (2007) characterised the relationship between biotopes and macroinvertebrates in selected rivers and found that differences exist between macroinvertebrate assemblages collected from different biotopes within the same river. Complex substrates are composed of a mix of cobbles, boulders, and gravel as well as many functional habitats that support a range of macroinvertebrates. In the results, taxa with a preference for the GSM biotope had the highest overall abundance in the Mooi River catchment, and was followed by the taxa which prefer the cobbles/stone biotope. Demars *et al.* (2012) showed that macroinvertebrate trait-biotope associations gave better predictions of variability in macroinvertebrate diversity and richness. This was true for MR4 where there was the highest number of macroinvertebrates recorded. Spatial distribution of macroinvertebrate assemblages in river ecosystems is complex because habitat, water chemistry as well as many other variables within each of these components interact with biotic components to create assemblages that differ through space and time. This study, did not show dominance in terms of the preferred biotopes and the trait data was able to confirm what was already established by MIRAI i.e. where the habitat metrics of the five reaches did not show extreme deviation from natural or reference conditions.

In reach MR2, the GSM taxa were dominant. Since the GSM biotope occurs mostly in pools, macroinvertebrates may prefer this biotope to seek refuge and avoid being swept away by high velocity currents (Odume *et al.*, 2015). Results were further complimented by the pool taxa abundance, which was the highest in MR2 (Figure 4-6). Macroinvertebrates that showed a preference for the vegetation habitat were abundant in MR3. According to the conclusions of Palmer *et al.* (1991), macroinvertebrate assemblages were not always associated with subjectively specific biotopes, especially where different biotopes tended to be smaller and less distinct. Their study further showed that stratified random sampling regimes could be utilized in stream research if the scale at which biotopes are recognised was clearly defined. The varying of trait characteristics also implied the presence of disturbances in the Mooi River catchment. Vegetation offers complex habitats that provide refuge from the current and predation; while providing food for

several herbivores and detritivores; providing attachment structures for filter feeding taxa and also providing points where emerging insects with aerial adult stages can exit (Akamagwuna and Odume, 2020). The cobble biotope had the highest abundance in MR3 and the stone/cobble based macroinvertebrate assemblages could still provide a sufficiently accurate bioassessment result even when there are limited resources (Odume, *et al.*, 2015)

The hydraulic microhabitats in a river system also referred to as biotopes indicated that taxa that are indifferent to the hydraulic variations were the most abundant at catchment level (Figure 4-7). Riffles and pools were two of the most conspicuous biotopes in rivers as was observed in the Mooi River (Table 3-1). These biotopes are differentiated by the speed of the water and may be a limiting factor for colonization by macroinvertebrates. The results in the study showed that taxa that prefer the riffles biotope had the lowest abundance in MR4 even though the highest number of macroinvertebrate individuals were recorded here. According to Kobayashi and Kagaya (2002), in order for macroinvertebrates to colonize leaf matter in riffles, they need to have adaptations that enable them to remain attached to the substratum in conditions of strong currents. Therefore, it is assumed that most of the taxa recorded in MR4 were not adapted to high flows and may be an indication that MR4 had low flows or discharge.

Differences in biotope richness can also be related to the wider stream network. According to Baker *et al.* (2016), sites or biotopes located nearer to the confluence of the main river to a tributary could be associated with an increased hydraulic disturbance. This disturbance may result in a reduction of the macroinvertebrate biodiversity within the confluence sites when compared to other sites located elsewhere within the same river. The results of the study revealed that MR3 had the highest abundance of taxa that prefer riffle biotopes. With riffle habitats such as those found in MR3, it would be expected that sensitive taxa would thrive in the running water therefore making them vulnerable to increased frequency and longer duration of reduced flow velocities that have been associated with major water abstraction (Dewson *et al.*, 2007). The results showed that moderately sensitive taxa were dominant in MR3. Reduced oxygen conditions are common in pool habitats, therefore may inhibit colonization by taxa with high oxygen requirements (Kobayashi and Kagaya, 2002).

Taxa that have a preference for the pool biotope were the most abundant in MR2 where the highest abundance of highly sensitive taxa was also recorded. Furthermore, the trend of the Ecological Category (EC) in the catchment showed that the most deviated reaches from the natural conditions were MR1, MR2 and MR3. Their EC scores were 46.73%, 45.51% and 44.64%, respectively. These scores placed them in the middle of the upper and lower limits of the EC of D (40%-59%); this was interpreted as having a significant loss of biodiversity for biota, habitat and ecosystem functions (Kleynhans *et al.*, 2008) (Table 3-3). Although MR4 was also in an EC of D,

its score (52.62%) placed this reach towards the upper limits of the category. It was still largely modified however not as deteriorated as MR5. The EC score for MR5 was 41.94%, which was closest to the lower limit of an EC of D. This reach was found to be largely modified bordering on being seriously modified (D/E) with a large loss of biodiversity, altered natural habitat with extensively modified ecosystem functions (Kleynhans *et al.*, 2008).

The relationship between water quality and macroinvertebrate community structure is important as different macroinvertebrates have different ecological requirements to facilitate them to successfully inhabit a particular environment. The poor EC score in MR5 could be due to several factors; one of which is the presence of wastewater or sewage discharges from the Potchefstroom Waste Water Treatment plant (WWTP) situated in this reach. There are two other WWTPs situated in the tributaries of the Mooi River. The Kokosi WWTP and the Flip Human WWTP are located in MR2 and MR4, respectively which is upstream of Potchefstroom WWTP (MR5). According to Venter *et al.* (2013), wastewater discharges into the Mooi River and its tributaries are regulated and serve as potable water for surrounding communities and livestock. Wastewater effluents have organic and inorganic substances that could be potentially toxic to aquatic biota (Ten Brink and Woudstra, 1991).

Riverine ecosystems are vulnerable various forms of pollution including salts, excess nutrients, metal contaminants and organic waste that is usually as a result of human excrement (Davies and Day, 1998). In a study by Seanego and Moyo (2013), the authors noted that total nitrogen, total phosphorus, conductivity and salinity as the major factors contributing to the variability of the Sand River water quality and associated macroinvertebrates such as Chironomidae, Belostomatidae and Chaoborus. The solubility of oxygen decreases as temperature increases, and dissolved oxygen (DO) decreases exponentially as salt levels increase. Dissolved oxygen is highly significant to all forms of aquatic organisms. In macroinvertebrates, varying DO concentrations can cause various trait responses, the most conspicuous being respiratory modes. In the Mooi River catchment the gill breathers had the highest overall abundance, and at reach level had the highest in MR3. This macroinvertebrate response was unexpected since MR3 is one of the reaches which had the lowest water quality metric, however what sparks an interest is that MR3 also had the highest abundance of moderately sensitive taxa. The latter finding would be in accordance with the high abundance of gill breathers in MR3. Because of this, it could be suggested that DO is not a limiting factor in the water quality of the catchment and the findings are in contrast with those of Chapman *et al.* (2004) because gill breathers were negatively correlated with DO. The authors suggested that gill breathers decreased in salty streams perhaps due to saline streams having low dissolved oxygen concentrations that could favour macroinvertebrates who can breathe atmospheric oxygen.

The aerial breathers had the second highest overall abundance in the Mooi River catchment. For instance, in studies by Statzner and Beche (2010) it was found that degraded stream areas with low DO favour aerial respiration and that aerial respiration occurs because the DO levels decrease in response to increasing and enhanced concentrations of organic pollutants. Therefore, this study indicated that DO was not the main contributor towards the degradation of water in the Mooi River catchment. Body size is a significant adaptive trait because it can influence exposure and absorption of dissolved pollutants due to body surface-area-to-volume ratio while also potentially regulating several other traits such as reproduction, locomotion and metabolic rate (Statzner and Beche, 2010). This would therefore mean that an organisms' body size distribution patterns would be influenced by the water quality of an aquatic ecosystem. In the results, a large body size (>20-40mm) was found to have the lowest overall abundance in the catchment.

This category also had the least abundance in MR5, where the flow metric was the lowest of all the reaches. This is in accordance with the study of Townsend and Hildrew (1994) and thus suggested that possession of a large body size may reduce surface area to volume ratio and would most likely accelerate the diffusion process of toxicants, making the organism more vulnerable to pollutants. This view would also be consistent with the hypothesis of the habitat template concept stating that a large body size is less associated with impacted sites because larger organisms tend to have fewer offspring. The findings are therefore in support of the hypothesis that the Mooi River catchment is impacted. The results also showed that the Mooi River catchment had the highest overall abundance of small-bodied macroinvertebrates (>5-10mm). It was noted by Statzner and Beche (2010) that a small body could be associated to resilience because of the large surface-area-to-volume ratio. The authors went on to find that this ratio could facilitate the organisms' persistence in rivers that were polluted by dissolved salts and other substances. The implications for this in the study could be that the catchment is impacted by pollution and that MR3 is highly polluted since the highest abundance of small-sized macroinvertebrates had the highest abundance in MR3. The results are also supported by the habitat template concept where it predicted that a small body size is associated with disturbed habitats (Townsend and Hildrew, 1994).

A significant part surviving in aquatic ecosystems means that organisms that inhabit this environment have to either last through episodes of droughts or be able to flee from polluted or drying habitats. An organism's mobility therefore is an important aspect of macroinvertebrate ecology. The distribution of mobility modes in the Mooi River catchment showed that swimmers had the highest overall abundance. Crawlers had the highest abundance in MR1 and according to Edegbene *et al.* (2020), crawling macroinvertebrates are positively correlated with least impacted sites. This is contrary to the results of this study, as MR1 was shown to be impacted. The

burrowing taxa had been among the categories with the lowest abundance in the catchment (12.88%).

According to the results found in Wagenhoff *et al.* (2012), sediment deposits begin by increasing habitat heterogeneity for macroinvertebrates especially for burrowing species; however, over time further increase of the deposits remove habitat for other taxa because interstitial spaces fill up, therefore burrowers decline beyond certain sediment levels. This could therefore suggest that MR1 may be impacted by sedimentation because MR1 had the lowest abundance of burrowing taxa at reach level. Reach MR1 is the Mooi River upstream of Wonderfontein Spruit has agriculture as the main land use activity, however there are also recreational activities (Table 3-1). Although clingers (CL) were present in the catchment, they are often overlooked because they are typically found in running waters or in rocky littoral zones of lakes (Merritt and Cummins, 2006). The highest clinger abundance was found in MR1, which suggest that there may be adequate vegetation for the taxa to cling on to.

Studies by Barnard *et al.* (2013) found that three reservoirs in the Mooi River catchment suffered from deteriorated water quality due to the influence of mining-related effluents on the quality of the freshwater resources. In this study, filter feeders had the lowest abundance in MR5 that could be as a result of the poor water quality in MR5. The findings of Mangadze *et al.* (2019b) noted that the introduction of fine sediments in water caused a shift in functional feeding groups (FFG) that leads to the elimination of the filter feeder FFG. Another contributing factor to this is that MR5 was the furthest downstream reach, beginning at the confluence of the Loop Spruit and Mooi River. Akamagwuna and Odume (2020) noted that EPT functional feeding groups were negatively influenced along a gradient of sediment stress with the exception of predators. In the current study, predators had the highest overall abundance in the catchment. Predator groups remained the same even if other FFGs were decreasing in response to shifting resources. According to Mantel *et al.* (2010), predators showed a downward trend in families such as Gomphidae and Libellulidae because of the impacts of small dams in the river. In the study, this was true for the predator group in MR1 (39.07%), MR2 (24.29%) and MR3 (14.28%) (Figure 4-8) where a downward trend in abundance was observed. The Boskop and Potchefstroom Dams are located within the vicinity of MR1 and MR2 and this is also in accordance with the findings of Mantel *et al.* (2010).

Macroinvertebrates are significant to aquatic food webs because they link organic matter and nutrient resources with higher trophic levels (Yoshimura *et al.*, 2006). The results highlighted the different feeding guilds that exist in the Mooi River catchment. Results showed that deposit feeders had the second highest abundance in the catchment and according to Nel *et al.* (2018), this FFG is often associated with sediments that may have low organic matter concentrations; further pointing to the argument that sediment is one of the impacts that were present in the Mooi River catchment.

This group had the highest abundance in MR3 which may also be suggestive of the cause of the deteriorated water quality in MR3. Wagenhoff *et al.* (2012) also found positive relationship between increasing percentage representation of deposit feeders and the rising levels of sediment along stressor gradients in New Zealand; while in Barbour *et al.* (1999), it was noted that the abundance of deposit feeders and filter feeders in downstream sites may be an indicator of effluent from farming activities because agricultural effluent contains organic matter that sustains the deposit and filter feeder groups.

Apart from mining, the Mooi River Catchment is also known to sustain a viable agricultural system. Irrigation and livestock farming are practiced at a large scale along the catchment. The results of this study also showed a minimal contribution from grazers (8.01%) across the Mooi River catchment (Figure 4-8) that was consistent with results of Delong and Brusven, (1998) who noted that where grazers were found to be the dominating FFG relative to other FFGs; it would be probably because grazers became more productive in more agriculturally impacted streams. At catchment level, grazers had their highest abundance in MR5 (23.23%), therefore could indicate agricultural effluent impacts in MR5. The low abundance of scrapers as well as the absence of shredders in the results was similar to findings of Farrell *et al.* (2015) where these FFGs were expected in high abundance because of the availability of algae in the Wilge River; but despite having deteriorated water quality; predators were the most prevalent FFG and this was credited to the availability of sites with sufficient vegetation and stones-in-current biotopes to support a majority of predators. The feeding strategies of scrapers, predators and shredders involve a higher form of mobility to use when searching for food or resting on unstable substrates such as leaf litter. An increased exposure to the flow may impose a risk of drift and therefore means that these FFGs could be incompatible with streams that have unpredictable flows (Usseglio-Polatera *et al.*, 2000).

From the seven steps that Resource Quality Objectives (RQOs) determination is involved, steps 5 is the most likely step of contestation for incorporation of macroinvertebrate trait information (Figure 2-1). It is in this step that draft RQO and numerical limits are established and set for the quantitative and qualitative descriptors of the different components of the resource such as the water quantity, quality, habitat and biota. The Mooi River catchment must be managed in a manner that promotes the maintenance of the risks and thresholds. According to DWS (2016), the water quality of the Mooi River catchment is generally acceptable and complied to the RQOs across the resource units (RUs) (Table 2-1) with some exceptions where the water quality, in terms of nutrients and salts need to be improved to levels that do not threaten the ecosystem and to provide for users and biota. Nonetheless, nutrients should still be monitored and managed because they have a detrimental contribution on the downstream users.

According to EWR, the Mooi River thresholds in this case would be water quality and flow dynamics as abiotic factors; macroinvertebrates and traits would form part of the biotic components together with other biotic elements. The set RQO is achieved by the application of different water resource management strategies. Results thereof are measured through the one numerical limit set for macroinvertebrate assemblages RQO (≥ 42 as EC limits for Mooi River macroinvertebrates). According to MIRAI results the catchment is within the accepted limits of the RQO, however the taxonomic macroinvertebrate analysis could be implemented hand in hand with a trait based approach (TBA) to yield more weighted and more accurate results regarding the state of the aquatic ecosystem it is subjected to. The state of the Mooi River catchment is clearly reflected by the macroinvertebrate trait data as presented with accompanying literature. Traits had a similar indication of a deteriorated catchment even though there is no RQO numerical limit set with the implementation of traits for the Upper Vaal WMA.

CHAPTER 6: CONCLUSIONS AND RECOMMENDATIONS

6.1 Conclusions

Scientific studies on macroinvertebrates have provided significant volumes of data from which different patterns of biological communities can be explored. This study aimed to assess the macroinvertebrate responses in the Mooi River catchment by applying the macroinvertebrate response assessment index (MIRAI) and macroinvertebrate traits as methods of ecological water requirements. The objectives as set out and illustrated in Chapter 1 have been reached. The results obtained for the macroinvertebrate responses confirm the presence of impacts associated with various anthropogenic activities already documented in the Mooi River catchment. The hypothesis that water quality within the Mooi River catchment should influence differences and abundances in the macroinvertebrate trait composition was supported for this study

Macroinvertebrate traits played a role in possible identification or cause of associated pollution due to their preferences towards certain habitats, water quality and flow conditions. Habitat preferences illustrated that the Mooi River catchment is dominated by very slow flowing waters and the dominating biotope is GSM. Decrease in the density of other feeding groups may be caused by the presence of predators with larger sizes than other groups. From the obtained results it can be concluded that although a variety of taxa were observed a majority of trait attributes indicated that the catchment was in a degraded state due to their association with deteriorating water quality. The implementation of macroinvertebrate traits along with commonly used EWR methods could be valuable towards the quality of assessments for water resource management. After concluding this study, it is possible to say that information obtained with the use of macroinvertebrate traits can be more informative than that obtained with sole analysis of the physico-chemical parameters or other biological parameters. In some reaches, it was shown that minimum EWRs could not be met. Monitoring of the catchment must take place in a strategic and adaptive manner as there are sufficient tools developed and in place to determine the EWR of river catchments; which are being used to meet the legislative requirements in SA.

In view of this, the South African resource quality objectives (RQOs) scope may need to be expanded to include newer approaches in EWR because at present, the scope of the RQO focus is mainly on the taxonomic analysis of macroinvertebrate assemblages. The results of the study support conclusions that identifications up to family level allow realistic functional description of lotic macroinvertebrate communities such as found in discussed literature. Macroinvertebrate traits analysed were successfully applied to demonstrate indications of pollution and or disturbances along the catchment. The task of assigning stream macroinvertebrates to a specific trait or attribute is not straightforward, and is, at times controversial, especially when assignments are not

supported by detailed information. However trait information sourced from Odume *et al.* (2018) was adequate enough to be in support of information generated by application of the macroinvertebrate response assessment index (MIRAI) in the Mooi River catchment, and therefore trait information can form an integral part in the formulation of the RQOs. In conclusion, the hypothesis that the macroinvertebrate assemblage responses and functional structures will reflect the presence of disturbances in the ecosystem of the Mooi River catchment could be accepted.

6.2 Recommendations

The following is recommended:

- Consideration of other methods to advance ecological water requirements of surface water ecosystems should be of priority.
- A framework needs to be developed to capture EWR study data to be used in long-term monitoring and future studies by interested stakeholders and government.
- Prioritising future studies that incorporate macroinvertebrate traits to support taxonomy based methods.
- Continuous education on social and legal perspectives of pollution for principal catchment users' needs to be in place.

CHAPTER 7: REFERENCES

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