E-FLOWS FOR THE LIMOPOPO RIVER BASIN:

PRESENT ECOLOGICAL STATE - ECOLOGICAL RESPONSE TO CHANGE

E-FLOWS FOR THE LIMPOPO RIVER BASIN: PRESENT ECOLOGICAL STATE - ECOLOGICAL RESPONSE TO CHANGE

(Submitted in partial fulfilment of Milestone 6 : Wet Season Field Survey Report)

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Below is the list of Project Reports. This report is highlighted

Report number	Report title E-FLOWS FOR THE LIMPOPO RIVER BASIN:
1	Inception Report
2	Basin Report
3	From Vision to Management
4	Specialist Literature and Data Review
5	Present Ecological State - Drivers of Ecosystem Change
6	Present Ecological State - Ecological Response to Change
7	Environmental Flow Determination
8	Risk of Altered Flows to the Ecosystem Services

Cover photo: Fish collected in the Limpopo River, May 2021 Credit: G O'Brien

SUMMARY

PROJECT TITLE:

E-flows for the Limpopo River - building more resilient communities and ecosystems through improved management of transboundary natural resources

REPORT TITLE:

Present Ecological State of the Limpopo River: Ecological Response to Change

PROJECT OBJECTIVES:

This project will provide the necessary evidence to secure environmental flows (e-flows) for increasing the resilience of communities and ecosystems in the Limpopo Basin to changes in streamflow resulting from basin activities and climate change.

CONTENT:

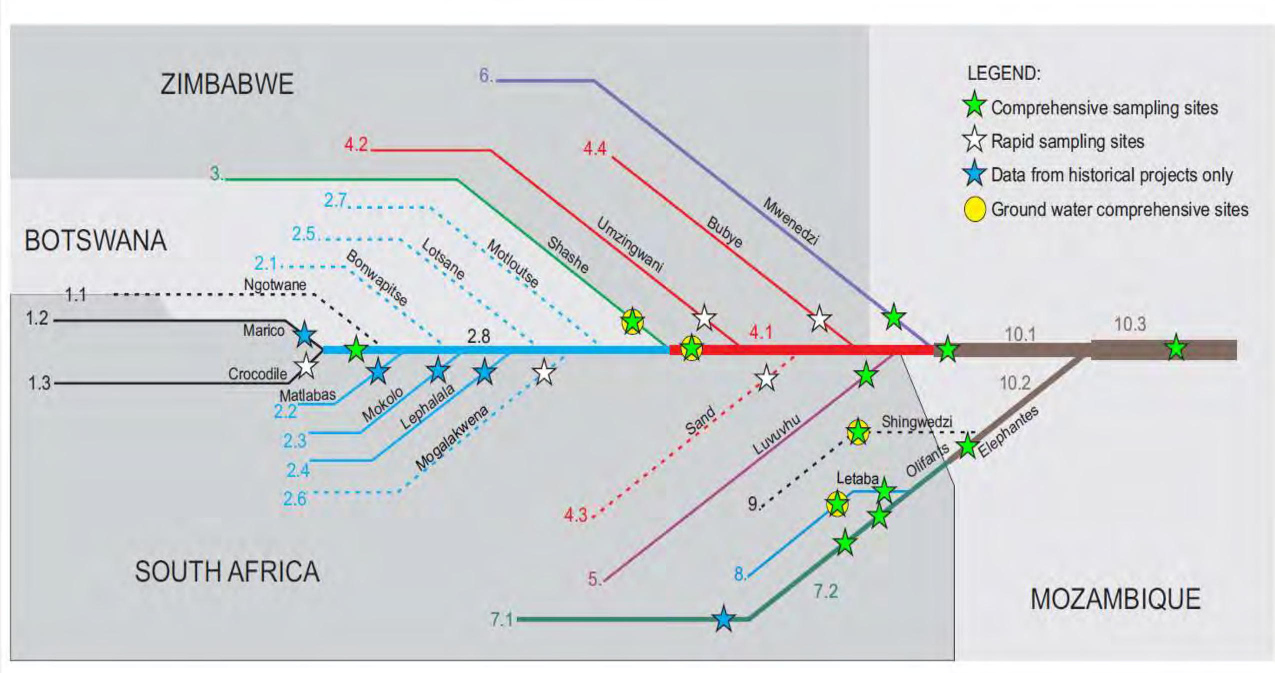
Six reports document the outputs of this project (see above). The first five reports describe the context for the e-flow derivation i.e., the socio-economic and biophysical characteristics of the basin (the Basin Description), and all the river-related biophysical background (the Specialist Literature and Data Review) and the drivers of ecosystem change.

The present report (**No. 5 Present Ecological State of the Limpopo River: Ecological Response to Change**) is based on the extensive field survey that was carried out during 2020 and 2021, and documents the results directly gained from that field survey in the form of an assessment of the present ecological state.

Data and information is given that describe the field survey sites. The report also describes the status quo of the ecosystem, the Present Ecological State, in terms of the **Response of the Ecosystem** (riparian vegetation, fish and invertebrates). It also summarises the ecosystem services provided by the river at each site.

SUMMARY RESULTS

The surface and groundwater sites contained within Risk Regions, are illustrated in the schematic given below. Data collected at these sites was a combination of data from the Monograph study (2011), field survey data collected during dry conditions (winter of 2020) and during wet conditions (autumn of 2021).



SCHEMATIC SHOWING RISK REGIONS, SUB-REGIONS AND SITES IN THE LIMPOPO RIVER BASIN

Large amounts of data provided evidence of the status quo of the ecosystem, and at the same time provided evidence that can be used to determine the relationship between the drivers of change and the response of the ecosystem. This evidence will be taken forward and used in the next phases of the project. The summary below represents just an overview of the information gathered, details are given in the next sections and the data is provided in the attached Annexures.

Response of the ecosystem

The drivers of ecosystem change (hydrology, hydraulics and geomorphology, water quality, and groundwater, all exert their influence over the instream and riparian ecosystem, the components of which are described below. Three approaches can be used to monitor ecosystem health: 1) Biotic and abiotic indicators, 2) measuring ecosystem resilience to understand its capacity to change, 3) the identification and management of risk variables to mitigate threats to ecosystem health. The preferred approach is using indicators to monitor ecosystem health. In the sections below, indicators for fish, macro-invertebrates and the riparian vegetation are all used to describe the present state of the ecosystem.

A classification of river state is used based on the table below (Kleynhans, 2008), which can be used for all response variables. A summary of all of the data is presented in the table below.

GUIDELINES USED TO DELINEATE THE PRESENT ECOLOGICAL STATE CATEGORIES BASED ON OBSERVED AND EXPECTED INTOLERANCE RATINGS (KLEYNHANS 2008).

Category	Description	% of Expected
A	Unmodified, or approximate natural conditions closely.	90 - 100
B	Largely natural with few modifications. A change in community characteristics may have taken place but species richness and presence of intolerant species indicate little modification.	80 - 89
C	Moderately Modified. A lower-than-expected species richness and presence of most intolerant species. Some impairment of health may be evident at the lower limit of this class.	60 - 79
D	Largely Modified. A clearly lower than expected species richness and absence or much lowered presence of intolerant and moderately intolerant species. Impairment of health may become more evident at the lower limit of this class.	40 - 59
E	Seriously Modified. A strikingly lower than expected species richness and general absence of intolerant and moderately intolerant species. Impairment of health may become very evident.	20 - 39
F	Critically Modified. An extremely lowered species richness and absence of intolerant and moderately intolerant species. Only tolerant species may be present with a complete loss of species at the lower limit of the class. Impairment of health generally very evident.	0 - 19

Fish

The community structures and attributes of fishes have been widely used as ecological indicators in the assessment of the integrity of riverine ecosystems. Some of the benefits of using fish as ecological indicators are their wide swimming ability, various trophic levels, long lifespan, convenient sampling, identification in the field, and high public awareness value. Various assessment methodologies have been used including community metric measures (biological indices) and established community structure assessment methodologies that are based on the attributes of fishes. These are widely incorporated in the management of local and international freshwater ecosystems.

This project has used the Fish Assemblage Integrity Index (FAII) with the purpose "to measure biological integrity of a river-based on attributes of the fish assemblage's native to the river". It is the assessment of fish communities to changing environmental conditions either through direct measurements or inferred from the availability and condition of habitat at each site. In 2007, FAII was updated to the Fish Response Assessment Index (FRAI) which was developed to strengthen the relationship between cause and effect).

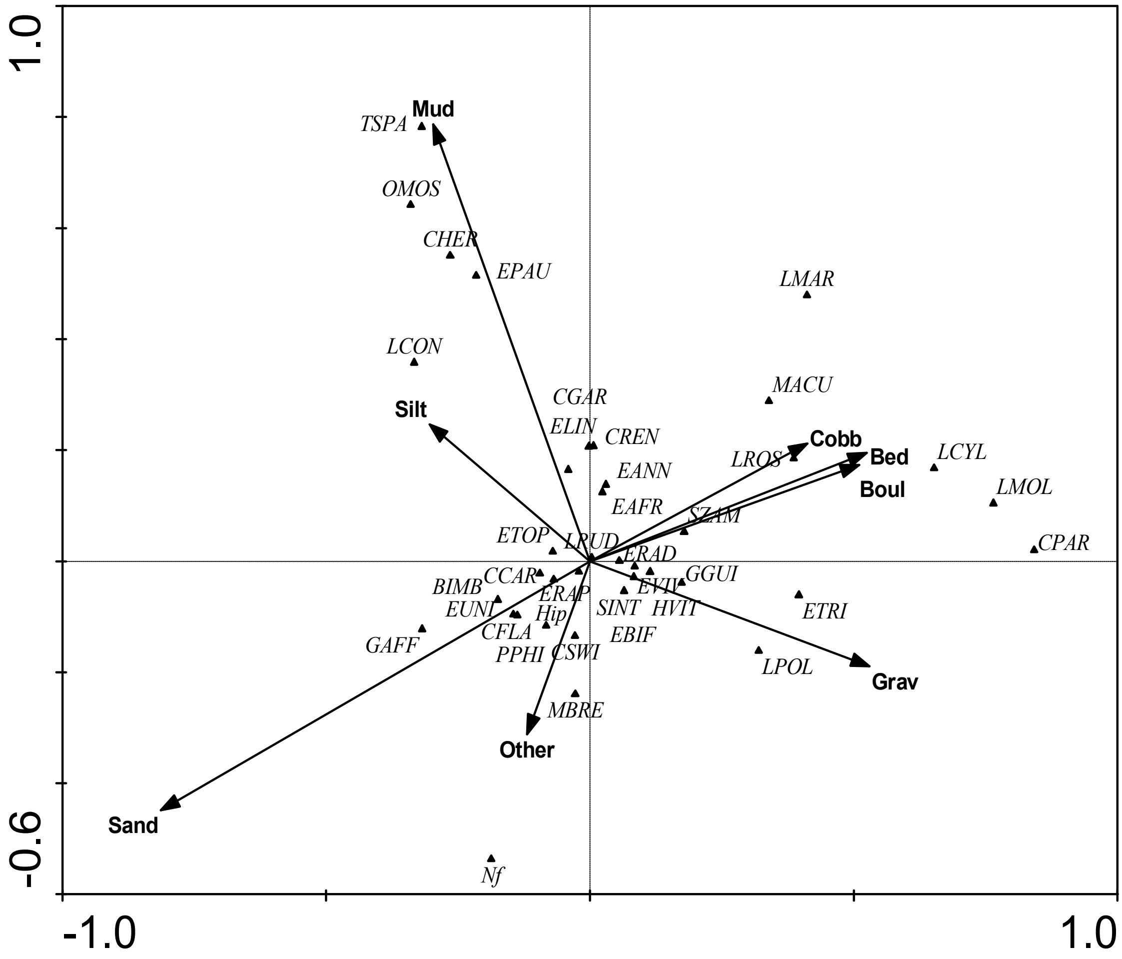
THE PRESENT ECOLOGICAL STATUS OF ALL RESPONSE VARIABLES IN THE LIMPOPO RIVER BASIN DURING THE SURVEY OF 2021

E-flow site	FISH	INVERTS	VEG
CROC-A24J-ROOIK	C/D	C/D	C
LIMP-A41D-SPANW	C	C	C/D
MATL-A41D-WDRAAI	B/C	C	C
LEPH-A50H-SEEKO	D	C/D	C
LIMP-A63C-LIMPK	D	C	C
MOGA-A63D-LIMPK	D	D	C
SHAS-Y20B-TULIB	D	C	D
LIMP-A71L-MAPUN	C/D	C	C
UMZI-Y20C-BEITB		C	D
SAND-A71K-R508B	C/D	C	B/C
LUVU-A91K-OUTPO	C	C	B
OLIF-B73C-MAMBA	C	C	C
OLIF-B73H-BALUL	C	C	C
GLET-B81J-LRANC	D	C	C
LETA-B83A-LONEB	C/D	C	C
ELEP-Y30C-SINGU	D	C	C/D
SHIN-B90H-POACH	D	B/C	B
LIMP-Y30F-CHOKW	C	C	D

This study aimed to determine the overall state of fish communities in the Limpopo River Basin. The multiple lines of evidence used in this study included Fish Response Assessment Index (FRAI) and Multivariate statistics (Redundancy Analysis). The multivariate analysis was used to validate the FRAI results and to provide insight into what the main drivers of change were.

The FRAII scores (summarised in the table above) obtained indicate that there is a noticeable and significant change in the community structure of the Limpopo River Basin. The explanatory data obtained for each site showed that substrate, habitat cover features, and depth and velocity classes differed between sites. Over the study period, only one site (MATL-A1D-WDRAAI) was in a class B/C, five sites were fair, moderately modified (Class C), four sites were intermediate in a class C/D and seven sites were poor and largely modified (Class D). It is concerning that none of the sites were in a mostly natural state (Ecological category = B). During the present study, the main impacts that caused such low FRAI scores were but not limited to, altered flows, altered habitats, barriers, water quality, alien invasives, and overexploitation. The sites closer to anthropogenic activities were in a poor state whereas sites within Kruger National Park had higher present ecological status. Of the expected 77 species only 37 species were collected during this survey. Multivariate statistics and FRAI scores were used to unpack the impacts and drivers of the fish community structure. Knowledge of the drivers of these fish communities is required to sustainably use and protect the fish in the basin and the rivers that they occur in.

The presence of fish at the different sites was studied in relation to the hydraulic, physical and chemical habitats. Understanding of these relationships is necessary to build the case towards



setting e-flows. Multivariate analyses showed that changes in velocity-depth classes, substrate type, cover features and water quality variations were significant drivers of fish communities. Alteration of flows affect these variables, and in turn affect the community structure.

EXAMPLE OF A MULTIVARIATE ASSESSMENT – IN THIS CASE SHOWING DISSIMILARITY BASED ON THE FISH COMMUNITIES AMONG SITES CONSIDERED IN THE STUDY, WITH DIFFERENT SUBSTRATES (ARROWS) AS ENVIRONMENTAL VARIABLES SUPERIMPOSED. THE TRI-PLOT DESCRIBES 76.3% OF THE VARIATION IN THE DATA WHERE 51.6% IS DISPLAYED ON THE FIRST AXIS (X) AND AN ADDITIONAL 24.4% ON THE SECOND AXIS (Y).

Benthic macroinvertebrates

Aquatic macroinvertebrates are one of the components used in this study as response indicators of different flow conditions. These organisms have been around since the Ordovician Period (485 – 444 million years ago) and have evolved and adapted to the environmental conditions which they were exposed to. These adaptations include droughts and flooding events in riverine ecosystems. The aquatic macroinvertebrate community would therefore respond to changes in natural flow condition. When there is an understanding of the requirements of individuals species throughout their life cycles, such information builds knowledge of community responses to changed biotic and abiotic conditions.

The aim of this study was:

- to determine which invertebrate taxa are present in the different available biotopes (flow, depth, substrate, hydraulic biotopes, vegetation);
- to determine aquatic invertebrate abundances within quantifiable biotopes to better understand habitat preference to the lowest possible classification (i.e., genus or species level); and
- to determine present stream conditions using existing classification tools.

Field surveys were carried out during September-October 2020, April-May 2021, and June- July 2021.

The water quality as well as the instream habitats were assessed from an invertebrate perspective. In addition, the habitats in each demarcated area were measured and then described in terms of velocity, depth, substrates, and hydraulic biotope. The aquatic macroinvertebrates encountered and collected within each demarcated area were identified to the lowest possible taxonomic level and counted to determine preferences of species and communities. Sampling was carried out using a Surber sampler, while a SASS net was used for gravel-sand-mud and vegetation biotopes.

The MIRAI (Macroinvertebrate Response Assessment Index) was applied to the data to interpret Ecological Condition of the macroinvertebrate community at each site. The MIRAI is a rule-based model developed by DWS in South Africa and considers the knowledge of water quality, flow preference, and habitat requirements of the invertebrates at family level. The method integrates the currently known ecological requirements of the invertebrate taxa at a family level to their responses to modified habitat conditions.

EcoStatus results per site are provided in the table below. Invertebrate status was categorised as moderately impaired (C-class) over most of the basin, with poor conditions in the Mogalakwena River, where flow was restricted to a trickle despite most other tributaries in the region experiencing high to moderate flows. The EcoStatus in the Shingwedzi River was categorised as largely natural to moderate.

Riparian vegetation

The biophysical survey for riparian vegetation at each site consisted of site and riparian zone delineation, determination of the present ecological status (PES) for riparian vegetation, and determination of indicator / environment links that will be used to determine e-flows for the riparian vegetation.

In situ data collection was conducted by using cross-section transects perpendicular to flow. Data collected from fixed quadrats included both biotic and abiotic data. Biotic data was vegetation-related and abiotic data included substrate, geomorphic feature, hydraulics, hydrology, water chemistry, ecotoxicology and elevation. Plant species were identified along the cross-sections with individual height and abundance (if woody classification) and cover percentage (if non-woody classification). In addition to vegetation data, the percentage cover of algae was also recorded for additional data relating to in-stream conditions.

ECOSTATUS BASED ON AQUATIC MACROINVERTEBRATES, USING THE MIRAI MODEL

LIMCOM 2021 SITE CODE	LIMCOM 2012 SITE CODE	FBIS SITE CODE	RIVER	ECOSTATUS	
				RQOs	April-May June 2021
CROC-A24J-ROOIB		A2CROC-ROOIB	Crocodile	C/D	C/D
LIMP-A41D-SPANW	LmEWR01	A4LIMP-SPANW	Limpopo	C	C
MATL-A41C-WDRAAI		A4MATL-PHOFU	Matlabas	C	C
LEPH-A50H-SEEKO		A5LEPH-SEEKO	Lephalale		C/D
LIMP-A63C-LIMPK		A6LIMP-LIMPK	Limpopo		C
MOGA-A63D-LIMPK		A6MOGA-LIMPK	Mogalakwe na		D
SHAS-Y20B-TULIB			Shashe		C
LIMP-A71L-MAPUN	LmEWR02	A7LIMP-MAPUN	Limpopo		C
UMZI-Y20C-BEITB			Umzimgwan		C
SAND-A71K-R508B		A7SAND-R508B	Sand		C
LUVU-A91K-OUTPO		A9LUVU-MUTAL	Luvuvhu		C
OLIF-B73C-MAMBA		B7OLIF-MAMB1	Olifants	C	C
OLIF-B73H-BALUL		B7OLIF-BALUL	Olifants	C	C
GLET-B81J-LRANC		B8GLET-IFR16	Great Letaba	C	C
LETA-B83A-LONEB		B8LETA-NGWEN	Letaba	C	C
ELEP-Y30C-SINGU		Y3ELEP-SINGU	Elephantes		C
SHIN-B90H-POACH	(LmEWR06)	B9SHIN-POACH	Shingwedzi		B/C
LIMP-Y30F-CHOKW	LmEwr07	Y3LIMP-CHOKW	Limpopo		C

The Present Ecological State (PES) of riparian EWR zones was assessed using the Riparian Vegetation Response Assessment Index (VEGRAI) level 4 (Kleynhans et al., 2007), with simplification to 2 broad zones i.e. the Macro-channel bank and the Macro-channel valley (floor). Since all VEGRAI assessments are relative to the natural unmodified conditions (reference state) it is necessary and important to define and describe the reference state for each site.

SUMMARY OF RIPARIAN VEGETATION PES, EXPRESSED AS CATEGORIES.

River	Site	Macro channel valley	Macro channel bank	Rip Zone
Crocodile	CROC-A24J-ROOIB	C	C	C
Limpopo @ Spanwerk	LIMP-A41D-SPANW	C	C/D	C/D
Matlabas	MATL-A41D-WDRAAI	B/C	C	C
Lephalala	LEPH-A50H-SEEKO	C	C	C
Limpopo @ Limpokwena	LIMP-A36C-LIMPK	B/C	C	C
Mogalakwena	MOGA-A36D-LIMPK	C	B/C	C
Shashe	SHAS-Y20B-TULIB	D	D	D
Limpopo @ Poachers Corner	LIMP-A71L-MAPUN	C	B/C	C
Umzingwani	UMZI-Y20C-BEITB	D	D	D
Sand	SAND-A71K-R508B	C	B/C	B/C
Luvuvhu	LUVU-A91K-OUTPO	B/C	B	B
Olifants @ Mamba	OLIF-B73C-MAMBA	C/D	C	C
Olifants @ Balule	OLIF-B73H-BALUL	C	C	C
Groot Letaba	GLET-B81J-LRANC	C	C	C
Letaba @ Lonely Bull	LETA-B83A-LONEB	C	C	C
Elephantes Below Massingir	ELEP-Y30C-SINGU	C	D	C/D
Shingwedzi	SHIN-B90H-POACH	B/C	B	B
Limpopo @ Chokwe	LIMP-Y30F-CHOKW	D	D	D

The results show that most of the sites have riparian vegetation that is significantly degraded from natural, with the Luvuvhu and Shongwedzi being the only two sites approaching natural. The Shashe, Umzingwani and Limpopo at Chokwe were the most degraded mostly due to over-utilisation.

Ecosystem Services

The Limpopo River Basin is home to an estimated 18 million people from Botswana, Zimbabwe, South Africa and Mozambique. According to UN-HABITAT/UNEP, (2007), the basin supports an estimated 5200 human settlements with different seasonal ecosystem services. According to Nhassengo, Somura and Wolfe, (2021) the Limpopo River Basin (LRB) sustains ecosystems and provide ecosystem services critical to the human livelihoods of local communities and economic activities. This report presents the different observed ecosystem services (ES) and benefits of the Limpopo Basin in different sites of the basin.

The MA categorized ES into provisioning (food, fresh water, fuel); regulating (water purification, climate regulation); cultural (recreation, spirituality); and supporting services (nutrient cycling, soil formation), which are important for the production of all other ecosystem services. Supporting and regulating services are often combined as their functions and processes can be interdependent

CATEGORIES OF THE ECOSYSTEM SERVICES OBSERVED AND DERIVED IN THE LIMPOPO BASIN

Types of services		Description
Provision	Water	Provision of water for irrigation, domestic use and livestock.
	Food, medicine	Wild fruits
	Livestock grazing	Flood plains and riverbank livestock grazing
	Raw material	Medicinal plants, craft material, ornamental artefacts
Regulation	Waste treatment	
Supporting services	Refugia	Breeding for fish and feeding for water population
Cultural		Cultural activities, spiritual and wellbeing rituals, social interaction Recreational use-ecotourism Research and education

Some detail of each of these ecosystem services is provided in the report below. The data was largely collected from the literature and from targeted interviews. The data shows that at most of the sites, there is major competition between uses and ecosystem services in the basin. In the upper reaches of the catchment (Lephalale, Marico) irrigation and commercial agriculture competes with smallholder livelihoods like fishing, subsistence agriculture. In the middle parts of the basin (Levhuvhu, Mogalekwena, Olifants) cultural services(eco-tourism) are the most common and compete with small holder provision services e.g fishing , household water use. In the lower reaches of the basin (Chokwe), the major competition is between irrigation and subsistence water use and fishing. Most of the rural local communities rely on the ecosystem services for subsistence needs, food security and livelihood activities. However, their degree of dependency differs across communities and regions, with very high dependence in Mozambique and Zimbabwe. It has been shown that there is uneven distribution of wealth, resources and opportunities across the basin and that people from Botswana and South Africa tend to be less dependent on ecosystem services.

Based on interactions with communities, there has been loss of ecosystem services at some sites e.g. Chokwe and Groot-Letaba where unpredictable low flows were identified as the main reason for loss of ecosystem services affecting livelihoods. Communities along the Groot-Letaba explained that they have experienced some periods of water shortage during their agriculture growing season which have resulted in lower-than-expected yields. Since these rural communities are highly dependent on the basin ecosystem goods and services, changes in the supply of these services would have major impacts on the sustainability of local livelihoods, and human well-being.

CONTENTS

1 INTRODUCTION

PROJECT Title:

E-flows for the Limpopo River - building more resilient communities and ecosystems through improved management of transboundary natural resources

1.1 OBJECTIVES

This project will provide the necessary evidence to secure environmental flows (e-flows) for increasing the resilience of communities and ecosystems in the Limpopo Basin to changes in streamflow resulting from basin activities and climate change.

1.2 THE LIMPOPO RIVER BASIN

The Limpopo River Basin is one of southern Africa's most studied transboundary basins, including its tributaries and sub-basins. The richness in culture, biodiversity and natural resources contribute towards this attention. The basin is however plagued by droughts, floods and water and food insecurity (Petri et. al. 2015). Climate variability has resulted in the unpredictability of the hydrological regime leaving the river in parts without flows for nearly 70% of the year (ADB, 2014). Notable studies that have been carried out include the 2012-2017 Resilience in the Limpopo Basin study (RESILIM, 2017), the 2013 Monograph reports on the Limpopo (Aurecon, 2013a) and the Joint Limpopo Scoping Study of 2010 (LBPTC, 2010). These reports form a foundation for in-depth analysis of the basin on which this study builds.

1.3 E-FLOWS IN THE LIMPOPO BASIN

This project responds to the problem of managing water resources to ensure that there is always enough water not only to sustain the ecosystem, but also to sustain the ecosystem services that are benefitting communities associated with the Limpopo River. The water resources of the Limpopo River are stressed, with present day flows substantially diminished when compared to the natural flows. There is thus an urgent need to establish sustainable resource management plans in the Limpopo Basin. Key to this is that an acceptable minimum (but varied) flow rate be established for the river that can be built into transboundary as well as national cooperation and management plans to secure the necessary ecosystems and ecosystem services. These are environmental flows (e-flows).

There is a history of e-flow assessment in the Limpopo River basin, with two complementary initiatives already in place. The Limpopo River Basin Monograph (Aurecon, 2013) included a supplementary report called "*Determination of Present Ecological State and Environmental Water Requirements*" that was published in 2013 (note that the team in this project is largely the same as undertook that study). Eight (8) sites that spanned the entire transboundary basin were surveyed to provide data for priority reaches on the main-stem Limpopo and important tributaries in Mozambique and Zimbabwe. The Changane in Mozambique was dropped in this report as it proved to be a wetland lacking a main channel. In addition, nine (9) sites were established in the estuary. The Monograph also summarizes the second source of e-flow data in the Limpopo Basin, i.e. the many e-flow assessments that have been carried out by the South African Department of Water and Sanitation (DWS) for tributaries located in South Africa. Subsequent to that report, further surveys have been carried out in South Africa, but have avoided the main-stem river because of its transboundary nature. There are no other documented Limpopo Basin e-flow studies from the other countries.

Previous e-flow assessments in the Limpopo Basin were confined to surface flow and did not directly consider the groundwater interaction beyond the estimation of baseflows (that are one of groundwater's contributions to stream flow). For the Limpopo Basin, this is a particularly important aspect given that many of the rivers have only intermittent or seasonal flows, partly due to increasing groundwater abstractions for various uses.

An approach to e-flows that embraces the connection between the flow of river water and the water requirements of stakeholders, including rural stakeholders requirements that will include such things as water for riparian irrigation, for domestic use, fish for food, and reeds for construction etc., is here being applied. Rural stakeholders rely to a greater degree on immediate ecosystem services from the river, and are most vulnerable when these flows are diverted elsewhere, or when climate changes causes overall long-term and seasonal flow patterns to change. The e-flow assessment done in this project considers the requirements of rural stakeholders for flow-related ecosystem services, and documents the quantities of water required in the river that will provide the services they require, and the risks to failure of this provision. As groundwater is becoming an increasingly critical resource for stakeholders in the basin, and groundwater abstraction close to the river is prevalent and indirectly influencing river flows, water requirements from both groundwater and surface water need to be understood. Management of environmental flows will require an integrated management of both surface water and groundwater.

This project builds on the Monograph study and the data provided by DWS in South Africa and extends the work done at the same sites as initiated in the Monograph by adding new sites as well as wet-season evidence on the ecological requirements and the role of groundwater and also to links stream flow to the requirements of stakeholders. Greater evidence on the ecological requirements is gained as this project focusses much of its efforts on the wet-season situation, something that was missed during the Monograph study. It also carries out more intensive field investigations, and most importantly, introduces a probabilistic approach to the e-flow investigation, thus enabling the results to be interpreted with greater understanding.

1.4 STRUCTURE OF THIS REPORT

This report describes the status quo of the response ecosystem (riparian vegetation, fish and invertebrates). It also summarises the ecosystem services available at each site.

The report has been structured to include the following sections:

- **Introduction**
    - E-Flow Sites
    - Field Survey
- **Response of Ecosystem to Drivers**
    - Fish
    - Macroinvertebrates
    - Riparian Vegetation
    - Ecosystem Services
- **Conclusions**
- **Data appendices**
    - These include detailed data from each section

2 FIELD SURVEY, RISK REGIONS & E-FLOW SITES

2.1 RISK REGIONS

The Limpopo River catchment has initially been divided into 11 main risk regions (RR) based on a number of criteria, including hydrological considerations One of the main hydrological considerations was to select regions where the various types of rivers (seasonal, perennial or ephemeral) are grouped within one region. Additionally, changes in flows from natural to present day due to developments (dam construction, irrigation, return flows or hydropower) were also taken into consideration to assist the assessment of the habitats and biota by the ecologists. These RRs have been revised and 10 final RRs have been selected, each with a number of sub-risk regions (mainly the major tributaries contributing flow to the RR). The final RRs and main tributaries (Sub-risk regions) are listed in the table below (Table 2.1) together with greater detail Table 2.1, and are also shown in the schematic (FIGURE 2.1) and the map in FIGURE 2.2. and Figure 2.3.

2.2 SITE SELECTION

The Limpopo River Basin Monograph (Aurecon, 2013) included a supplementary report called "*Determination of Present Ecological State and Environmental Water Requirements*" that was published in 2013. Eight (8) sites that spanned the entire transboundary basin were surveyed in that report to provide data for priority reaches on the main-stem Limpopo and important tributaries. For this study in 2020/2021, additional sites were added to the above in order to ensure a better distribution of data. These sites are shown in FIGURE 2.1 and 2.3. TABLE 2.2 provides the details of each site and also indicators which biophysical characteristics were surveyed.

The sites were located based on the following criteria:

- Each site represented an ecoregion
- Each site represented a major tributary
- The existence of data from previous studies and/or monitoring programmes
- Socio-economic or political governance situations were NOT included in the site selection. This appears to have skewed the site selection to favour sites in South Africa, but that dominance was driven by the number of large tributaries and existing data in South Africa. Tributaries from Botswana were discounted as they are largely dry meaning that e-flows are not meaningful. The site at Mwanedzi in Zimbabwe had to be dropped from the survey because at the time access was impossible due to Covid restrictions. This was not considered to be serious because good data for the site was collected during the 2013 Monograph study. The Changane in Mozambique was also dropped following the Monograph study, because during that study the site was found to be unsuitable for determination of e-flows because it is largely a saline wetland without a clear channel flow.

TABLE 2.1 FINAL RISK REGIONS AND MAIN TRIBUTARIES PER RISK REGION IN THE LIMPOPO RIVER BASIN

Risk region	Rivers	E-flow site/ COMMENTS
RR1	1.1 Ngotwane	Confluence with Limpopo (no site selected, mainly groundwater and flood driven in the lower reaches
	1.2 Marico	Existing intermediate site MAR_EWR4 Support site and Reserve/ RQOs gazetted
	1.3 Crocodile (West)	Reserve/ RQOs gazetted based on desktop results New e-flow site selected
RR2	2.1 Bonwapitse	Confluence with Limpopo (no site selected) mainly groundwater and flood driven in the lower reaches
	2.2 Matlabas	Reserve/ RQOs gazetted based on desktop results New e-flow site selected
	2.3 Mokolo	Existing intermediate site MOK_EWR4 Support site and Reserve/ RQOs gazetted
	2.4 Lephalale	New e-flow site selected
	2.5 Lotsane	Confluence with Limpopo (no site selected) mainly groundwater and flood driven in the lower reaches
	2.6 Mogalakwena	New e-flow site selected
	2.7 Motloutse	Confluence with Limpopo (no site selected) mainly groundwater and flood driven in the lower reaches
	2.8 Limpopo to Lotsane confluence	Re-survey LmEWR01 at Spanwerk
	2.9 Limpopo – Lotsane to Shashe	New e-flow site selected
RR3	3.1 Shashe	New e-flow site selected
RR4	4.1 Limpopo – Shashe to Mzingwani	Re-survey LmEWR02 at Mapungubwe
	4.2 Mmzingwani	New e-flow site selected
	4.3 Sand	New e-flow site selected
	4.4 Bubye	Confluence with Limpopo (no site selected) mainly groundwater and flood driven in the lower reaches
RR5	5.1 Luvuvhu	New e-flow site selected
RR6	6.1 Mwanedzi	Resurvey LmEWR03 at Malapai
RR7	7.1 Olifants – to Blyde	Existing intermediate site Olifants_EWR11 Support site and Reserve/ RQOs gazetted
	7.2 Olifants – to Letaba	Existing intermediate site Olifants_EWR16 Support site and Reserve/ RQOs gazetted
RR8	8.1 Letaba – to Little Letaba	Existing intermediate site Letaba_EWR4 Support site and Reserve/ RQOs gazetted

Risk region	Rivers	E-flow site/ COMMENTS
	8.2 Letaba – Little Letaba to Olifants	Existing rapid site LET2 Support site and Reserve/ RQOs gazetted
RR9	9.1 Shingwedzi	Existing rapid site SHI1 Support site and Reserve/ RQOs gazetted
RR10	10.1 Limpopo – Mzingwani to Mwanedzi	Re-survey existing site LmEWR04 at Pafuri
	10.2 Elephantes	New e-flow site selected
	10.3 Limpopo – to estuary	Re-survey existing site LmEWR07 at Chokwe

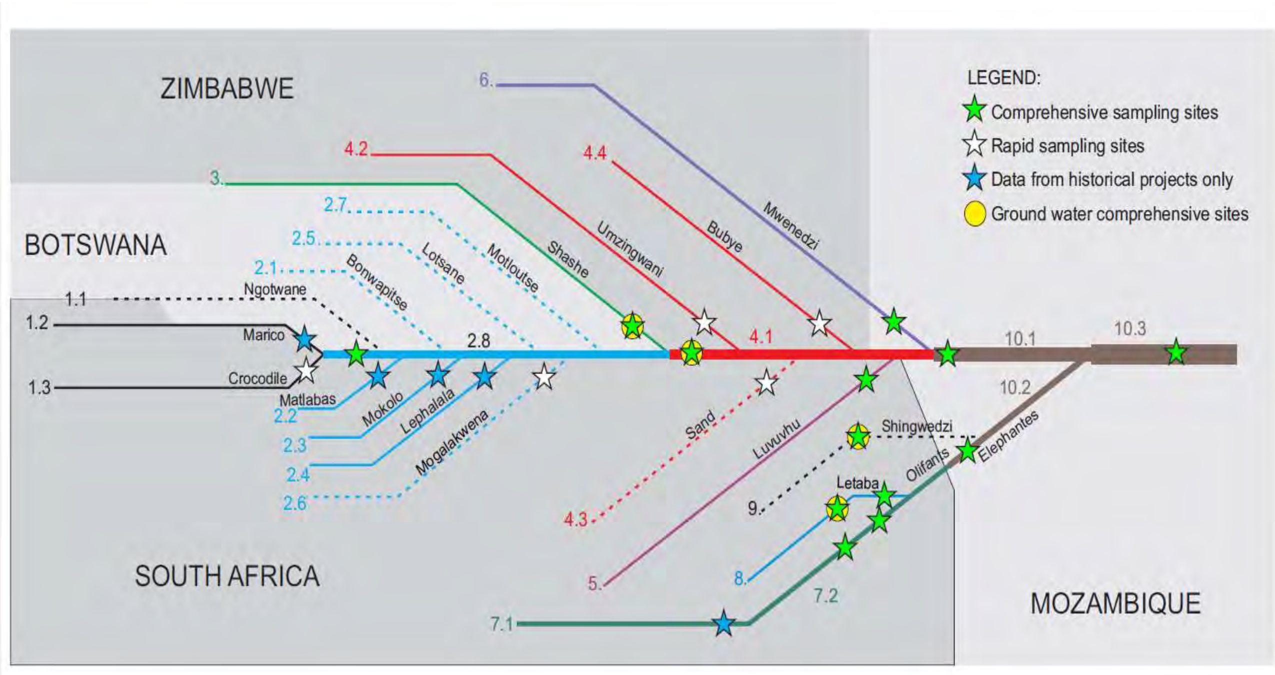


FIGURE 2.1 SCHEMATIC SHOWING RISK REGIONS, SUB-REGIONS AND SITES IN THE LIMPOPO RIVER BASIN

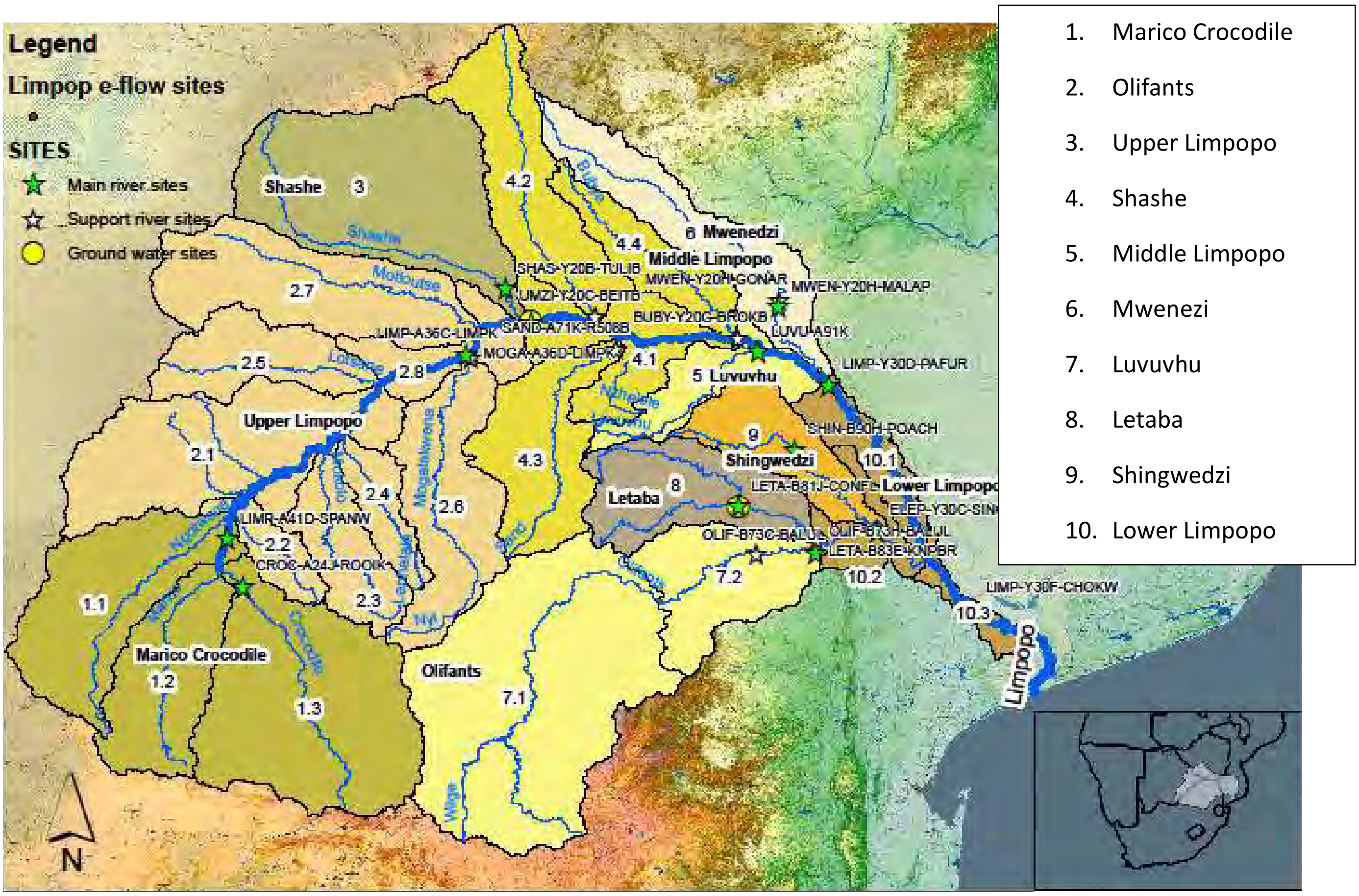


FIGURE 2.2 RISK REGIONS IN THE LIMPOPO BASIN. THE GREEN STARS INDICATE SITE LOCATIONS.

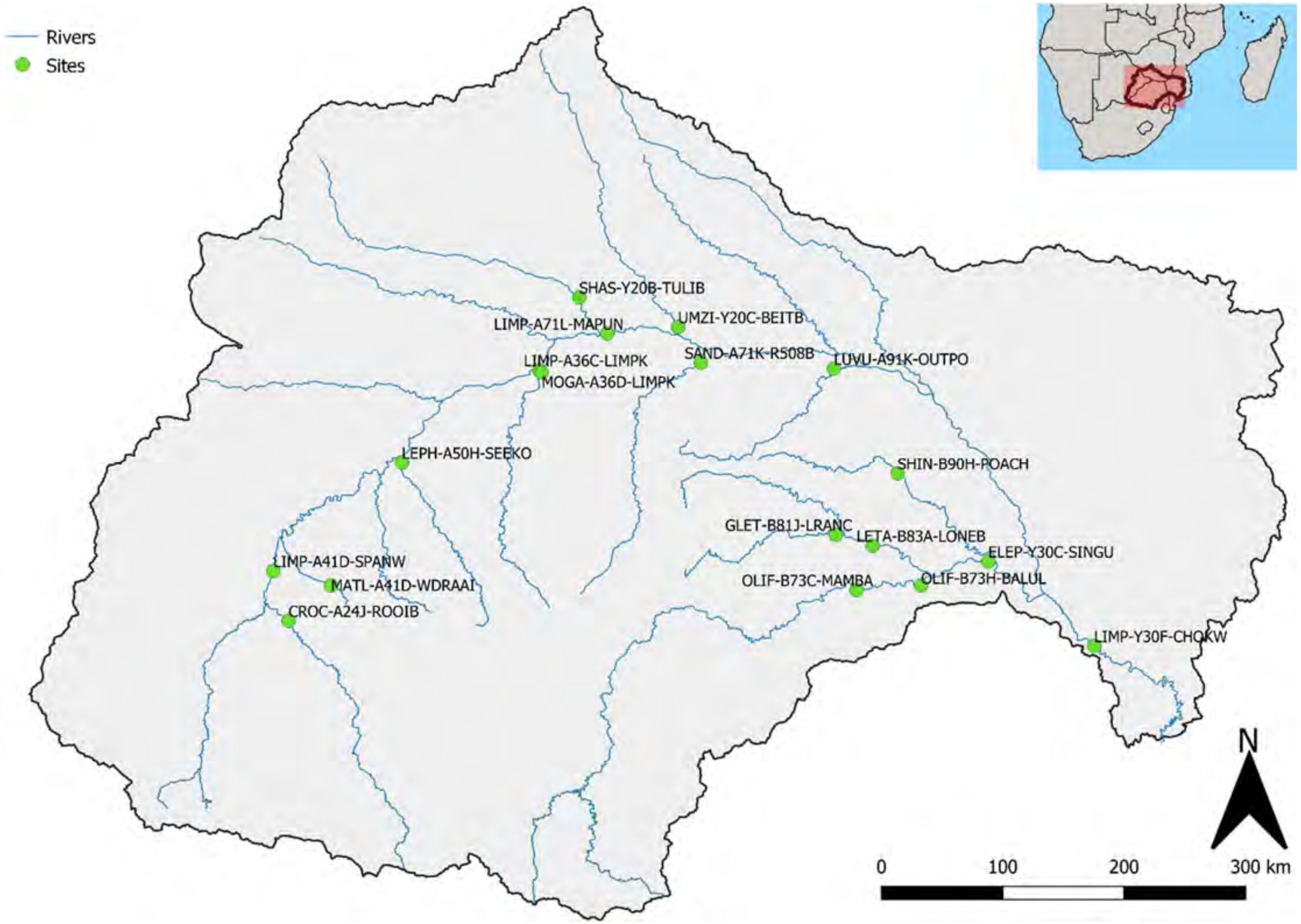


FIGURE 2.3 MAP OF SELECTED E-FLOW SITES

TABLE 2.2: SUMMARY OF THE SITES AND BIO-PHYSICAL DATA COLLECTED FROM EACH SURFACE WATER SITE.

Name	Description	Latitude	Longitude	Type	Vege-tation	Macro-inverts	Fish
CROC-A24J-ROOIB	Crocodile River upstream of confluence with Marico River. Accessed site from Gerhard Diedericks of Rooibokkraal (+27824665697).	-24.314167	27.046139	Main	x	x	x
LIMP-A41D-SPANW	Limpopo River at Spanwerk below confluence of Marico and Crocodile Rivers. Confluence on Limcroma Farm of Reinier Els (+27836259119)	-23.945556	26.932028	Main	x	x	x
MATL-A41D-WDRAAII	Site located on the Wegdraai Farm of Mr. Tjaart vd Walt (+27603305369).	-24.051861	27.359639	Support	x	x	x
LEPH-A50H-SEEKO	Accessed site on land of Mr. Petrie Gous (+27823718218) on farm. Zeekoegat farm.	-23.141278	27.885028	Support	x	x	x
LIMP-A36C-LIMPK	Limpopo River located on Limpokwena Nature Reserve - Contact Manager Riley Bouchet (+27732584252)	-22.455194	28.901750	Main	x	x	x
MOGA-A36D-LIMPK	Mogalakwena R. upstream of confluence with Limpopo River.	-22.473444	28.919500	Support	x	x	x
SHAS-Y20B-TULIB	Shashe river in Zimbabwe	-21.916236	29.198356	Support	x	x	x
LIMP-A71L-MAPUN	Site just upstream of poacher's corner in Mpaungopwe National Park.	-22.183833	29.405194	Main	x	x	x
UMZI-Y20C-BEITB	Umzingwani river in Zimbabwe	-22.135897	29.930200	Support	x	x	N/A

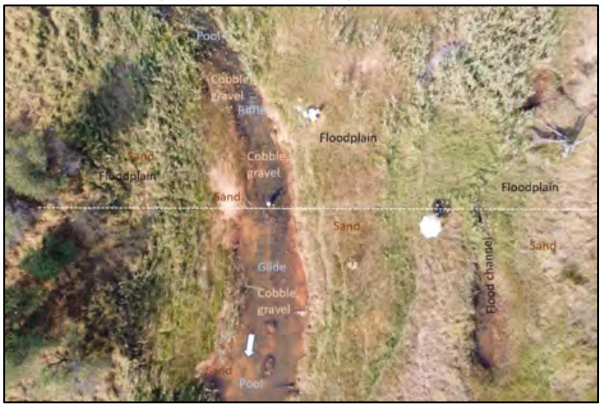
Name	Description	Latitude	Longitude	Type	Vege-tation	Macro-inverts	Fish
SAND-A71K-R508B	Sand River upstream of R508B bridge from Messina to Tsipise.	-22.399278	30.099417	Support	x	x	x
LUVU-A91K-OUTPO	Luvuvhu River in Kruger National Park below Outpost private lodge.	-22.444444	31.083444	Support	x	x	x
SHIN-B90H-POACH	Shingwedzi River within Kruger National Park at Poachers Corner.	-23.221944	31.554917	Main	x	x	x
OLIF-B73C-MAMBA	Olifants River within the Kruger National Park, South Africa at the Mamba Weir close to Phalaborwa in the Kruger National Park.	-24.086417	31.250944	Main	x	x	x
OLIF-B73H-BALUL	Olifants River within the Kruger National Park, South Africa at the Balule Weir, below the Olifants River rest camp.	-24.052139	31.728778	Main	x	x	x
GLET-B81J-LRANC	Groot-Letaba River, Letaba Ranch upstream of confluence with Klein Letaba River.	-23.677083	31.098333	Support	x	x	x
LETA-B83A-LONEB	Letaba River upstream of the Letaba Rest Camp in the Kruger National Park, South Africa.	-23.758333	31.369972	Support	x	x	x
ELEP-Y30C-SINGU	Elephantes river downstream of Lake Massingir	-23.875120	32.226237	Support	x	x	x
LIMP-Y30F-CHOKW	Limpopo river close to Chokwe in Mozambique	-24.500200	33.010400	Main	x	x	x

2.3 SURFACE WATER SITE PHOTOGRAPHS

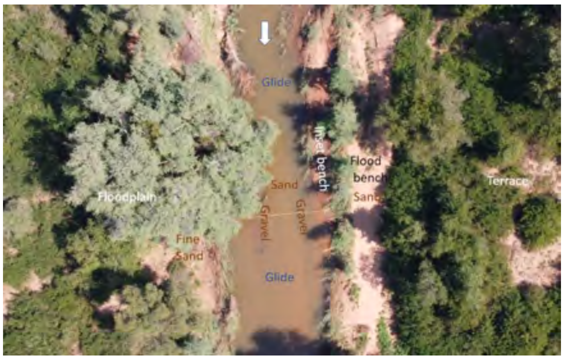
Below are aerial photographs from each site. Further pictures are shown in the various sections that follow.

Crocodile River (CROC-A24J-ROOIB)

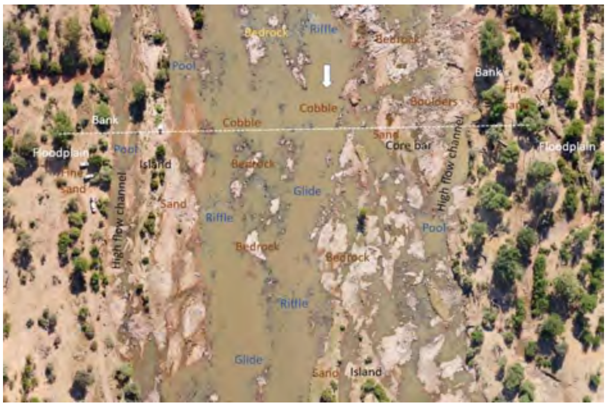
Limpopo River at Spanwerk (LIMP-A41D-SPANW)



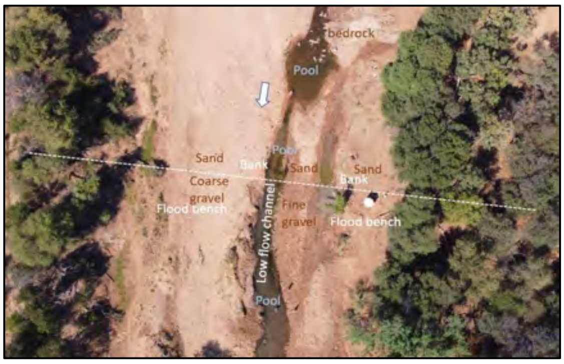
Matlabas River (MATL-A41C-WDRAA)



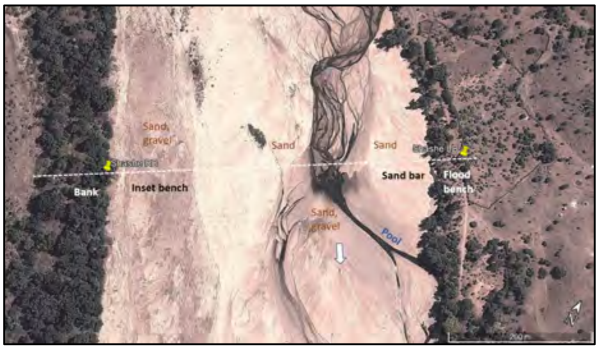
Lephalala River (LEPH-A50H-SEEKO)



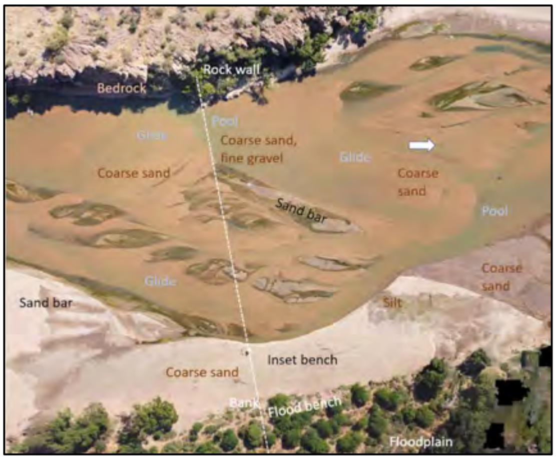
Limpopo River at Limpokwena (LIMP-A36C-LIMPK)



Mogalakwena River (MOGA-A63D-LIMPK)



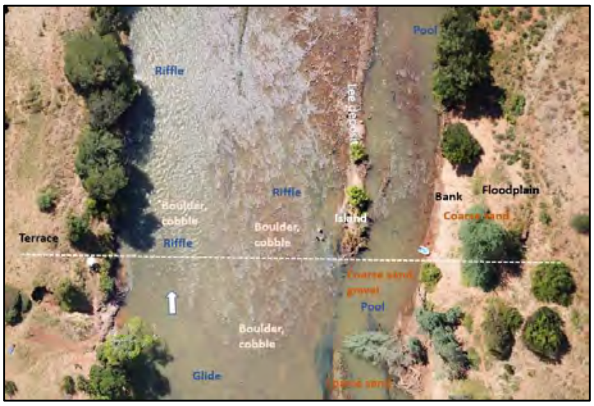
Shashe River (SHAS-Y20B-TULIB)



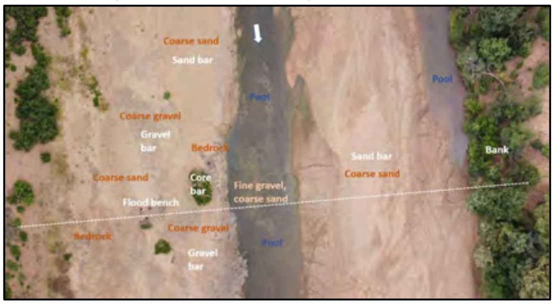
Limpopo River at Mapumgubwe (LIMP-A71L-MAPUN)

Umzingwani River (UMZI-Y20C-BEITB)

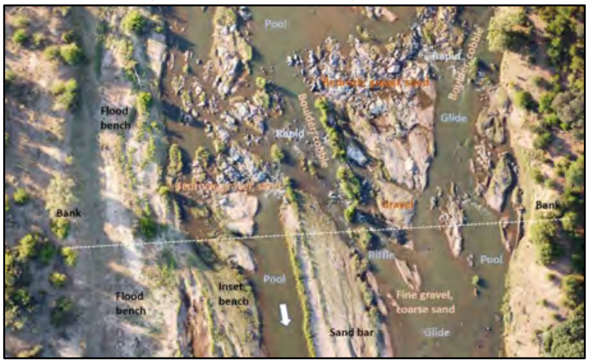
Sand River (SAND-A71K-R508B)



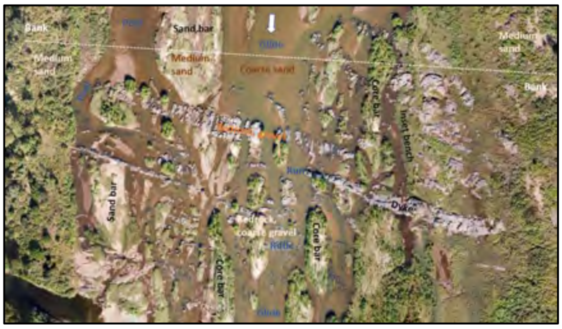
Luvuvhu River (LUVU-A91K-OUTPO)



Shingwedzi River (SHIN-B90H-POACH)



Olifants River at Mamba Weir (OLIF-B73C-MAMBA)



Olifants River at Balule Weir (OLIF-B73H-BALUL)

Groot Letaba River (GLET-B81J-LRANC)

Letaba River at Lonely Bull (LETA-B83A-LONEB)

Elefantes River at Massingir (ELEP-Y30C-SINGU)

Limpopo River at Chokwe (LIMP-Y30F-CHOK)

2.4 FIELD SURVEY

This chapter provides an account of the survey in the upper, middle, lower Limpopo River Catchment undertaken from 27 April to 26 July 2021 as a part of the project "E-flows for the Limpopo River building more resilient communities and ecosystems through improved management of transboundary natural resources". The data collected from this survey contributes to achieving the aim of the project to secure environmental flows (e-flows) for increasing the resilience of communities and ecosystems in the Limpopo Basin to changes in streamflow resulting from basin activities and climate change. The survey was commissioned by the International Water Management Institute (IWMI) and led by Dr. Gordon O'Brien of the Rivers of Life Aquatic Health Services Programme of the University of Mpumalanga. The specialist team on the survey included Dr. Benjamin Van Der Waal (Geomorphology and Hydraulics), Mr. James MacKenzie and Ms. Stacey Gerber (Riparian Vegetation), Mr. Gerhard Diedericks and Chantelle Barendze (Macroinvertebrates), Dr. Gordon O'Brien and Angelica Kaiser (Fish), Ms. Vuyisile Dlamini (Ecosystem Services) and Mr. Hanro Pearson and Herman Le Roux (Water Quality and Ecotoxicology).

Also documented is the parallel groundwater monitoring survey led by Dr. Manuel Magombeyi (IWMI) together with Dr. Eddie Riddell -Water Resources & Mr Robin Petersen - Freshwater Ecologist and Jacques Venter (South African National Parks) and Rion Lerm (South African Environmental Observation Network (SAEON).

Note that details of the Driver field survey are contained within the Driver report.

2.4.1 Riparian vegetation

In situ data collection was conducted with the use of cross-section transects perpendicular to flow. Cross-section locations were determined by on-site geomorphologist and riparian vegetation specialists. As far as possible, sites were placed across single or less complicated channels, perpendicular to flow and included vegetation species that represented flow-dependant community compositions (woody and non-woody).

Data collected along cross-section transects were assessed within a 1m2 area from the base of the staff as a standard and included both biotic and abiotic data. Biotic data was vegetation-related and abiotic data included substrate, geomorphic feature, hydraulics, hydrology, water chemistry, ecotoxicology and elevation.

Cross-sections were surveyed using a Leica TCR403 Power total station (FIGURE 5.1). Intervals of recorded points along transects depended upon the variation of topography and vegetation composition along transects. During the setup process, permanent markers (benchmarks) were created in order to ensure future replication of transects. Benchmarks were created in the form of steel pegs inserted into the ground, pegs inserted into the base of large trees or drilled markers on large boulders, bedrock or infrastructure. The purpose of the benchmarks was to allow for the linking of future cross-section profiles to this study. In some cases, sites had been previously surveyed, therefore existing benchmarks were utilized in order to link historical cross-section data to transects surveyed during this study.

At each site the riparian vegetation and riparian habitats were described, species lists compiled and the ecological status assessed using VEGRAI (vegetation response assessment index) which is a tool that was designed to rapidly evaluate the ecological status of riparian vegetation at any riparian site (Kleynhans et al., 2007). It requires an understanding of the reference (natural) condition against which change of vegetation structure, composition and distribution are measured. The deviation from the natural condition, in which no anthropogenic impacts occur, is expressed as a percentage score commonly referred to as the present ecological state (PES) and can be categorised into meaningful management units (A-F). The PES score itself may be used as a monitoring metric to assess whether overall ecological health changes over time but is specifically intended to derive a current measure of ecological condition in the riparian zone. In order to determine the e-flows individual plants of riparian indicator species were surveyed, together with a transect profile, and geomorphic feature and substrate preferences. This will enable the determination of the hydraulic niche for each species in combination with geomorphic and substrate preferences. Once these habitat preferences are described and empirically defined the flow requirement can be determined and used within modelling frameworks for management and scenario evaluation.

2.4.2 Aquatic Macroinvertebrates

Abiotic and biotic data were collected at fourteen sites in the Limpopo and Olifants Rivers, and some of their major tributaries. This summary presents sampling methods applied.

In each biotope selected for sampling, and area of 40 cm x 40 cm were sampled. With the stones in current and gravel in current biotopes, a surber sampler with dimensions of 40 cm x 40 cm and mesh size of 500 µm2 were used. In the vegetation and gravel-sand-mud biotopes, and area of 40 cm x 40 cm was demarcated and sampled with a standard SASS-net (30 cm x 30 cm, mesh size 1mm2).

In the stones biotopes, coarser gravel (15 – 64 mm), cobble (64 – 254 mm) and boulders (>254 mm) were measured with a standard 30 cm ruler. Only substrate loosely arranged on the riverbed were measured. Three angles of individual substrates (boulders, cobble, coarse gravel) were measured.

Velocity and depth measurements were carried out with an OTT MF pro at each biotope sampled. The handheld OTT MF pro unit's sensor uses a magnetic-inductive current to accurately determine stream velocity. Depth in meters is measured first, after which velocity (m/s) measurements are taken at a depth of 20%, 60% and 80% below the water surface.

Substrate composition was calculated from the number of measured gravel-cobble-boulder substrates, and sand-fine gravel substrate was estimated. The abundance of algae at each biotope was visually estimated. In the marginal vegetation biotope, plant species were identified where possible, and abundance rated from 1 to 5, with 1 being rare and 5 very abundant.

The snail abundance and density were also analysed in the survey by sampling randomly within the site area, using a standard aluminium sieve. Snails were preserved in ethanol to be identified, measured, and counted. Snail parasite infection was investigated by collecting at least 100 individuals per species if possible. Individual snails were exposed to a light source for one hour and screened for the presence of cercariae under a stereomicroscope for three consecutive days, whereafter they were dissected and examined for trematode infections.

2.4.3 Fish

Fish community structures were evaluated at all sites surveys in the upper Limpopo catchment. All sites had water and or at least refuge pools where fish were sampled. Sampling methods selected to samples fish were appropriate to the type of habitat being evaluated. Deep habitats were sampled using active seine (drag) nets, and cast nets and passive fyke nets (only in the main stem where time allowed). All wadable habitats were sampled using electrofishers (generator set up and Samus) and running (6m) seines. All fish were collected using fine mesh landing nets and kept alive in buckets and keep nets/traps in situ. Fish collected were identified to species, measured and released back into the river where they had been collected. Due to the pioneering nature of this survey, voucher fish samples were collected for each species per main segment of the catchment. Additional genetic samples and voucher photographs were collected. During the survey > 6000 fish were processed representing >37 species. Diversity and abundances of fishes varied throughout the basin and preliminary findings suggest that the reaches of the main stem Limpopo River and larger tributaries that are seasonal and or have been exposed to recent floods included highly mobile adults who have migrated into these reaches. The data demonstrates the importance of perennial tributaries and links between these tributaries and the mainstem. The population, community and movement information collected during the survey is suitable to meet the objectives of the fish part of the study for these sites including:

- determine the present ecological state of fish communities,
- evaluate the flow, quality and habitat drivers of fish communities, and
- characterise environmental preferences of fishes to contribute to the risk assessment for e-flow determination in the study.

2.4.4 Ecosystem services

The Limpopo River provides a wide range of ecosystem services which include supporting services, provisioning services, regulating services, and cultural services (Table 2.3). Ecosystem services are the benefits provided to people, both directly and indirectly, by ecosystems and biodiversity. This includes human use of products from the river e.g medicinal plants, food products, etc. and the functions ecosystems perform that are used and valued by human societies, such as the provision of clean water. Such services are linked to the functionality of ecosystem processes in terms of achieving the environmental objectives of river basins. The Limpopo Basin provide cultural, regulating, and supporting services that contribute directly and indirectly to recreation, aesthetics values of the catchment and maintenance of fisheries. The water resources of the Limpopo Basin, also plays a role in sustaining freshwater-dependent ecosystems e.g riparian zone which provide services to local communities for reed grass.

TABLE 2.3 SUMMARY OF THE REVIEW OF ECOSYSTEM SERVICES EVALUATED DURING THE SURVEY.

Site	Ecosystem services observed
CROC-A24J-ROOIK	Site is upstream associated with a number of commercial farms. The main ecosystem services are provisioning (water for irrigation in the farms for vegetables and cash crops, water supply to municipality and communities). Supporting services are also important for the life cycle of many fish species in the river which depend on the natural variability in the river flow.
LIMP-A41D-SPANW	A number of commercial farms are found around this site and most with instream irrigation pump houses. Some parts of this site are used for cultural and spiritual rituals. Flow is regarded as an important attribute in this site for water supply to the farms and for the cultural rituals as some rituals only take place at high flow.
MATL-A41D-WDRAAI	The main ecosystem service in this site is commercial irrigated agriculture mainly for cash crops which prefer dry conditions e.g. tobacco and beans. The farms are allocated about 200l/sec to irrigate 120 ha. Subsistence fishing is also an important ecosystem service in this part of the catchment .
LIMP-A36C-LIMPK	The site is situated within the Limpokwena nature reserve and the main ecosystem services are the aesthetics services from ecotourism and provisioning of water for farm irrigation within the reserve
MOGA-A36D-LIMPK	The Mogalakwena River system was identified as a floodplain system, which is attributed for fishing, farming services and enhancement of water quality with the removal of phosphates as well as by removing nitrates and toxicants. The water is also used for household and small hold agriculture.

Site	Ecosystem services observed
LIMP-A71L-MAPUN	This site is within the Mapungupwe Transfrontier park shared by Zimbabwe, and South Africa. In South Africa, the main ecosystem services are the maintenance and refugee for fish as a variety of fish species depends on the natural variability in river flows in this site and maintaining the site for aesthetics(tourism). However, this site has competing ecosystem services demands as the rural villages in Zimbabwe also derive provisioning ecosystem services which include water for domestic use, fishing and practise spiritual baptism.
SAND-A71K-R508B	The site is downstream of the Musina town. This is an important part of the catchment that supports the population from Musina for water provisioning, fishing and agriculture. Community members fish a number of species in this site which includes Tilapia, Carp and Tigerfish. Further downstream of this site, subsistence and commercial irrigation farming (tomatoes, beans) in downstream villages(Masisi) is common. Fresh produce shops around the Masisi village rely on groundwater (adverts for groundwater drilling). Cultural and spiritual ecosystem services were observed in this part of the catchment as burnt candles from these rituals were observed. This site is also used to harvest medicinal plants.
LUVU-A91K-OUTP	The site is within the Kruger National Park, the flow regime at this site is important to maintain the site's aesthetics which is an important feature for the Outpost Lodge tourists. It also supports the delivery of a range of different provisioning services such as clean water and supporting services which is maintaining aquatic plants and fish habitats within the Kruger park
SHIN-B90H-POACH	The site is within the Kruger National Park, so it is most important for tourists' attraction (aesthetics) as it is along a tourist road to camping sites. The site also supports fish diversity.
LETA-B83E-KNPBR	The site is within the Kruger National Park, site is upstream of villages and commercial farms. The main ecosystem services in this part of the catchment is the maintenance of the area' aesthetics and provision of irrigation water downstream.
LETA-B83A-LONEB	Site within the Kruger National Park close to the Lonely Bull Trail which starts from Mopani Rest Camp and is conducted in the large wilderness area between the Letaba low water bridge and the Mingerhout dam along the Letaba River. The site is important for maintenance of the area's aesthetics for eco-tourism.
OLIF-B73H-BALUL	Site is within Balule nature reserve, the main ecosystem service in this site is maintenance of the area's aesthetics for tourists' attraction, maintenance and supporting of river' riparian zones and instream biodiversity.

Site	Ecosystem services observed
OLIF-B73C-MAMBA	Site is at Mamba Kruger national park and the main ecosystem services are to support and maintain the ecosystem for conservation and aesthetics for tourist attraction.
GLET-B81J-LRANC	Site is in the Groot-Letaba River, upstream of the Kruger National park. This site is downstream of Seloane community which use the river for fishing, abstract commercial and subsistence agriculture irrigation water. The riparian vegetation is over-utilised, mainly for firewood, fence construction, furniture, medicinal purposes and food.
LIMP-Y30F-CHOKWE	In this part of the catchment, the river's flow is mostly important for crop irrigation. This site is within a community who fish, fetch water and practise subsistence farming. This site is in the lowest part of the Limpopo Basin, which means it is a sink region. Very close to the site most communities wash their cars and tents. This was very common around riffles areas.
ELE-730C-SINGU	At this site, communities were mostly rural and mostly used the river to collect water and wash their clothes. Flood plain subsistence farming was also common and use of riparian woody plants to fence their crops from cattle. The site is also prominent for spiritual and cultural baptisms
SHAS-Y20B-TULIB	The site is also within a rural community. The river is mostly used to irrigate their household gardens and water for their households. Cultural and spiritual baptism was also most prominent around pool areas. Some community members harvest some trees for medicinal purposes and for household firewood. Livestock riparian grazing (goats and cattle) was most common around this site and around the flood plains. In areas where the flow is low, communities created depression holes around the floods plains for their livestock to get drinking water.
UMZI-Y20C-BEITB	This site was close to rural communities which use the riparian zone to irrigate their subsistence farming and graze their livestock around the riparian zone (cattle, donkey). This site also has an off-stream cattle dipping area. The bulk of the population of the catchment is resource-poor smallholder farmers. These farmers live at the margins of economically sustainable agriculture.

RESPONSE OF THE ECOSYSTEM TO DRIVERS OF CHANGE

3 FISH

Contributors: Angelica Kaiser, Gordon O'Brien

3.1 INTRODUCTION

Anthropogenic activities, climate change, land transformation, unsuitable and unsuccessful law enforcement of biodiversity and natural habitats are degrading river systems (Allan et al. 2005; Ashton 2007, 2010; Dudgeon et al. 2006; Vaughn 2010). The loss of biodiversity and ecosystem functionality reduces the ability of aquatic ecosystems to provide the essential ecosystem services human communities rely on (Daily 2000; Deksissa, Ashton and Vanrolleghem 2003; Hooper et al. 2005; Loreau et al. 2001; Vaughn 2010). The threat to human water security and biodiversity are well correlated (Vörösmarty et al. 2010), thus it is important to find a balance between human use and ecosystem protection (Nel et al. 2007).

There is a trade-off between the protection of river ecosystems and the use of the ecosystem services that they provide. Monitoring aquatic ecosystems is one of the tools used in their protection, as it allows for environmental degradation to be detected and measured (Levin, Woodford and Snow 2019). It is thus important to monitor river systems to ensure that a healthy ecosystem is maintained (Rodríguez et al. 2006). Three approaches can be used to monitor ecosystem health: 1) Biotic and abiotic indicators, 2) measuring ecosystem resilience to understand its capacity to change, 3) the identification and management of risk variables to mitigate threats to ecosystem health (Ganasan and Hughes 1998; Karr 1991; Rapport 1989). The preferred approach is using indicators (physical, chemical or biological) to monitor ecosystem health (Rapport 1989). Chemical indicators have limitations in that it does not account for anthropogenic-induced changes such as habitat loss (Whitfield and Elliott 2002b). Physical indicators, on the other hand, do not take into consideration chemical changes that are likely to have a negative impact on the river system's biota. Biological monitoring is the preferred method because anthropogenic-induced changes both physical and chemical can be detected. After all, organisms respond to changes (Rapport 1989).

The community structures and attributes of fishes have widely been used as ecological indicators in the assessment of the integrity of Riverine ecosystems (Kleynhans 1999; Kotze 2002; O'Brien 2013). Some of the benefits of using fish as ecological indicators are primarily due to their wide swimming ability, various trophic levels, long lifespan, convenient sampling, identification in the field, and high public awareness value (Whitfield and Elliott 2002b). In particular, the use of various assessment methodologies including community metric measures (biological indices) and established community structure assessment methodologies that are based on the attributes of fishes are widely incorporated in the management of local and international freshwater ecosystems (Karr 1981; Kleynhans 1999; Kotze 2002).

The first fish-based biological index (The index of Biotic Integrity (IBI)) was developed in the United States of America in 1981 (Karr 1981; Simon 1998). This index uses fish assemblages to evaluate the water environment which reflects the physical (habitat), chemical and biological conditions of aquatic ecosystems (Karr 1981). Indices developed for developed countries cannot be used for rivers in developing countries like Africa because the objectives of the indices fail due to unforeseen impacts associated with developing countries (Hocutt et al. 1994; Hocutt, Bally and Stauffer 1992). For example, in developing countries, many local communities depend on rivers for food and water but growing industries are deteriorating water quality and quantity in these river systems (Hocutt et al. 1994). Additional problems of the IBI in Africa is that it requires historical and ecological data which are not always available (Hocutt et al. 1994; Kleynhans 1999), and the equipment and running costs are too expensive (Kleynhans 1999). This led to the development of the Fish Assemblage Integrity Index (FAII) with the purpose "to measure biological integrity of a river-based on attributes of the fish assemblage's native to the river". It is the assessment of fish communities to changing environmental conditions either through direct measurements or inferred from the availability and condition of habitat at each site (Kleynhans 2007). In 2007, FAII was updated to the Fish Response Assessment Index (FRAI) which was developed to strengthen the relationship between cause and effect (Kleynhans and Louw 2007).

The limitations of FRAI is that it is a rapid assessment, the tolerances and preferences are opinions based (expert opinions and inferred knowledge), the impact of alien and extra-limital freshwater fish species are only negative (habitat and predacious behaviour) and are not recognised for their potential of being good indicators of ecosystem health (Kennard et al. 2005; Molony 2001). To establish clear cause and effect relationships between stressors entering and impacting the ecosystem, however, the use of a community metric measure in isolation is limited and more in-depth assessments such as the use of multivariate statistical assessment methods are recommended (O'Brien and Wepener 2012). A Redundancy Analysis ordination technique (RDA) allows for the direct interpretation of the community structures of fish in terms of the taxa obtained during detailed surveys. Furthermore, when combined with Monte Carlo permutation testing, the statistical significance of the hypothesised differences in the community structure can be tested (Van den Brink et al. 2003). This approach allows the habitat drivers of change in fish community structures of riverine ecosystems to be statistically evaluated. The use of multiple validated lines of evidence (LoE) to evaluate the wellbeing of the ecosystem is considered the best scientific practice as it provides a greater level of certainty. Each LoE is perhaps not completely robust by itself but when integrated with other lines of evidence, the uncertainty of the outcomes are generally reduced.

The Limpopo River Basin is one of the most important basins in southern Africa and is known for its rich biodiversity (genes, species and ecosystems), a wide variety of landscapes and people and contains several centres of endemism (Petrie et al. 2014). Unfortunately, the basin is also one of the most water-stressed river basins in sub-Saharan Africa (Ashton and Dabrowski 2011; Baker and Greenfield 2019; Dabrowski et al. 2015; Kemp et al. 2014, 2016; Malakane 2019; Marr, Mohlala and Swemmer 2017; Matlou, Addo-Bediako and Jooste 2017; Pollard and Retief 2017; Rasifudi et al. 2018; Riddell et al. 2019; de Villiers and Mkwelo 2009). The vulnerability of the Limpopo River Basin is that it is mostly semi-arid, with a highly variable climate and is periodically exposed to severe droughts and floods. The basin is diversified in its land-use patterns, ecosystems, social, economic and governance systems. The water resources have been over-subscribed, agriculture is dependent on rainfed water, livelihoods are based on climate-sensitive natural resources, half of the population is poor and live in rural conditions and there are insufficient public and private resources to deal with poverty and shocks (resources shortage and climate change risks)(Petrie et al. 2014; Trambauer et al. 2014; Zhu and Ringler 2012). The political fragmented nature of the Limpopo basin has pushed biologists away from working in the basin (Van der Waal and Bills 2000).

O'Brien (2013) was the first study to consider fish on a regional scale in the Limpopo River Basin. This study conducted an FRAII assessment, used multivariate statistical techniques to investigate the fish community structure and conducted a fish flow habitat assessment index (FFHA) with available hydrology and hydraulic data. The results of the study showed that the fish communities are in a moderately modified ecological state which could be due to the drought experienced in the year of sampling (O'Brien 2013). The absence of fish species tolerant to low flows and altered water quality suggest that this system is heavily impacted by anthropogenic activities (O'Brien 2013). As there is a large understanding of how anthropogenic changes/environmental changes affect the basin we will get a better understanding of how to flow and non-flow related variables to affect the basin and the fishes within. Deteriorating water quality, altered flows, and habitat destruction have been identified as drivers of change for fish communities (O'Brien 2013). Invasive species and climate change have also been identified as drivers of change (Rankoana 2016).

This study aimed to determine the overall state of fish communities in the Limpopo River Basin. The multiple LoE used in this study included Fish Response Assessment Index (FRAI) (Kleynhans and Louw 2007) and Multivariate statistics (Redundancy Analysis). The multivariate analysis was used to validate the FRAI results and to provide insight into what the main drivers of change were.

3.2 METHODOLOGY

3.2.1 ETHICS

The project and procedures were sanctioned by the ethical committee of both SANParks (ref: 012/16) and the University of Mpumalanga Animal Science Research Ethics Committee (project number NAS044/2019).

3.2.2 STUDY AREA

Eighteen sites were selected in the Limpopo River Basin (FIGURE 3.1). The sites were selected based on historical data available (EWR studies conducted at the site previously), sites on the tributaries and the Limpopo River main stem, sites in Botswana, Mozambique and Zimbabwe, and to include sampling in protected areas (Kruger National Park, Mapungubwe National Park, Greater Limpopo Trans frontier Park. Each site was divided into different efforts based on the habitat and velocity depth classes (**TABLE 3.1**) as proposed by Kleynhans et al. (2007).

FIGURE 3.1: PHOTOS OF THE DIFFERENT SITES THE ORDER FROM TOP LEFT CONNER IS CROC-A24J-ROOIK, LIMP-A41D-SPANW, MATL-A41D-WDRAAI, LEPH-A50H-SEEKO, LIMP-A36C-LIMPK, MOGA-A36D-LIMPK, LIMP-A71-MAPUN, SAND-A71K-R508B, LUVU-A91K-OUTP, OLIF-B73C-MAMBA, OLIF-B73H-BALUL, GLET-B81J-LRANC, LETA-B83A-LONEB, ELE-730C-SINGU, SHIN-B90H-POACH, LIMP-Y30F-CHOKWE.

3.2.3 FISH SAMPLING

Fish communities were sampled at the different sampling sites in the Limpopo River Basin in May and June of 2021. There was no available water at the UMZI-Y20C-BEITB site and thus no fish community data were collected. Historical data from 2012 were used to fill in any gaps in available data. Fish communities were sampled using various active (cast net, running seine net, electro-fisher, generator, angling techniques) and passive (fyke nets) sampling methods based on different habitats available (Oliveira et al. 2014). The diversity, abundances, and size (standard length) of sampled fish were documented as catch per unit effort along with the associated habitat variability. This included three depths (mm) and velocities (m/s) measurements per unit effort measured with a transparent velocity head rod (TVHR: Ground truth Consulting, Hilton KwaZulu Natal), the substrate distributions (%) (percentage silt, mud, and, gravel, cobble, boulders, bedrock) were estimated per unit effort based on the classification of Fouché (2009) and Rowntree et al. (2000)(TABLE 3.2), and cover types were identified (undercut bank, substrate, depth, marginal vegetation, aquatic vegetation, overhanging vegetation, roots, other) and their extent estimated and scored as adapted from Fouché (2009) and Kleynhans (2007)(TABLE 3.3).

TABLE 3.1: HABITAT CLASSIFICATION BASED ON VELOCITY-DEPTH CLASSES PROPOSED BY KLEYNHANS ET AL. (2007)

Flow-Depth Class	Velocity (m/s)	Depth(m)
Slow-deep (SD)	Less than 0.3	0.5 and deeper
Fast- deep (FD)	0.3 and above	0.5 and deeper
Slow-shallow (SS)	Less than 0.3	Less than 0.5
Fast-Shallow (FS)	0.3 and above	Less than 0.5

TABLE 3.2: SUBSTRATE CLASSIFICATION ADAPTED FROM ROWNTREE AND WADESON (2000)

Substrate class	Size (mm)	Practical description (used in the field)
Silt and clay	<0.06	Powdery or soapy, grains not visible
Sand	0.06-2	Individual grains visible
Gravel	2-64	From thumb to the size of an adult fist
Cobbles	64-256	From a fist to smaller than an adult head
Boulder	>256	Larger than an adult head
Bedrock	N/A	

TABLE 3.3: COVER TYPE RATES ADAPTED FROM KLEYNHANS (2007).

Descriptor	Relative ecological value/ abundance score	Occurrence (% of the area covered)
None	0	0
Rare	1	0-5
Sparse	2	6-25
Common/Moderate	3	25-75
Abundant	4	75-90
Very abundant	5	90-100

3.2.4 FISH WATER QUALITY

At each site, the surfaces water samples were collected from the water column with 1L polypropylene (PP) bottle as described by Musselman (2012). These samples were analysed at Northwest University. The constituents included calcium (Ca), chloride (Cl-), potassium (K), magnesium (Mg+), sodium (Na), ammonium nitrogen (NH4+- N), nitrate-nitrogen/nitrite nitrogen (NO3- -N/ NO2- -N), orthophosphate (PO43-) and sulphates (SO42-) and chlorophyll a. Physiochemical water quality variables including temperature (°C), pH, dissolved oxygen (mg/L), oxygen saturation (%) and electrical conductivity (µS/cm2) were measured in situ at each sampling site in the different sites. The measurements were taken using an Extech DO610 Exstik Ii Dissolved oxygen, pH and conductivity kit.

3.3 THE ECOLOGICAL WELLBEING OF THE FISH IN THE LIMPOPO RIVER BASIN

The present ecological state of the Limpopo River Basin was determined through the fish response assessment index (FRAI) I and II (Kleynhans 2007). The DWS has developed the FRAI approach which is a multiple-criteria decision analyses model in Microsoft®(Kleynhans 2007; Kleynhans and Louw 2007). The eight-step process of the FRAI methodology was used to obtain a modelled and adjust FRAI scores (FRAI I), the target and scenario FRAI scores (FRAI II), score each metric, and asses which altered driver component contributed to the ecological state obtained at each site.

Multivariate statistical procedures (Redundancy Analysis ordination technique (Ter Braak and Šmilauer 2002) were used to evaluate the shifts in community structure(Van den Brink, Van den Brink and Ter Braak 2003; O’Brien, Swemmer and Wepener 2009). The direct correlation of changes in fish community structures in terms of taxa obtained during surveys can be interpreted and combined with Monte Carlo permutation testing to see if there are a statistical significance between the relationship of community structures and environmental variables (Van den Brink, Van den Brink and Ter Braak 2003; O’Brien, Swemmer and Wepener 2009). Fish sampled data and species ordination were overlain with environmental variables to determine the drivers of shift in the fish community structures of the Limpopo River basin.

3.3.1 STATISTICS

In this study direct or constrained analyses were undertaken which involves overlaying captured variance of the explanatory environmental variables onto fish sample and taxa ordination diagrams. The linear response mode used to achieve this is a redundancy analysis (RDA), a derivative of principle component analyses (PCA) using the Canoco version 4.5 software package (Ter Braak, 1994). Data sets used in this assessment is the same fish data from 16 sites collected during April to June 2021 survey. Because abundance data were available, the data were transformed using a Log X+2 - transformation (Van den Brink et al., 2003).

3.4 RESULTS

3.4.1 Fish communities

During the survey from April to July 2021, 134 sampling efforts were carried out which resulted in the collection of 6387 fish from the 17 sites selected for the study (TABLE 3.4). There was no available water at the UMZI-Y20C-BEITB site and thus no fish community data were collected. Thirty-seven of the expected 77 different species were collected during the survey. LIMP-A41D-SPANW was the site with the highest abundance of fish (total: 2125) and SHAS-Y20B-TULIB was the site with the lowest abundance of fish (total: 50). LIMP-A63C-LIMPK was the site with the highest diversity of fish species (20 fish species) followed by LEPH-A50H-SEEKO, LIMP-A71L-MAPUN and OLIF-B73C-MAMBA with 18 different fish species at each of these sites. SHAS-Y20B-TULIB (3 fish species) and ELEP-Y30C-SINGU (6 fish species) had the lowest diversity of fish present.

Oreochromis mossambicus (16 sites), Clarias gariepinus (14 sites), Chiloglanis paratus (11 sites), Enteromius trimaculatus (11 sites), Labeo molybdinus (11 sites), Labeo cylindricus (10 sites) were collected at most of the sites. Chiloglanis paratus (n=2198), O. mossambicus (n=991), Micralestes acutidens (n=836), and L. molybdinus (n=536) were the most abundant fish species caught during the survey. Chetia flaviventris (n=1), Enteromius bifrenatus (n=1), Chiloglanis swierstrai (n=1), and Carnax herberi (n=1) were the least abundant fish species caught.

The proximity of LIMP-Y30F-CHOKW to its river mouth and estuary led to the detection of species associated with these habitats namely, C. herberi and Hippichthys spp and Glossogobius giuris. Glossogobius giuris were also collected at ELEP-Y30C-SINGU, LETA-B83A-LONEB, LIMP-A71L-MAPUN, LUVU-A91K-OUTPO, SHIN-B90H-POACH.

The invasive species caught were Gambusia affinis (3 sites, n=17), and Cyprinus carpio (2 sites, n=1). Possible O. mossambicus and Oreochromis niloticus hybrids were also recorded at 10 of the sites. No catchment scale migrators (Anguilla bengalensis, Anguilla mossambica) expected to be, were collected during the survey. Locals did mention catching Anguilid eels in the past. Oreochromis mossambicus was the only species with the IUCN category above least concerned that were sampled during the survey. Other species with a vulnerable (Enteromius motebensis), near threatened (Enteromius sp. 'Waterberg'), endangered (Enteromius treurensis, Serranochromis meridianus) and critically endangered (Kneria sp. 'South Africa') were not collected.

The FRAII scores obtained indicate that there is a noticeable and significant change in the community structure of the Limpopo River Basin (TABLE 3.5). The explanatory data obtained for each site showed that substrate, habitat cover features, and depth and velocity classes differed between sites

(TABLE 3.6). Over the study period, one site (MATL-A1D-WDRAAI) were in a class B/C, five sites were fair, moderately modified (Class C), seven sites were poor and largely modified (Class D), four sites were in a class C/D. The FRAI score obtained for LUVU-A91K-OUTP is most likely caused by sampling error, based on the minimal threats identified and the better fish community structure obtained with a later survey (September, Robin Peterson). During the present study, the main impacts that caused such low FRAI scores were but not limited to, barriers, water quality, altered flows and overexploitation. The sites closer to anthropogenic activities were in a poor state whereas sites within Kruger National Park had an improved present ecological status.

Overall, there was a significant difference (p=0.001; TABLE 3.4; Figure 104) between the fish community structures at the different sites. LIMP-A41D-SPANW (LIMPS; RDA test, F=11.12, p=0.001) differed the most between the sites. C. paratus, L. molybdinus, Labeobarbus marequensis were associated with this site. These species have a high preference for substrates. Micralestes acutidens were associated with MATL-A41D-WDRAAI (MATL; RDA test, F=4.78, p=0.002). These species have preferences for slow velocity and overhanging vegetation. Glossogobius giuris were associated with ELEP-Y30C-SINGU (ELEP, RDA test, F=3.20, p=0.02).

TABLE 3.4 DIVERSITY AND ABUNDANCE OF FISHES OBTAINED FROM SITES IN THE LIMPOPO CATCHMENT DURING THE 2021 SURVEY.

Species	CROC-A24J-ROOIK	LIMP-A41D-SPANW	MATL-A41D-WDRAAI	LEPH-A50H-SEEKO	LIMP-A63C-LIMPK	MOGA-A63D-LIMPK	SHAS-Y20B-TULIB	LIMP-A71L-MAPUN	SAND-A71K-R508B	LUVU-A91K-OUTPO	OLIF-B73C-MAMBA	OLIF-B73H-BALUL	GLET-B81J-LRANC	LETA-B83A-LONEB	ELEP-Y30C-SINGU	SHIN-B90H-POACH	LIMP-Y30F-CHOKW
BIMB				1	7			30						3			10
CCAR									2								
CGAR	1	14		2	3	34		8	20	6	2	6	4	15	10	48	1
CHER																	1
CPAR		1435	3	106	22	2		33		6	62	110	19	400			
TREN				11			12			5	3		1	5			
CSWI	1																
BFRI				3	1			30	23				7			19	
BANN			12		2			4			1		1			1	
BBIF					1												
BLIN			10			6											
BPAL	69	74	9		4	21			11		2						
BRAD				6												1	

Species	CROC-A24J-ROOIK	LIMP-A41D-SPANW	MATL-A41D-WDRAAI	LEPH-A50H-SEEKO	LIMP-A63C-LIMPK	MOGA-A63D-LIMPK	SHAS-Y20B-TULIB	LIMP-A71L-MAPUN	SAND-A71K-R508B	LUVU-A91K-OUTPO	OLIF-B73C-MAMBA	OLIF-B73H-BALUL	GLET-B81J-LRANC	LETA-B83A-LONEB	ELEP-Y30C-SINGU	SHIN-B90H-POACH	LIMP-Y30F-CHOKW
BMAT	2			1	1	4											
BPOL											5		19				
BTOP									2		7						
BTRI	3	23	20	22	12	8		3	42		24	30	25			3	
BUNI	2	8	3	5	2	1		5	1								
BVIV			3		3			1	4		119		18			2	
GAFF		1										2			14		
GGIU								1		7				1	67	15	2
HVIT														4			
LCON								1									8
LCYL	1	32	2	4	3					5	12	5	1	48		1	
BMAR	24	103	1	6	5						35	40	12	36			
LMOL	6	274	1	26	35			20	4		41	21	25	78		5	
LROS	1	72		53	8			6		1	17					6	
LRUD	7		5	3				1			12					10	
MACU		16	249	335	1			1		208					15		
MBRE	1				12			10					4				
OMOS	81	73	13	15	12	22	30	136	146	4	15	54	42	65	19	249	27
Pipefish																	3
PPHI	24		9	1		2	8		3		1						
CFLA								1									
SINT			3		5			2		3	1						
SZAM				5	1						2						
TSPA														4	1		
ABUNDANCE	223	2125	343	605	140	100		293	258	245	361	268	178	659	126	360	52
DIVERSITY	14	12	15	18	20	9		18	11	9	18	8	13	11	6	12	7

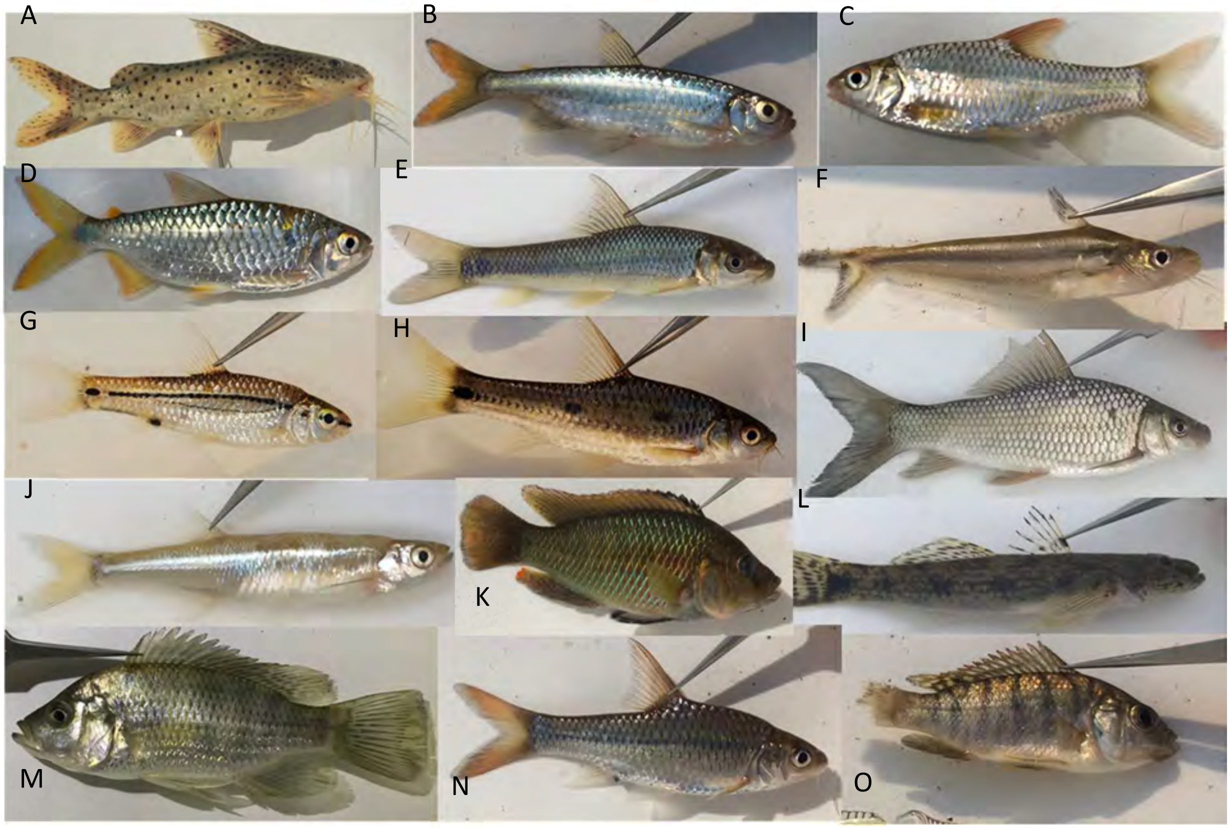


FIGURE 3.2: SOME OF THE DIFFERENT FISH SPECIES SAMPLED DURING THE SURVEY. A – SYNODONTIS ZAMBEZENSIS, B – MICRALESTES ACUTIDENS, C – LABEOBARBUS MAREQUENSIS, D – BRYCINUS IMBERI, E – LABEO MOLYBDINUS, F – SCHILBE INTERMEDIUS, G – ENTEROMIUS BIFRENATUS, H – ENTEROMIUS TRIMACULATUS, I – LABEO ROSAE, J – MESOBOLA BREVIANALS, K – PSEUDOCRENILABRUS PHILANDER, L – GLOSSOGOBIUS GIURIS, M – CHETIA FLAVIVENTRIS, N – ENTEROMIUS PALUDINOSUS, O – OREOCHROMIS MOSSAMBICUS.

TABLE 3.5: THE PRESENT ECOLOGICAL STATUS OF THE LIMPOPO RIVER BASIN DURING THE SURVEY OF 2021.

		CROC-A24J-ROOIK	LIMP-A41D-SPANW	MATL-A41D-WDRAAI	LEPH-A50H-SEEKO	LIMP-A63C-LIMPK	MOGA-A63D-LIMPK	SHAS-Y20B-TULIB	LIMP-A71L-MAPUN	SAND-A71K-R508B	LUVU-A91K-OUTPO	OLIF-B73C-MAMBA	OLIF-B73H-BALUL	GLET-B81J-LRANC	LETA-B83A-LONEB	ELEP-Y30C-SINGU	SHIN-B90H-POACH	LIMP-Y30F-CHOKW
Automated	FRAII I (%)	52.6	66.5	77.5	56.7	67.5	36.3	17.2	66	38.0	33.1	58	44.1	39.4	42.8	22.6	40.1	26.1
	FRAII I (Class)	D	C	B/C	D	C	E	F	C	D/E	E	C/D	D	D/E	D	E	D/E	E
Adjusted	FRAII I (%)	70.4	87.1	85.6	74.8	85.8	72.6	69.1	86	68.9	86.9	71.9	69.3	76.2	81.4	70.3	74.4	61.6
	FRAII I (Class)	C	B	B	C	B	C	C	B	C	B	C	C	C	B/C	C	C	C/D
Present	FRAII II (%)	58	70	81	56	57	48	55	62	59	62	62	69	49	61	48	45	73
	FRAII II (Class)	C/D	C	B/C	D	D	D	D	C/D	C/D	C	C	C	D	C/D	D	D	C

TABLE 3.6: SAMPLING EFFORTS, TYPE OF SAMPLING, SUBSTRATE TYPE, AND COVER FEATURES OF DIFFERENT HABITATS SAMPLED FOR FISH.

Site	Efforts	Angling	Electrofisher	Cast net	Fyke net	Gill	Generator	L Seine	SASS	S Seine	Visual obs.	Silt	Mud	Sand	Gravel	Cobble	Boulders	Bedrock	Other	Undercut bank	Roots	Substrate	Depth	Aveg	Mveg	Oveg	Other
CROC	10		1	1				1					18.0	64.0	18.0					1.0		1.3	3.9				
LIMPS	9		1			1						1.1	4.4	3.0	13.3	12.2	28.9	1.0		1.8	2.3	3.7	2.9		1.5	3.0	
MATL	4		1							1			12.5	52.5	23.8	8.8	2.5				2.3	1.7	2.7		2.0	1.5	1.5
LEPH	9		1	1			1			1				32.1			3.6	57.1	7.1			3.1	2.9				1.7
LIMPL	15	1	1		1		1							49.7	5.0	1.6	13.1	3.6				2.4	2.7				
MOGA	4		1											82.5	7.5		2.5	7.5				1.7	3.0			5.0	
SHAS	5		1							1				100									1	5			
LIMPM	11		1	1			1						1.8	88.2	1.0							3.0	3.5	2.0			
SAND	6		1									1.8		68.3	5.8	8.3	3.3	3.3				2.0	2.0	1.0	2.6	3.1	
LUVU	9						1						3.3	9.4	2.6	4.0	26.7			1.4		3.9	2.3	3.0		2.1	2.0
OLIFM	6	1	1	1									1.7	7.8	6.7	5.0	3.3	12.5				3.4	2.4		1.2		

Site	Efforts	Angling	Electrofisher	Cast net	Fyke net	Gill	Generator	L Seine	SASS	S Seine	Visual obs.	Silt	Mud	Sand	Gravel	Cobble	Boulders	Bedrock	Other	Undercut bank	Roots	Substrate	Depth	Aveg	Mveg	Oveg	Other
OLIFB	13	1	1	1					1			5.6		64.4	9.7	8.1	0.6	7.8	3.8			2.9	2.3		1.4		
GLET	6		1											48.3	36.7		8.3	6.7				2.4	2.6		3.4		
LETA	5	1	1									4.0	2.0	26.0	22.0	18.0	1.0			1.0		2.6	3.5		1.5		3.0
ELEP	6		1	1							1			1.0								1.0	1.7	4.0	3.6	5.0	
SHIN	8		1	1										45.6			17.8	36.7		3.9		3.1	3.8	1.4			
LIMPC	8		1	1						1			8.8	9.0	1.3							1.0	3.7		3.0		3.0

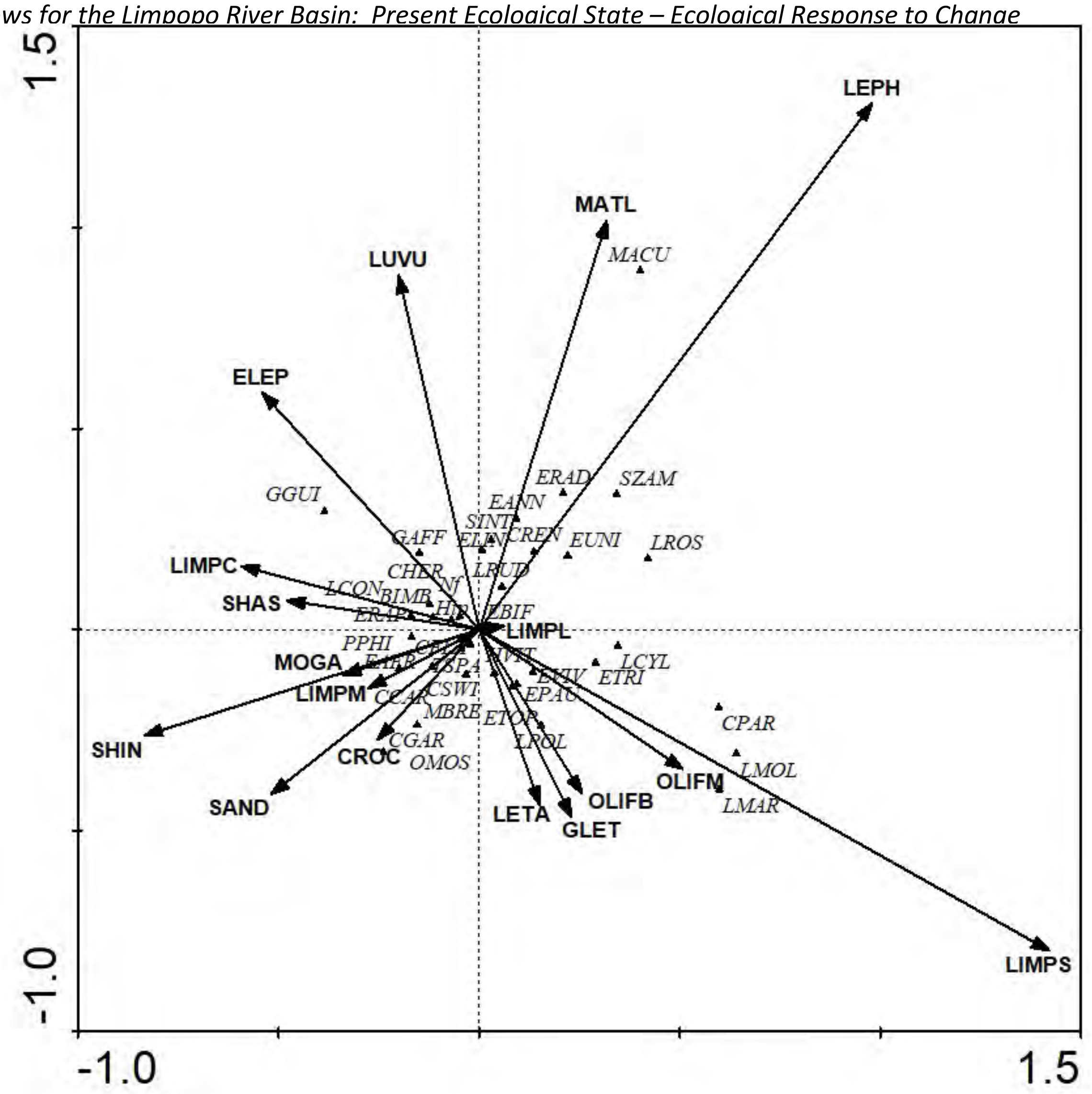


FIGURE 3.3: REDUNDANCY ANALYSES PLOTS SHOWING DISSIMILARITY BASED ON THE FISH COMMUNITIES AMONG SITES CONSIDERED IN THE STUDY, WITH SITES (ARROWS) AS ENVIRONMENTAL VARIABLES SUPERIMPOSED. THE TRI-PLOT DESCRIBES 54.4% OF THE VARIATION IN THE DATA WHERE 29.5% IS DISPLAYED ON THE FIRST AXIS(X) AND AN ADDITIONAL 24.9% ON THE SECOND AXIS (Y).

There was a significant difference (RDA test, p<0.001) between the fish community structure and the different velocity depth classes (Figure 105). The different velocity depth classes explained 98% of the variation seen in the fish community structure. Fast shallow (FS; p=0.001) and Slow shallow (SS; p=0.008) velocity depth classes were significantly different and accounted for most of the variation seen in the fish communities.

There was a significant difference between the fish community structure in relation to their preferences for different substrate types (Figure 106). The different substrate types explained 76.3% of the variation seen in the fish community structure. Of all the substrate types, sand accounted for the greatest variation in fish community structure (RDA test; F=5.91, p=0.001). Chiloglanis paratus, Labeo molybdinus, Labeo cylindricus and Labeobarbus marequensis were closely associated with cobbles, boulders and bedrock. Tilapia sparrmanii, Oreochromis mossambicus, Enteromius paludinosus and Carnax herberi were associated with mud. Enteromius trimaculatus were associated with gravel.

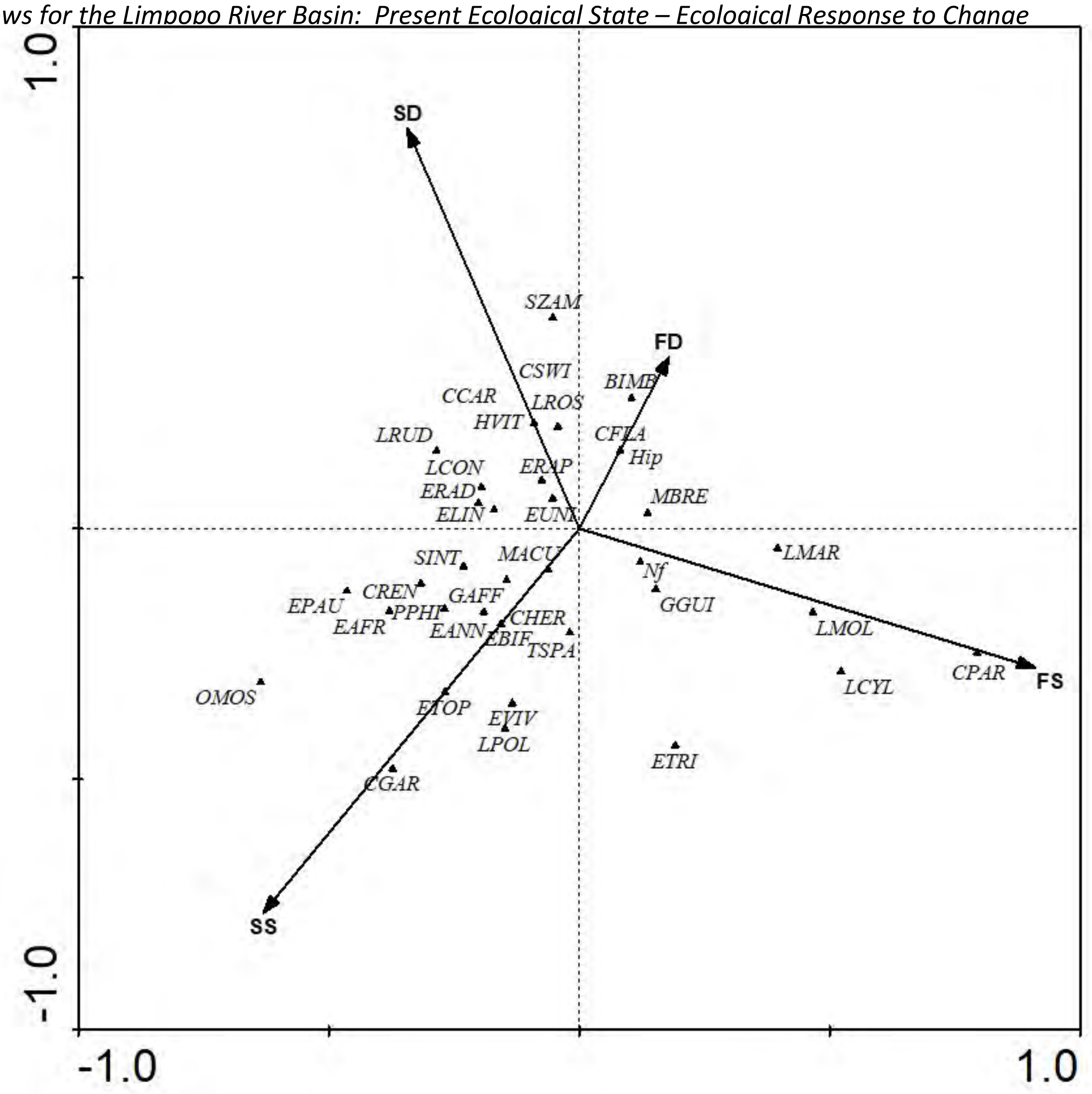


FIGURE 3.4: REDUNDANCY ANALYSES PLOTS SHOWING DISSIMILARITY BASED ON THE FISH COMMUNITIES AMONG SITES CONSIDERED IN THE STUDY, WITH VELOCITY-DEPTH CLASSES (ARROWS) AS ENVIRONMENTAL VARIABLES SUPERIMPOSED. THE TRI-PLOT DESCRIBES 98% OF THE VARIATION IN THE DATA WHERE 75.4% IS DISPLAYED ON THE FIRST AXIS (X) AND AN ADDITIONAL 22.6% ON THE SECOND AXIS (Y).

There was a significant difference between the fish community structure in relation to their preferences for different cover types (Figure 107). The different covers features explained 61.3 % of the variation seen in fish community structure. Of all cover features substrate accounted for the greatest variation in fish community structure (RDA test; F=6.97, p=0.001). Chiloglanis paratus, Labeo molybdinus, Labeo cylindricus were associated with the substrate as a cover feature. Enteromius annectens, Micralestes acutidens and Synodontis zambezensis were associated with roots and depth as cover features.

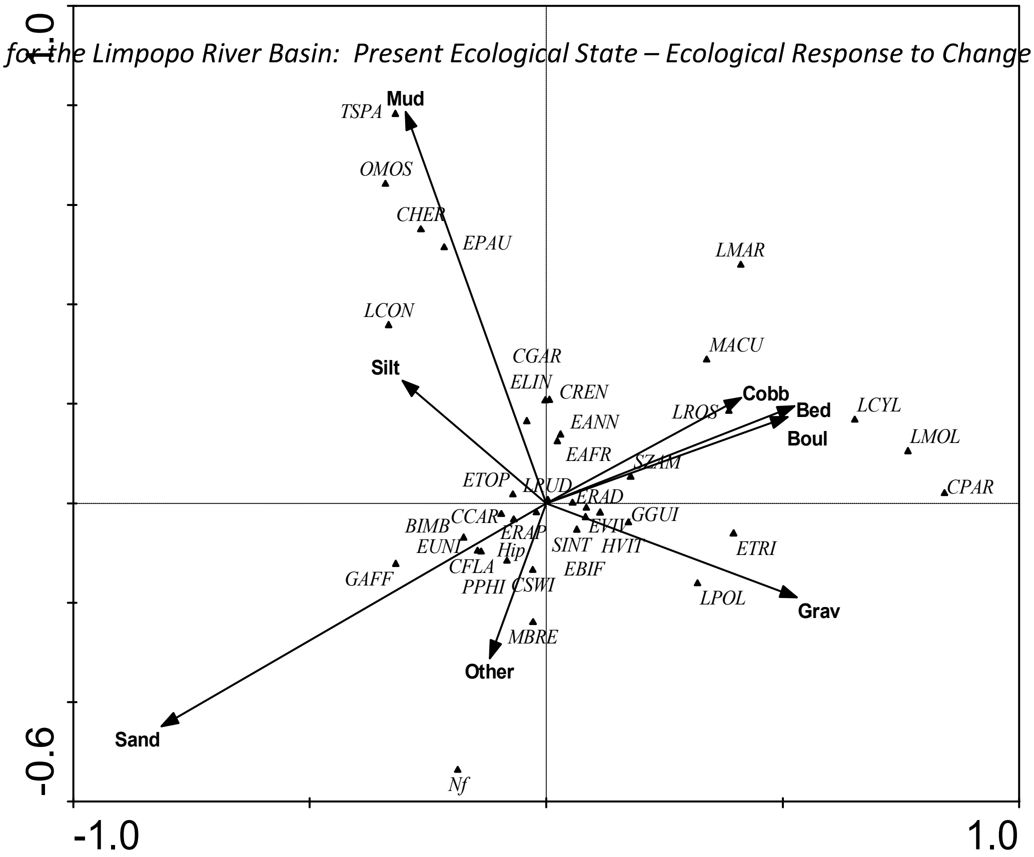


FIGURE 3.5: REDUNDANCY ANALYSES PLOTS SHOWING DISSIMILARITY BASED ON THE FISH COMMUNITIES AMONG SITES CONSIDERED IN THE STUDY, WITH DIFFERENT SUBSTRATES (ARROWS) AS ENVIRONMENTAL VARIABLES SUPERIMPOSED. THE TRI-PLOT DESCRIBES 76.3% OF THE VARIATION IN THE DATA WHERE 51.6% IS DISPLAYED ON THE FIRST AXIS (X) AND AN ADDITIONAL 24.4% ON THE SECOND AXIS (Y).

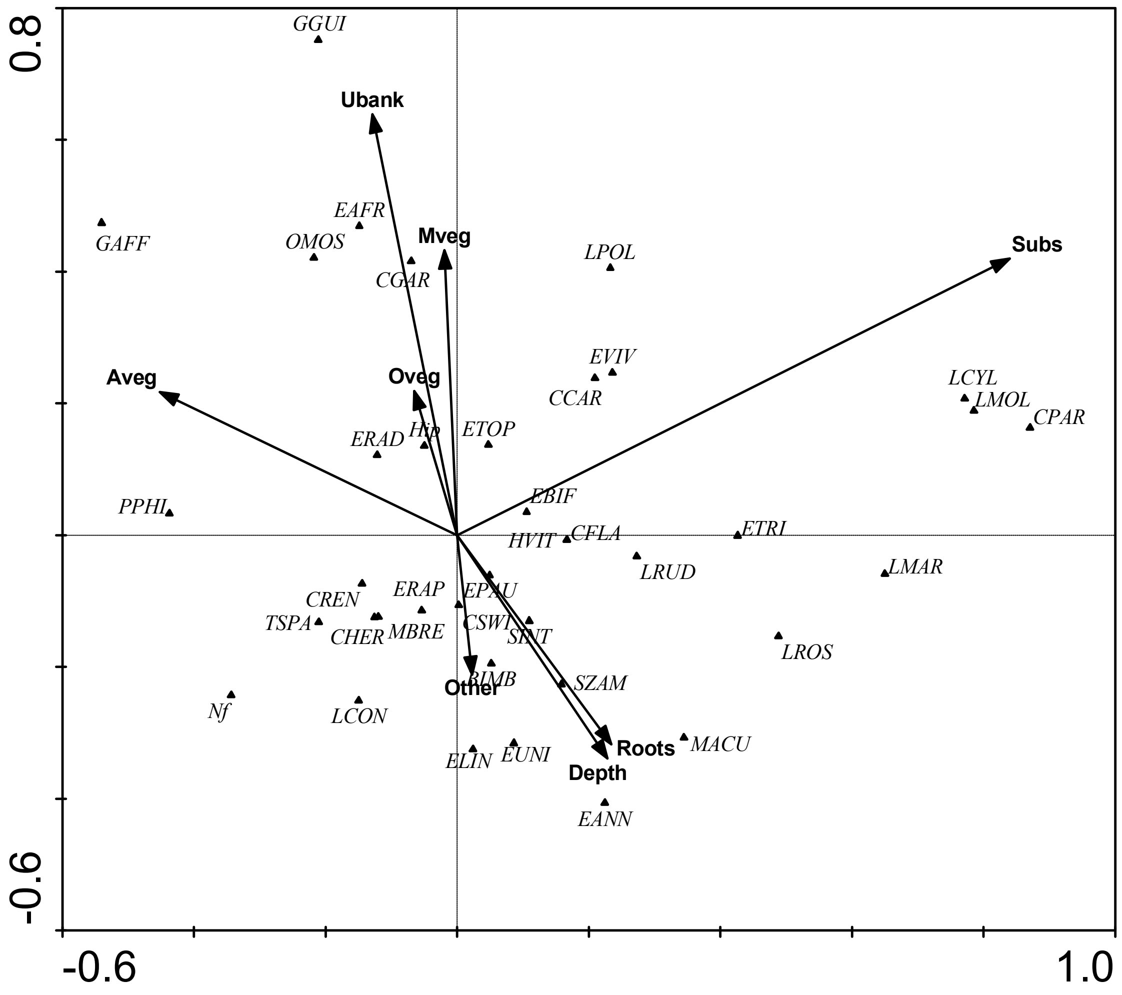
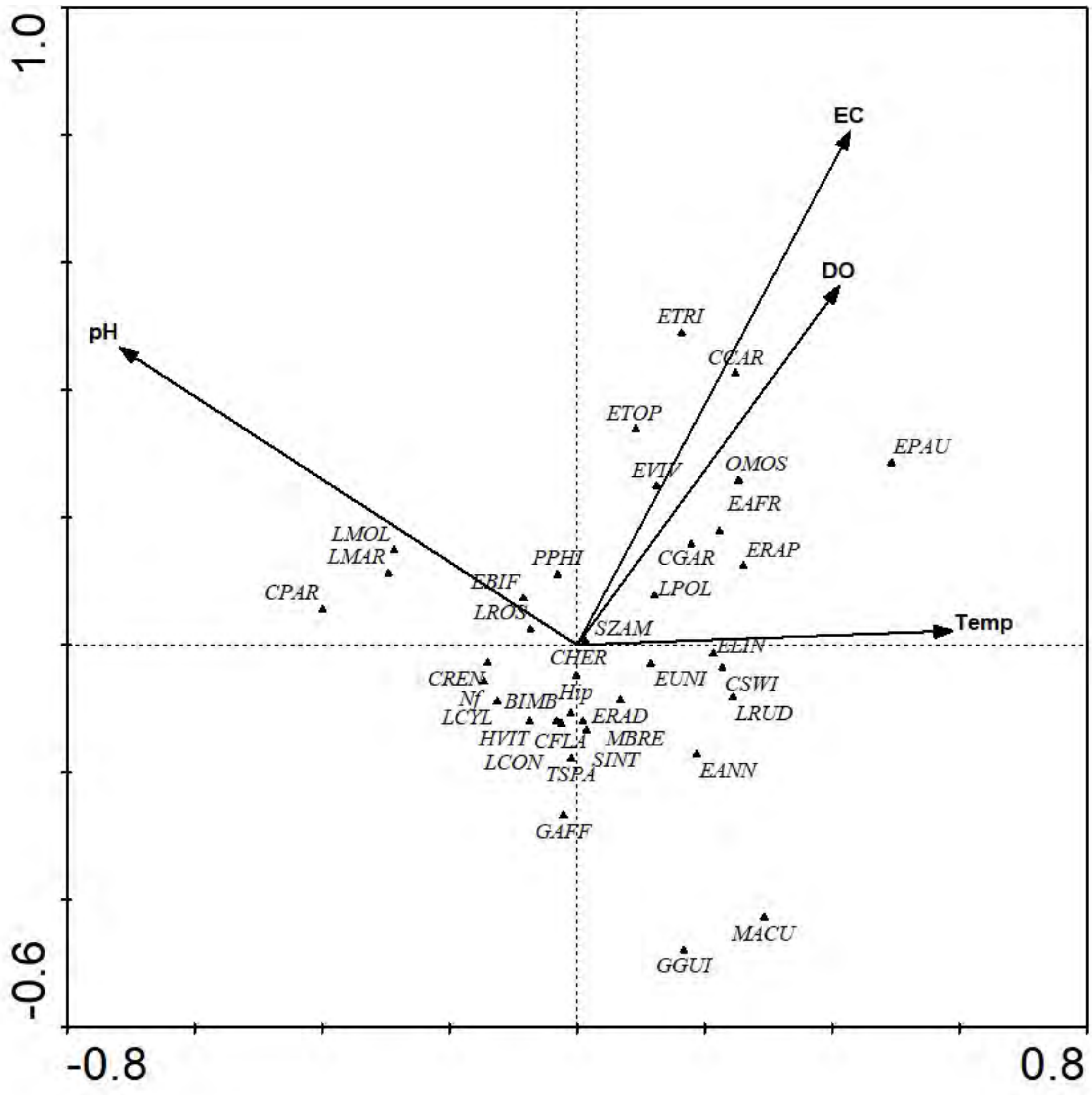


FIGURE 3.6: REDUNDANCY ANALYSES PLOTS SHOWING DISSIMILARITY BASED ON THE FISH COMMUNITIES CONSIDERED IN THE STUDY, WITH DIFFERENT COVER FEATURES (ARROWS) AS ENVIRONMENTAL VARIABLES SUPERIMPOSED. THE TRI-PLOT DESCRIBES 61.3% OF THE VARIATION IN THE DATA WHERE 45.7% IS DISPLAYED ON THE FIRST AXIS (X) AND AN ADDITIONAL 15.6% ON THE SECOND AXIS (Y).

The variation (77.9%; Figure 108) in water quality were found to be a significant influence on fish community structure (RDA test; p=0.001). Electrical conductivity accounted for most of the variation (RDA test, F=3.60,p=0.002). Chiloglanis paratus, Labeo molybdinus, Labeobarbus marequensis were



associated with lower pH values.

FIGURE 3.7: REDUNDANCY ANALYSES PLOTS SHOWING DISSIMILARITY BASED ON THE FISH COMMUNITIES CONSIDERED IN THE STUDY, WITH DIFFERENT WATER QUALITY PARAMETERS (ARROWS) AS ENVIRONMENTAL VARIABLES SUPERIMPOSED. THE TRI-PLOT DESCRIBES 77.9% OF THE VARIATION IN THE DATA WHERE 41.7% IS DISPLAYED ON THE FIRST AXIS (X) AND AN ADDITIONAL 36.2% ON THE SECOND AXIS (Y).

3.5 DISCUSSION

Of the expected 77 species only 37 species were collected during this survey (TABLE 3.4). The overall ecological integrity of the Limpopo River Basin is altered and ranges from a largely natural/moderately modified (Class B/C) state to a largely modified (Class D) state. These results can be attributed to the existence of water-related stressors, including altered flows, poor water quality, altered habitats and other stressors including alien invasive species and human disturbance to wildlife impacts. Multivariate statistics and FRAI scores were used to unpack the impacts and drivers of the fish community structure (Evans et al. 2021; O'Brien, Swemmer and Wepener 2009; Wepener et al. 2011). Knowledge of the drivers of these fish communities is required to sustainably use and protect the fish in the basin and the rivers that they occur in.

3.5.1 Fish communities

Thirty-seven fish species were captured from 17 sites sampling sites. Thirteen of these species were uncommon where less than ten individuals were observed per species. This study was not targeting specific threatened species but rather focused on the broad-scale understanding of fish community integrity across the Limpopo River Basin. Although attempts were made to collect a representative sample of all species by effectively sampling all available habitat types, the absence of some of the fishes from the assessment may reflect inadequate sampling effort. Species not captured were however likely rare, if not absent. In the present study G. affinis (sites = 3, n = 17), C. carpio (sites = 1, n = 2) and possible O. mossambicus and O. niloticus hybrids (sites = 10) were recorded. This hybridisation is one of the main threats affecting the indigenous O. mossambicus which led to the change of the conservation status to 'near threatened' in 2007 (Cambray and Swartz 2007). In addition to this, O. niloticus outcompetes O. mossambicus because of their similar niche space (Cambray and Swartz 2007; Weyl et al. 2020). It is suspected that O. niloticus is spreading through Southern Africa due to aquaculture and anglers (Ellender and Weyl 2014; Weyl et al. 2020). Gambusia affinis has a strong impact on the vital rates of native fish populations (Howe et al. 1997; Lawler et al. 1999; Segev, Mangel and Blaustein 2009). C. carpio causes habitat destruction, change water clarity and are competition to native fish species (Parkos, Santucci and Wahl 2003; Roberts et al. 1995; Weyl et al. 2020; Zambrano et al. 2006). Previous studies have reported Micropterus salmoides in the Limpopo River Basin, but no individuals were caught in the rivers during this survey (Kimberg et al. 2014; De Moor 1996; Weyl et al. 2020). The extent to which invasive species affect the fish communities in the basin is unclear. The ecological effect of invasive species can be severe and range from behavioural shifts of native fauna to the restructuring of food webs and the extinction of species (Rahel 2000; Vander Zanden and Rasmussen 1999). The invasion potential is of concern in the Limpopo River Basin. There is a need for conservation management to remove of invasive species and control the further spread in the Basin.

Oreochromis mossambicus was the only species with the IUCN category above least concerned that were sampled during the survey (IUCN 2021). Additional expected species with conservation status that were not collected include: E. motebensis (vulnerable), Enteromius. sp. 'Waterberg' (near threatened), E. treurensis, S. meridianus (endangered) and Kneria sp. 'South Africa' (critically endangered) were not collected (IUCN 2021). Enteromius motebensis was expected to occur in the Notwane, Marico and Crocodile Rivers (DWS 2014; Skelton 2001). This species is moderately intolerant to modified water quality (DWS 2014) and have a negative spatial association with M. salmoides (Kimberg et al. 2014). Altered water quality is a known impact that affects the Crocodile (Keller 1960; Preez et al. 2018; Roux, S.P., Oelofse 2010). Similarly, E. treurensis was expected to occur in the Lower Olifants river but is highly intolerant to altered water quality (DWS 2014). The absence of S. meridianus, and Kneria sp. requires further investigation.

Oreochromis mossambicus (n=991, site=16), C. paratus (n=2198,site=11) and L. molybdinus(n=536, site=11) were found at most of the sites and occurred in the highest abundance (TABLE 3.4). C. paratus and L. molybdinus are moderately intolerant to no flow conditions and moderately intolerant to modified water quality (DWS 2014). They are substate specialists and require mostly fast flows, however, L. molybdinus does prefer slow deep habitats (DWS 2014; Skelton 2001). The absence of these species at 6 of the sites are attributed to or in the combination of the absence of preferred habitat (ELEP-Y30C-SINGU, LIMP-Y30F-CHOKW, SAND-A71K-R508B, SHIN-B90H-POACH, SHAS-Y20B-TULIB), altered flows (MOGA-A36D-LIMPK, LIMP-Y30F-CHOKW, ELEP-Y30C-SINGU), and altered water quality (ELEP-Y30C-SINGU, SAND-A71K-R508B).

Labeobarbus marequensis is a good indicator species for aquatic ecosystems (Burnett 2013; Ellender, 2008; De Villiers and Ellender 2008a & 2008b; Impson, Bills and Wolhuter 2007; O'Brien and De Villiers 2011) The low occurrence (sites= 9, n=262) of this species across the Limpopo River basin is of concern. This species is sensitive to anthropogenic activities that cause changes in the condition of rivers. It is particularly sensitive to dam building, altered flows, pollution and siltation (Benejam Vidal 2008; Fouché 2009; Impson, Bills and Wolhuter 2007). This can indicate how altered flows, pollution and river connectivity have impacted the basin.

Anguillids were absent in this study which raises concerns about the connectivity of the rivers in the Limpopo River Basin. These species are migratory catadromous species (Bruton, Africa and Davies 1987; Hanzen et al. 2019; Skelton 2001; Whitfield 1998), with four species found in the Limpopo River Basin; A. mossambicus, A. marmorata, A. bicolor and A. bengalensis (Hanzen et al. 2019). The increase in populations and anthropogenic activities in the basin cause an increased demand for water (Petrie et al. 2014). This leads to the building of additional impoundments for water security and continues to add pressure on aquatic ecosystems.

3.5.2 FISH Associated water quality and instream habitat stressors

The overall habitat integrity in the Limpopo River Basin is in a fair, moderately modified state. The water in the Limpopo River Basin has been oversubscribed which caused the Limpopo River Basin to approach water resource closure (Petrie et al. 2014). Overexploitation and the natural semi-arid variable climate of the Limpopo River Basin have changed the river from a strong-flowing perennial to a weakly-flowing perennial river (Nhassengo, Somura and Wolfe 2021). Individual fish species have evolved different life histories and strategies to survive and are dependent on the available physical habitats and different flow regimes (Baumgartner et al. 2014; Gehrke et al. 1995; Humphries, Koehn and Alison 1999; Poff et al. 2010; Tedesco et al. 2008).

For most of the sampling sites, the water quality was in a good range. The sites associated with urban and agricultural land uses had elevated salt and fertiliser-derived nutrients. Evidence of eutrophication occurred at LIMP-A41D-SPANWERK, CROC-A24J-ROOIK, SHAS-Y20B-TULIB. Nutrient pollution causes a decline in biodiversity, through both a loss in species and through increased dominance of certain primary producers (Barker 2006; Cardinale 2011; Nie et al. 2018).

Zinc was in a "poor" classification at MATL-A41D-WDRAAI, LEPH-A50H-SEEK, MOGA-A63D-LIMPK, LUVU-A91K-OUTPO, and SHIN-B90H-POACH. Zinc along with mercury, cadmium, copper, and lead are the most important heavy metal pollutants that affect the aquatic environment and health of fish (Authman et al. 2015). These metals accumulate in fish tissues (Authman et al. 2015) posing a risk to fish and the human communities that rely on them. The main target of Zinc toxicity is in fish gills where it disrupts the Ca^{2+} uptake (Authman et al. 2015; Niyogi and Wood 2006). The other endpoints of toxicity included mortality, growth retardation, respiratory and cardiac changes, and inhibition of spawning (Authman et al. 2015).

The major sources of sedimentation input in this study were agriculture, urban development and in-stream barriers (bridges, weirs, culverts) as found in other studies (LBPTCT 2010; FAO 2004). There is a strong relationship between riparian vegetation, instream habitat and community structure in aquatic ecosystems (Cruz, Miranda and Cetra 2013; Dala-Corte et al. 2016). The degradation of riparian zones and wetlands, lowers the water table, causes bank erosion and increases the turbidity of the water (Kori and Mathada 2012). This alters the available habitats resulting in changes in the fish community structure (Dudgeon 2000).

3.5.3 Integrated water quality, habitat and fish communities

The different velocity depth classes had a significant influence on the fish community structures (Figure 105). Hydrological variability influences the physical habitat of riverine systems and thus shapes the structure and diversity of aquatic fauna and flora communities (Cattanéo 2005; Kleynhans 2007; Poff and Allan 1995; Vidal 2008). Fish have evolved different life-history stages and strategies to adapt to the availability of physical habitats and are thus dependent on different flow regime requirements to complete their lifecycles (Gehrke et al. 1995; Humphries, Koehn and Alison 1999; Poff and Zimmerman 2010; Tedesco et al. 2008). A reduction in water velocity would result in a shift of the fish community structure towards limnophilic or semi-rheophilic species. Fish species correlated with the high-velocity flow (L. marequensis, L. molybdinus, L. cylindricus, C. paratus) would shift to species associated with slow-flowing water (O. mossambicus, Enteromius spp., Coptodon rendalli, Tilapia sparmanii, C. gariepinus) (Lamouroux et al. 2006; Poff et al. 1997; Propst and Gido 2004; Richter et al. 2003). For example, at MOGA-A63D-LIMPK and SHAS-Y20B-TULIB the fish community structure consisted only out of pool loving species (TABLE 3.4) (DWS 2014).

There was a significant difference between the fish community structure in relation to their preferences for different substrate types (Figure 106). The presence of gravel, cobbles and boulders are ecologically important because several fish species occurring in the Limpopo River basin rely on these substrates for breeding and feeding (Skelton 2001). C. paratus, L. molybdinus, L. cylindricus and L. marequensis showed preferences for cobbles, boulders and bedrock associated with fast velocities. Chiloglanis paratus in the Shashe river associate with Phragmites bed because of the absence of any structured substrate (Marshall 2010). Cichlid species (T. sparrmanii, O. mossambicus) were more associated with mud and sand in slower velocities. Reduced flows create habitats that are more associated with sand and silt and may decrease the occurrence of species reliant on faster flows associated with structured substrates. Reduced flows cause sediments deposition which inundated the substrates. Resulting in the loss of ecologically important substrates which are no longer useful as cover features for fish (Bunn and Arthington 2002; Kleynhans 2007). Loss of these substrates could result in fish community shifts and reduced abundances (Bunn and Arthington

2002; Hall, Jordaan and Fris 2011; Poff et al. 1997). The main sources of sedimentation in rivers are agriculture, urban development, forestry and sand mining (Dugan et al. 2010; Mcintyre et al. 2016; Waters 1995). Most of the sites sampled during this survey had commercial farms, overgrazing, dirt roads and urban areas around the sites. This resulted in sedimentation at CROC-A24J-ROOIK, LIMP-A63C-LIMPK, GLET-B81J-LRANC, OLIF-B73H-BALUL, MOGA-A63D-LIMPK, and LEPH-A50H-SEEKO. The confluence of the Shashe river with the Limpopo River results in sand deposits as observed at the LIMP-A71L-MAPUN site. The increase in sand mining in the Limpopo River Basin (South Africa and Botswana) cause an increase in sedimentation which poses a large risk to the fish communities (FAO 2004).

There was a significant difference between the fish community structure in relation to their preferences for different cover features (Figure 107), though not as much as the other environmental variables as it only accounted for 61.3% of the variation. One of the main drivers in the community structure were substrates as a cover feature. Species like C. paratus, L. molybdinus, L. cylindricus associate with the substrate as a cover feature. Whereas species like Enteromius annectens, M. acutidens and S. zambezensis associate with roots and depth as cover features. Different fish species and life stages have different preferences for the availability of cover features (Allouche 2002). Cover structures have three main functions; protection against predators, visual isolation reducing competition and hydraulic shelter (Allouche 2002; Pusey and Arthington 2003; Skelton 2001). Habitat complexity influences the community composition in aquatic ecosystems (Jackson, Peres-Neto and Olden 2001) because it provides a wide range of niche space, decreasing niche overlap and increasing diversity (Beisel, Usseglio-Polatera and Moreteau 2000; Downes et al. 1998; Huston and DeAngelis 1994; Smith, Jonhston and Clark 2014).

The variation in water quality was a significant driver of the fish community structure (Figure 108). Electrical conductivity as a water quality parameter was one of the main drivers in the community structure. Run-off from agricultural activities can result in increased conductivity in water (Namugize, Jewitt and Graham 2018; Walser and Bart 1999). High levels of conductivity can have a detrimental effect on fish communities (de Sousa et al. 2014; Thompson, Brandes and Kney 2012; Walser and Bart 1999). Enteromius eutaenia, Enteromius lineomaculatus, Chiloglanis pretoriae, C. swierstrai, Opseridium periguel are species expected in the Limpopo River Bain which are intolerant to modified water quality (DWS 2014). During this survey, E. lineomaculatus were collected at LUVU-A91K-OUTPO and MATL-A41D-WDRAAI. This species had a weak association with any of the water quality parameters. Labeobarbus marequensis, C. paratus, Labeo congoro, L.cylindricus, L. molybdinus, M. acutidens are fish expected in the Limpopo River Bain that are moderately intolerant to water quality (DWS 2014). Most of the sites sampled during the survey had at least four of these species present except for ELEP-Y30C-SINGU, LIMP-Y30F-CHOKW, MOGA-A63D-LIMPK, SHAS-Y20B-TULIB, SAND-A71K-R508B. Of these sites mentioned above the in-situ water quality range were in a good range (LIMCOM 2013) except for the SAND-A71K-R508B site. Agricultural, industrial, urban and informal settlements are land-use activities found around these sites which have the potential to compromise the water quality. The absence of desired habitats and the presence of no-flow conditions (SHAS-Y20B-TULIB and MOGA-A63D-LIMPK) could additionally explain the absence of species. Poor water quality results in the decline of fish species, this is due to both the intolerances of fish species and a decline in their food sources (DWAF 1996; Bilotta and Brazier 2008). Altered water quality can cause an increase in the presence of invasive species because they are often more tolerant to deteriorated and polluted waters (Bunn and Arthington 2002; Dudgeon 2014; Gao et al. 2019).

Of the 17 sites sampled in the Limpopo River Basin seven of the sites were in a "largely modified" state (Ecological Category =D), five were in a "moderately modified state" (Ecological Category =C), four were in a C/D ecological category and only one site was in a B/C ecological category TABLE 3.5). It is concerning that none of the sites were in a mostly natural state (Ecological category = B).

Agricultural activities were the predominant land use activities that occurred around most of the sites. This has an impact on the habitat availability (sedimentation and erosion) (Carpenter et al. 1998; Quinton et al. 2010), water quality (pesticides, herbicides, fertilisers, and leachates) and quantity (Rosegrant, Ringler and Zhu 2009) which are important drivers of fish communities. In addition to agricultural activities, the treated and partially treated effluents from wastewater treatment works, urban areas, industrial and informal settlements have impacted sites like the SAND-A71K-R508B, OLIF-B73C-MAMBA, and CROC-A24J-ROOIK. The poor water availability at site SHAS-Y20B-TULIB and MOGA-A63D-LIMPK may have contributed to the lack of references species. Especially those that prefer flowing water (L. marequensis, L. molybdinus, L. cylindricus, C. paratus)and that have migratory requirements (L. marequensis, Anguilla spp., Labeo spp.) (DWS 2014; Skelton 2001)

Most of the sites have impoundments (weirs, dams low water bridges) either upstream or downstream (ELEP-Y30C-SINGU, GLET-B81J-LRANC, LETA-B83A-LONEB, LIMP-A63C-LIMPK, MOGA-A63D-LIMPK, OLIF-B73H-BALUL, SHAS-Y20B-TULIB). This has an effect on the flows (Anania 2015) and migration ability of fish species which both have negative effect on fish biodiversity (Dudgeon et al. 2006; Grill et al. 2019). Flow alterations affect the habitats, sediment deposition, migration and life history cues such as recruitment and growth of fish (Bunn and Arthington 2002; Hall, Jordaan and Fris 2011; Poff et al. 1997). Fish have evolved different life-history stages and strategies to adapted to the availability of physical habitats and are thus dependent on different flow regime requirements to complete their lifecycles (Gehrke et al. 1995; Humphries, Koehn and Alison 1999; Poff et al. 2010; Tedesco et al. 2008). More than 100 fish species that require some form of migration for their survival in South Africa (Bok et al. 2007; O'Brien et al. 2018; Whitfield and Elliott 2002). The presence of invasive species could have had an additional impact on the ecological integrity of the fish community. Invasive species are more tolerable to unfavourable conditions such as increase in temperature and flow modifications (Bunn and Arthington 2002; Dudgeon 2014). At the LUVU-A91K-OUTPO site the ecological category of a C was under estimated because of high flows which limited sampling effort and was not attributed to large modification of habitats. O'Brien (2013) obtained the same ecological status for fish at the sites which overlapped with this study (LIMP-A41D-SPANW=C, LIMP-A71L-MAPUN=C/D, SHIN-B90H-POACH=D, LIMP-Y30F-CHOKW=C). This implies that there was neither an improvement nor a worsening of the ecological status of the fish communities at these sites. Rivers that remain in Classes D and E have serious consequences on the resilience of the river systems, which threatens the health of fish communities (Evans et al. 2021).

3.6 CONCLUSION

The fish communities of the Limpopo River Basin are presently in an altered state. All sites contain species that were modified from expected fish communities. Anthropogenic activities that occur throughout the basin and cumulate in many parts of the basin caused this altered state. Deteriorating water quality, altered flows, habitat destruction, barriers and invasive species are drivers of change for fish communities in the Limpopo River Basin (O'Brien 2013). However, more work is needed to understand the less abundant species or those species that were absent due to sampling effort.

Multivariate analyses showed that changes in velocity-depth classes, substrate type, cover features and water quality variations were significantly drivers of fish communities. Alteration of flows affect these variables, and in turn affect the community structure. Fish communities are indicators of ecosystem integrity because of their predictable responses to anthropogenic disturbances (Wepener et al 2008). Multimeric indices like FRAI are used to monitor anthropogenic disturbances and are able to identify the drivers of fish communities. The FRAI scores showed that all the sites were in a moderately to largely modified state during this study period. This is primarily because of the loss of habitat and unsustainable use of freshwater. The water in the Limpopo River Basin has approached water resource closure. Continued overuse without an increase in protection of freshwater systems will result in a loss of structure (biodiversity and physical ecosystem features) and function (ecosystem process and services) of ecosystems and will have socio-economic consequences. If management actions or laws are not implemented soon, a decrease in biodiversity both in this study and global freshwater systems will continue. The increased modification of natural environments will continue to cause a decline in fish communities' resilience

The only way of ensuring water security is to manage water resources under worst case future scenarios (Vörösmarty et al. 2010). Aquatic ecosystem management has failed to evolve from binary presence/absence type monitoring towards more dynamic ecosystem process-based techniques. These techniques have the capacity to manage ecological functionality in the absence of sufficient flows. There is a need to evolve the capacity of water management authorities in Limpopo River Basin, so that they can deal with changing environments, increases in water demand and shortages of supply.

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4 MACROINVERTEBRATES

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4.1 INTRODUCTION

Sampling of aquatic macroinvertebrates as part of the Limpopo Watercourse Commission (LIMCOM) 2021 High Flow Survey was carried out at selected sites in the Limpopo Basin, following up on a low flow survey conducted in July 2012.

This study was prompted by recognition that the Limpopo River is stressed due to overutilisation. The challenge is determining the water flow requirements to ensure sufficient water for a perceived sustainable functioning ecosystem (focused on the need of a functional natural environment), while meeting ecosystem services (focused on the needs of people). Meeting such requirements is to be achieved for all people in the basin across human demarcated country boundaries.

Aquatic macroinvertebrates are one of the components used in this study as responsive indicators of different flow conditions. Insects have been around since the Ordovician Period (485 – 444 million years ago) and have evolved and adapted to the environmental conditions which they were exposed to ever since (Engel 2015). These adaptations include droughts and flooding events in riverine ecosystems (De la Fuente et al. 2018). The aquatic macroinvertebrate community would therefore respond to changes in natural flow conditions. When there is an understanding of the requirements of individuals species throughout their life cycles, such information builds knowledge of community responses to changes biotic and abiotic conditions.

4.1.1 The aim of this study was:

- to determine which invertebrate taxa are present in the different available biotopes (flow, depth, substrate, hydraulic biotopes, vegetation);
- to determine aquatic invertebrate abundances within quantifiable biotopes to better understand habitat preference to the lowest possible classification (i.e., genus or species level); and
- to determine present stream conditions using existing classification tools.

In this report, the ecological conditions based on present and previous surveys are presented for each site sampled. Detailed habitat preferences based on collected data will be presented once all taxa have been identified to the lowest possible taxonomic level and counted.

4.1.2 STUDY AREA

General

The Limpopo System drains a surface area of 416 296 km2, encapsulating South Africa, Botswana, Zimbabwe, and Mozambique (Food and Agriculture Organisation 2004). A large portion of the basin flows through arid regions with low rainfall, so the catchment is affected by both physical and economic water scarcity. For this study, the bulk of sites were sampled in the main Limpopo River and its tributaries (**Error! Reference source not found.**), since biological data is relative scarce despite the size of the catchment.

Biomonitoring sites

A total of seventeen sites were surveyed for this report, of which two were surveyed in September 2020, and twelve in May 2021, two in June 2021, and two in July 2021. Biomonitoring site locations are indicated in the schematic and topographical map in FIGURE 2.1, and FIGURE 2.2. Details of the biomonitoring sites are presented in TABLE 2.2. During the different surveys, different projects used different site codes. For comparative purposes, the standardised site codes used in the old South African River Health Database (RHDB), recently upgraded to the Freshwater Biodiversity Information Centre (FBIS), are also included. Site codes used in the June 2021 survey are also included in TABLE 4.1 to minimise confusion when comparing old data sets. Photographs of biomonitoring sites are included in Appendix A.

TABLE 4.1. DETAILS OF BIOMONITORING SITES RELATED TO THE SOUTH AFRICAN RIVER HEALTH DATABASE (RHDB) AND THE FRESHWATER BIODIVERSITY INFORMATION CENTRE (FBIS),

Code (River-Quat-Farm)	FBIS/RHDB Site Code	River	Risk Area	Latitude (S)	Longitude (E)	Elevation (M a.s.l.)
CROC-A24J-ROOIB	A2CROC-ROOIB	Crocodile	RR1	-24.31417	27.04614	885
LIMP-A41D-SPANW	A4LIMP-SPANW	Limpopo	RR1	-23.9485	26.93123	857
MATL-A41C-WDRAAI	A4MATL-PHOFU	Matlabas	RR2	-24.05186	27.35964	916
LEPH-A50H-SEEKO	A5LEPH-SEEKO	Lephalale	RR2	-23.14128	27.88503	794
LIMP-A63C-LIMPK	A6LIMP-LIMPK	Limpopo		-22.45519	28.90175	631
MOGA-A63D-LIMPK	A6MOGA-LINPK	Mogalakwena	RR2	-22.47344	28.91950	636
SHAS-Y20B-TULIB		Shashe	RR3.1	-21.91624	29.19836	578
LIMP-A71L-MAPUN	A7LIMP-MAPUN	Limpopo		-22.18383	29.40519	511
UMZI-Y20C-BEITB		Umzingwani	RR4.2	-22.13590	29.93020	465
SAND-A71K-R508B	A7SAND-R508B	Sand	RR4	-22.39928	30.09942	447
LUVU-A91K-OUTPO	A9LUVU-MUTAL	Luvuvhu	RR5	-22.44444	31.08344	249
OLIF-B73C-MAMBA	B7OLIF-MAMB1	Olifants	RR7	-24.08642	31.25094	278
OLIF-B73H-BALUL	B7OLIF-BALUL	Olifants	RR7	-24.05214	31.72878	185
LETA-B83A-LONEB	B8LETA-NGWEN	Letaba	RR8	-23.75833	31.36997	264
ELEP-Y30C-SINGU	Y3ELEP-SINGU	Elephantes	RR10	-23.87512	32.22627	89
SHIN-B90H-POACH	B9SHIN-POACH	Shingwedzi	RR9	-23.22194	31.55492	241

LIMP-Y30F-CHOKW	Y3LIMP-CHOKW	Limpopo	RR11	-24.50006	33.00818	30

4.2 METHODS

4.2.1 Review

A review of relevant ecological data was undertaken (Dickens et al. 2020). Key sources of information include previous ecological studies conducted:

- Checklist of Decapoda recorded in the Kruger National Park (Pienaar 1961)
- Survey of the Freshwater molluscs of the rivers in the Kruger National Park (Oberholzer & van Eeden 1967)
- Distribution of Crustacea: Decapoda: Palaemonidae: Macrobrachium of rivers in the Kruger National Park (Taylor 1990)
- Checklist of leeches (Hirudinea) of the Kruger National Park (Oosthuizen 1991)
- Aquatic macroinvertebrate high and low flow survey of the Elephantes River downstream of Massingir Dam and Limpopo River downstream from the Limpopo-Elephantes confluence in 2005/6 (Palmer 2006)
- LIMCOM 2012 low flow survey (Dickens et al. 2013)
- Summary of SASS data collected in the rivers of the Kruger National Park since 2010 (Sithole et al. 2018),
- the Freshwater Biodiversity Information System (FBIS) database (Freshwater Research Centre 2020), and
- Two new Caenis species (Insecta: Ephemeroptera: Caenidae) from the Kruger National Park (Malzacher & Barber-James 2020).

4.2.2 Field Survey

Field surveys for this report was carried out during September-October 2020, April-May 2021, and June 2021.

- 29 Sep – 04 Oct 2021: Three sites on Olifants River, Kruger National Park.
- 21 Apr – 06 May 2021: Fourteen sites on the Limpopo River and some of its major tributaries, and the Olifants, Shingwedzi, and Letaba River in the Kruger National Park, and
- 09 – 10 June 2021: Elephantes and Limpopo River in Mozambique.
- 23 – 25 July 2021: Shasehe and Umzingwani streams, Zimbabwe.

Sampling dates with a summary of site conditions are indicated in TABLE 4.2

TABLE 4.2. SAMPLING DATES FOR THE VARIOUS SITES WITH GENERAL COMMENTS.

Date	Sites	Comments
29 Sep 2020	OLIF-B73C-MAMBA	Low flow, water, algae very dominant on substrates in flowing portions. Habitat heterogeneity high.
1-4 Oct 2020	OLIF-B73H-BALUL	High rainfall in the upper catchment and on-site resulted in dramatic changes, e.g., turbidity, inundated substrates, accessibility, and more. Water turned from clear to red brown.
21 April 2021	CROC-A24J-ROOIK	High flow, water turbid, habitat heterogeneity moderate to low. Time at the site was limited, but so was habitat.
22 April 2021	LIMP-A41D-SPANW	High flow, water clearer, habitat heterogeneity very high. Time at the site was limited.
23 April 2021	MATL-A41C-WDRAAI	Moderate to low flow, crystal clear water, low to moderate habitat heterogeneity.
24 April 2021	LEPH-A50H-SEEKO	High flow, water slightly discoloured, downstream from a weir with some good habitat, but reduced habitat heterogeneity further downstream.
25 April 2021	LIMP-A63C-LIMPK	High flow, water light to red brown, with high habitat heterogeneity.
26 April 2021	MOGA-A63D-LIMPK	Flow limited to a trickle at one location downstream from a dam wall. Rest of stream made up of isolated pools. Water clear, with potentially high habitat heterogeneity. Sampling time was limited but so was habitat diversity.
27 April 2021	LIMP-A71L-MAPUN	High flow, water slightly clear with greenish tint.
28 April 2021	SAND-A71K-R508B	Very low flow, water clear with substrate dominated with sand. Habitat heterogeneity was low, and sampling time was limited.
29 April 2021	LUVU-A91K-OUTPO	Very high flow, with deeper fast flowing sections wadeable during low flow (Sep 2018) inaccessible). Habitat heterogeneity was high with cobble-boulder substrates dominant and different velocity-depth classes. Matumi root wads were inaccessible due to high flow. Sampling time limited.
01 May 2021	SHIN-B90H-POACH	Moderate to low flow, with pool habitats and flow over dominant. Stones biotopes sampled in the vicinity of the bridge, dominated by bedrock.

Date	Sites	Comments
03 May 2021	OLIF-B73H-BALUL	High flow, with high habitat heterogeneity. Deposition occurs above the crossing during high flows, with gravel-cobble-sand bed several layers deep.
04 May 2021	LETA-B83E-LBULL	Moderate to low flow, water clear with high habitat heterogeneity.
05 May 2021	OLIF-B73C-MAMBA	High flow, slightly turbid waters with high habitat heterogeneity.
06 May 2021	GLET-B81J-LRANC	Moderate to low flow over sand-gravel-bedrock bed, with moderate habitat heterogeneity.
09 June 2021	ELEP-Y30C-SINGU	Very high flow with sand-gravel dominated streambed, and marginal vegetation. Habitat heterogeneity moderate.
10 June 2021	LIMP-Y30F-CHOKW	High flow with sand-mud dominated streambed, and gravel scarce. Habitat heterogeneity low.
23 July 2021	SHAS-Y20F-TULIB	Imperceptible flow over shallow (max depth measured 29 cm) pool, sand-mud dominated stream bed. Habitat heterogeneity low.
25 July 2021	UMZI-Y20C-BEITB	Imperceptible flow over shallow (max depth measured 19 cm) substrates dominated by sand, but with bedrock and some rocky substrates present. Habitat heterogeneity low.

4.2.3 Site Photographs

The following pictures clearly illustrate the nature of each site from an invertebrate assessment point of view, showing the biotopes sampled.

FIGURE 4.1. CROCODILE RIVER AT ROOIBOKKRAAL (CROC-A24J-ROOIB – A2CROC-ROOIB), 21 APRIL 2021.

FIGURE 4.2. LIMPOPO RIVER AT SPANWERK (LIMP-A41D-SPANW – A4LIMP-SPANW), 22 APRIL 2021.

FIGURE 4.3. MATLABAS RIVER AT PHOFU (MATL-A41C-PHOFU – A4MATL-PHOFU), 23 APRIL 2021.

FIGURE 4.4. LEPHALALE RIVER AT SEEKOEIGAT (LEPH-A50H-SEEKO), 24 APRIL 2021.

FIGURE 4.5. LIMPOPO RIVER AT LIMPOKWENA (LIMP-A63C-LIMPK), 25 APRIL 2021.

FIGURE 4.6. MOGALAKWENA RIVER AT LIMPOKWENA (MOGA-A63D-LIMPK), 26 APRIL 2021.

FIGURE 4.7. LIMPOPO RIVER AT MAPUNGUBWE (LIMP-A71L-MAPUN), 27 APRIL 2021.

FIGURE 4.8. SAND RIVER AT REGIONAL ROAD BRIDGE R508 (SAND-A71K-R508B), 28 APRIL 2021.

FIGURE 4.9. LUVUVUHU RIVER AT THE OUTPOST, DOWNSTREAM FROM THE MUTALE CONFLUENCE (LUVU-A91K-OUTPO), 29 APRIL 2021.

FIGURE 4.10. OLIFANTS RIVER DOWNSTREAM FROM THE KLASERIE CONFLUENCE (OLIF-B73C-MAMBA), 05 MAY 2021.

FIGURE 4.11. OLIFANTS RIVER AT BALULE (OLIF-B73H-BALUL), 03 MAY 2021.

FIGURE 4.12. GREAT LETABA RIVER AT THE RANCH (GLET-B81J-LRANC), 06 MAY 2021.

FIGURE 4.13. LETABA RIVER UPSTREAM FROM THE H14 BRIDGE (LETA-B83A-LBULL), 04 MAY 2021.

FIGURE 4.14. ELEPHANTES RIVER DOWNSTREAM FROM MASSINGIHR DAM (ELEP-Y30C-SINGU), 09 JUNE 2021.

FIGURE 4.15. SHINGWEDZI RIVER AT POACHER DRIFT, CLOSE TO RIVER EXITING KRUGER NATIONAL PARK (SHIN-B90H-POACH), 01 MAY 2021.

FIGURE 4.16. LIMPOPO RIVER AT CHOKWANE, MOZAMBIQUE (LIMP-Y30F-CHOKW), 10 JUNE 2021

4.2.4 Invertebrate Water Quality

Spot measurements of selected water quality variables were taken at each site using portable field meters. The following variables were measured: conductivity (µS/cm); Oxygen (% and g/L); water temperature (°C); and pH. Water samples were also collected infield for chemical analysis. These results are discussed in a separate section but will be referred to where relevant. Where possible data are compared to previously available data to determine whether there are significant changes.

4.2.5 Instream Habitat

Quantitative data are collected by sampling specific demarcated areas within different hydraulic biotopes, substrates, depths, vegetation types, and velocities. The habitat in each demarcated area were measured and then described in terms of velocity, depth, substrates, and hydraulic biotope. The aquatic macroinvertebrates encountered and collected within each demarcated area are then identified to the lowest possible taxonomic level and counted to determine preferences of species and communities.

In the stone biotopes, coarser gravel (15 – 64 mm), cobble (64 – 254 mm) and boulders (>254 mm) were measured with a standard 30 cm ruler. Only substrate loosely arranged on the riverbed was measured. Three angles of individual substrates (boulders, cobble, coarse gravel) were measured. This was to quantify substrate as accurately as possible. The measurements of stones were expressed as area and as a percentage of the square sampled. This provides an indication of surface roughness, and hence provides a rough indication of available cover.

Velocity and depth measurements were carried out with an OTT MF pro at each biotope sampled. The handheld OTT MF pro unit's sensor uses a magnetic-inductive current to accurately determine stream velocity. Depth in meters is measured first, after which velocity (m/s) measurements are taken at a depth of 20%, 60% and 80% below the water surface. This information is used to calculate turbulence and provides insight with species-genus abundances on microhabitat preferences.

Substrate composition was calculated from the number of measured gravel-cobble-boulder substrates, and sand-fine gravel substrate was estimated. The abundance of algae at each biotope was visually estimated. In the marginal vegetation biotope, plant species were identified where possible, and abundance rated from 1 to 5, with 1 being rare and 5 very abundant.

Turbulence was calculated using Froude's Number. The formula considers depth, velocity, and a constant value for gravitational flow (Gore 1978). White et al. (2019) indicated that when considering invertebrate community responses to flow-related characteristics, turbulence (Froude number) exerted the greatest statistical influence. In TABLE 4.4 is a colour-coded matrix that indicate change in turbulence compared to depth and velocity.

TABLE 4.3. VELOCITY, DEPTH, SUBSTRATE, HYDRAULIC BIOTOPE, AND TURBULENCE CATEGORIES USED IN DETERMINING HABITAT HETEROGENEITY.

Velocity	Fast	Moderate	Slow	Stagnant				
(m3/s)	>0.6	0.6 – 0.3	0.3 – 0.1	<0.1				
Depth (m)	SHALLOW					DEEP		
	Very shallow	Shallow	Shallow Intermediate	Intermediate	Deep Intermediate	Deep	Not wadable	
	<0.1	0.1 – 0.2	0.2 – 0.3	0.3 – 0.4	0.4 – 0.5	>0.5	>1.5	
Substrate	Bedrock	Boulder	Cobble	Gravel	Sand	Mud	Silt	
Vegetation	Grass	Herbs	Sedges	Reeds	Branches	Root wads	Algae	
Hydraulic Biotope	Cascade	Chute	Rapid	Riffle	Run	Glide	Pool	
Turbulence	1	2	3	4	5	6	7	8
Fr[1]	>0.7	0.7 – 0.6	0.6 – 0.5	0.5 – 0.4	0.4 – 0.3	0.3 – 0.2	0.2 – 0.1	<0.1
	High ←						→ Low	

1 $Fr = V/\sqrt{gD}$, where Fr = Froude's number, V = Velocity, g = gravitational flow, D = depth.

TABLE 4.4. TABLE INDICATING DIFFERENT TURBULENCE AT DIFFERENT VELOCITY-DEPTH CATEGORIES. VELOCITIES IN RIVERS CAN REACH A MAXIMUM OF 310 CM/S, AND DEPTHS WERE LIMITED TO WADEABLE DEPTHS.

Velocity (cm/s)

Depth (cm)

0	10	20	30	40	50	60	70	80	90	100	150	200	250	300	310
0.1	1.0	2.0	3.0	4.0	5.1	6.1	7.1	8.1	9.1	10.1	15.2	20.2	25.3	30.3	31.3
0.2	0.7	1.4	2.1	2.9	3.6	4.3	5.0	5.7	6.4	7.1	10.7	14.3	17.9	21.4	22.1
0.3	0.6	1.2	1.7	2.3	2.9	3.5	4.1	4.7	5.2	5.8	8.7	11.7	14.6	17.5	18.1
0.4	0.5	1.0	1.5	2.0	2.5	3.0	3.5	4.0	4.5	5.1	7.6	10.1	12.6	15.2	15.7
0.5	0.5	0.9	1.4	1.8	2.3	2.7	3.2	3.6	4.1	4.5	6.8	9.0	11.3	13.6	14.0
0.6	0.4	0.8	1.2	1.6	2.1	2.5	2.9	3.3	3.7	4.1	6.2	8.2	10.3	12.4	12.8
0.7	0.4	0.8	1.1	1.5	1.9	2.3	2.7	3.1	3.4	3.8	5.7	7.6	9.5	11.5	11.8
0.8	0.4	0.7	1.1	1.4	1.8	2.1	2.5	2.9	3.2	3.6	5.4	7.1	8.9	10.7	11.1
0.9	0.3	0.7	1.0	1.3	1.7	2.0	2.4	2.7	3.0	3.4	5.1	6.7	8.4	10.1	10.4
1	0.3	0.6	1.0	1.3	1.6	1.9	2.2	2.6	2.9	3.2	4.8	6.4	8.0	9.6	9.9
2	0.2	0.5	0.7	0.9	1.1	1.4	1.6	1.8	2.0	2.3	3.4	4.5	5.6	6.8	7.0
3	0.2	0.4	0.6	0.7	0.9	1.1	1.3	1.5	1.7	1.8	2.8	3.7	4.6	5.5	5.7
4	0.2	0.3	0.5	0.6	0.8	1.0	1.1	1.3	1.4	1.6	2.4	3.2	4.0	4.8	5.0
5	0.1	0.3	0.4	0.6	0.7	0.9	1.0	1.1	1.3	1.4	2.1	2.9	3.6	4.3	4.4
6	0.1	0.3	0.4	0.5	0.7	0.8	0.9	1.0	1.2	1.3	2.0	2.6	3.3	3.9	4.0
7	0.1	0.2	0.4	0.5	0.6	0.7	0.8	1.0	1.1	1.2	1.8	2.4	3.0	3.6	3.7
8	0.1	0.2	0.3	0.5	0.6	0.7	0.8	0.9	1.0	1.1	1.7	2.3	2.8	3.4	3.5
9	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.9	1.0	1.1	1.6	2.1	2.7	3.2	3.3
10	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9	1.0	1.5	2.0	2.5	3.0	3.1
20	0.1	0.1	0.2	0.3	0.4	0.4	0.5	0.6	0.6	0.7	1.1	1.4	1.8	2.1	2.2
30	0.1	0.1	0.2	0.2	0.3	0.3	0.4	0.5	0.5	0.6	0.9	1.2	1.5	1.7	1.8
40	0.1	0.1	0.2	0.2	0.3	0.3	0.4	0.4	0.5	0.5	0.8	1.0	1.3	1.5	1.6
50	0.0	0.1	0.1	0.2	0.2	0.3	0.3	0.4	0.4	0.5	0.7	0.9	1.1	1.4	1.4
60	0.0	0.1	0.1	0.2	0.2	0.2	0.3	0.3	0.4	0.4	0.6	0.8	1.0	1.2	1.3
70	0.0	0.1	0.1	0.2	0.2	0.2	0.3	0.3	0.3	0.4	0.6	0.8	1.0	1.1	1.2
80	0.0	0.1	0.1	0.1	0.2	0.2	0.3	0.3	0.3	0.4	0.5	0.7	0.9	1.1	1.1
90	0.0	0.1	0.1	0.1	0.2	0.2	0.2	0.3	0.3	0.3	0.5	0.7	0.8	1.0	1.0
100	0.0	0.1	0.1	0.1	0.2	0.2	0.2	0.3	0.3	0.3	0.5	0.6	0.8	1.0	1.0

4.2.6 Aquatic Macroinvertebrates

Aquatic macroinvertebrates were collected in different perceived comparable biotopes selected at each sampling site. An area of 40 cm x 40 cm was sampled for each biotope-effort. For stones in current and gravel in current biotopes, a surber sampler with dimensions of 40 cm x 40 cm and mesh size of 500 µm2 were used. In the vegetation and gravel-sand-mud biotopes, and area of 40 cm x 40 cm was demarcated and sampled with a standard SASS-net (30 cm x 30 cm, mesh size 1mm2). All the invertebrates sampled were collected and preserved in ethanol (70%) for further off-site identification and counting. Identification is still ongoing and is attempting to key taxa sampled to the lowest resolution possible.

Aquatic macroinvertebrate data was mainly collected in six biotopes, representing SASS5 biotopes (where available) in the form of stones in and out of current, marginal vegetation in and out of current, and gravel-sand-mud in and out of current. The MIRAI (Macroinvertebrate Response Assessment Index) was applied to the data to interpret Ecological Condition of the macroinvertebrate community at each site. The MIRAI is a rule-based model developed by DWAF (Thirion, 2008) considering current limited knowledge of water quality, flow preference, and habitat requirements of invertebrates at family level. The method integrates the currently known ecological requirements of the invertebrate taxa on family level in a community or assemblage to their responses to modified habitat conditions.

TABLE 4.5. GUIDELINES USED TO DELINEATE THE PRESENT ECOLOGICAL STATE CATEGORIES BASED ON OBSERVED AND EXPECTED INTOLERANCE RATINGS (KLEYNHANS 2008).

Category	Description	% of Expected
A	Unmodified, or approximate natural conditions closely.	90 - 100
B	Largely natural with few modifications. A change in community characteristics may have taken place but species richness and presence of intolerant species indicate little modification.	80 - 89
C	Moderately Modified. A lower-than-expected species richness and presence of most intolerant species. Some impairment of health may be evident at the lower limit of this class.	60 - 79
D	Largely Modified. A clearly lower than expected species richness and absence or much lowered presence of intolerant and moderately intolerant species. Impairment of health may become more evident at the lower limit of this class.	40 - 59
E	Seriously Modified. A strikingly lower than expected species richness and general absence of intolerant and moderately intolerant species. Impairment of health may become very evident.	20 - 39
F	Critically Modified. An extremely lowered species richness and absence of intolerant and moderately intolerant species. Only tolerant species may be present with a complete loss of species at the lower limit of the class. Impairment of health generally very evident.	0 - 19

4.2.7 Assumptions and limitations

Sampling Effort

Distances to sites, fences, locked gates, and searching for landowners meant arriving late at some of the sampling sites, limiting data collection time. At sites with a high diversity of habitats, several habitats could not be sampled due to limited time on site.

Sampling following high flows events can produce misleading results, with the hydroperiod of inundated areas mostly unknown. Low taxa diversity would be expected in areas which experienced a brief period of inundation, compared to areas with an extended period of inundation.

Aquatic Macroinvertebrate Data

In this study sampling was focused on quantifying the habitat sampled and identifying the invertebrates in each biotope to the lowest possible taxonomic level (i.e., species level) where possible. Therefore, all the invertebrates sampled are collected with the aim of counting individuals to provide better insight into taxa preferences on genus or species level. To still be able to determine ecological conditions with existing models, in this case MIRAI, SASS5 biotopes were sampled within the SASS time-area limit as much as practically possible.

Identification to the lowest possible level takes time, as do the counting. At the time of this report, invertebrate samples were still being identified and counted to be analysed and the information are therefore not incorporated into this report.

Present Ecological State of Aquatic Macroinvertebrates

MIRAI uses "expert" input to determine stream conditions. In this report data collected drive ecological status output to determine conditions instead of expert opinion. MIRAI results for all available SASS data were calculated using a standard format to improve consistency and reduce subjectivity.

The model also uses "expert opinion based" reference conditions to which collected data are compared. Changes in the reference list can potentially have considerable influence on the ecological category. Where limited data is available, reference conditions may change considerably as more information is gathered. This possibly explain differences in Ecological Classes presented in this report at some of the sites compared to those presented in the LIMCOM 2013 report.

4.3 RESULTS

Results are presented for each site in sequence from highest (drainage basin sequence) in the system to lowest. Results per site are presented in terms of in situ discharge and water quality (TABLE 4.6), instream habitat (TABLE 4.7), and aquatic macroinvertebrates (TABLE 4.8).

TABLE 4.6. A SUMMARY OF RIVER-STREAM TYPE BASED ON DISCHARGE ON THE DAY (MAYBECK ET AL. 1996), AND WATER TEMPERATURE (RIVERS-MOORE ET AL. 2004).

Site Code	Categories			
	Based on sampling date Discharge	Temperature	pH	EC
CROC-A24J-ROOIB	Stream	Cool	Alkaline	Freshwater
LIMP-A41D-SPANW	Stream	Cool	Alkaline	Freshwater
MATL-A41C-WDRAAI	Small stream	Cool	Alkaline	Freshwater
LEPH-A50H-SEEKO	Stream	Cool	Circum-neutral	Freshwater
LIMP-A63C-LIMPK	Small river	Cool	Alkaline	Freshwater
MOGA-A63D-LIMPK	Trickle-pools	Cool-warm	Circum-neutral	Subsaline
LIMP-A71L-MAPUN	Stream	Warm	Alkaline	Freshwater
SAND-A71K-R508B	Headwater	Warm	Alkaline	Subsaline
LUVU-A91K-OUTPO	Small river	Cool-warm	Alkaline	Freshwater
OLIF-B73C-MAMBA	Stream	Cool	Alkaline	Subsaline
OLIF-B73H-BALUL	Small river	Cold-cool	Alkaline	Freshwater
GLET-B81J-LRANC	Stream	Cool	Alkaline	Subsaline
LETA-B83A-LONEB	Stream	Cool	Alkaline	Freshwater
ELEP-Y30C-SINGU	Small river	Cool	Alkaline	Freshwater
SHIN-B90H-POACH	Headwater	Cool	Alkaline	Freshwater
LIMP-Y30F-CHOKW	Small river	Cool	Alkaline	Freshwater

Subsaline conditions was recorded at four of the sites (TABLE 4.6):

- the Mogalakwena where flow was reduced to a trickle
- the Sand which is already elevated close to its source (Pietersburg)
- the Olifants River close to where it enters the Kruger National Park (Mamba site), and
- the Great Letaba River at the Ranch.

TABLE 4.7. HABITAT HETEROGENEITY IS EXPRESSED AS A PERCENTAGE FOR EACH SITE, BASED ON THE DIVERSITY OF TURBULENCE, SUBSTRATES, VEGETATION, DEPTH, VELOCITY, AND HYDRAULIC BIOTPES SAMPLED. AREA IN METERS SQUARE REPRESENTS THE DEMARCATED AREAS SAMPLED AT EACH SITE IN TERMS OF DEPTH, WIDTH, AND LENGTH.

Site	Date	Efforts	Categories						Habitat	Area
			Depth	Velocity	Turbulence	Hydraulic	Substrate	Vegetation	Heterogeneity	m^3
CROC-A24J-ROOIB	21-Apr-21	5	3	3	3	2	4	2	46%	0.250
LIMP-A41D-SPANW	22-Apr-21	6	2	3	5	4	6	5	68%	0.216
MATL-A41C-WDRAAI	23-Apr-21	6	2	3	3	3	6	2	51%	0.258
LEPH-A50H-SEEKO	24-Apr-21	6	2	3	3	5	7	1	59%	0.227
LIMP-A63C-LIMPK	25-Apr-21	8	2	3	5	5	7	4	70%	0.293
MOGA-A63D-LIMPO	26-Apr-21	3	3	1	1	2	7	1	41%	0.090
LIMP-A71L-MAPUN	27-Apr-21	7	2	3	4	2	4	2	46%	0.197
SAND-A71K-R508B	28-Apr-21	6	2	2	2	3	6	3	49%	0.115
LUVU-A91K-OUTPO	29-Apr-21	6	2	3	4	5	6	3	62%	0.215
SHIN-B90H-POACH	1-May-21	6	3	3	3	4	7	2	59%	0.154
LETA-B83E-LONEB	4-May-21	6	2	3	5	5	6	2	62%	0.206
OLIF-B73C-MAMBA	5-May-21	6	2	3	4	4	7	3	62%	0.236
OLIF-B73H-BALUL	3-May-21	6	3	3	5	4	7	3	68%	0.219
GLET-B81J-LRANC	6-May-21	6	2	3	4	5	7	3	65%	0.206
ELEP-Y30C-SINGU	9-Jun-21	6	2	4	3	4	5	3	57%	0.335
LIMP-Y30F-CHOKW	10-Jun-21	6	3	3	3	3	4	4	54%	0.244

The variety of habitats were compared to potential habitats (see TABLE 4.3), and expressed as a percentage (i.e., Habitat Heterogeneity). Area sampled (i.e., a combination of the depth, width, length of each sampling effort) was calculated for each of the biotopes.

Low habitat heterogeneity was encountered at:

- the Rooibokkraal site in the Crocodile River (turbulence, hydraulic, substrate, and marginal vegetation)
- the Mogalakwena (velocity, turbulence, hydraulic and marginal vegetation)
- Limpopo River at Mapungubwe (depth, hydraulic, substrate, and marginal vegetation), and
- The Sand (depth, velocity, turbulence, substrate, and marginal vegetation)

High habitat heterogeneity was encountered in the Limpopo River at the two sites upstream from the Sasha confluence, A41D-SPANW, and A63C-LIMPK, and the Olifants River at Mamba and Balule. At the Luvuvhu River site, habitat heterogeneity was high, but areas with deeper strong flows with stable substrates were not wadeable.

Ecostatus results per site, based on the available data is included for each site. The table below summarises results for the June 2012, April-May 2021, and June 2021 sampling events.

Conditions were predominantly categorised as moderately impaired (C-class), with poor conditions in 2021 encountered in the Mogalakwena River. Flow was restricted to a trickle in the Mogalakwena despite most other tributaries in the region experiencing high to moderate flows. Lack of flow in April 2021 is the main driver of poor conditions in the Mogalakwena.

The ecostatus in the Shingwedzi River in 2021 was categorised as largely natural to moderate, despite the relative low number of taxa encountered. The reference or expected taxa is low, therefore reflecting relatively good conditions.

TABLE 4.8. ECOSTATUS BASED ON AQUATIC MACROINVERTEBRATES, USING THE MIRAI MODEL.

LIMCOM 2021 SITE CODE	LIMCOM 2012 SITE CODE	FBIS SITE CODE	RIVER	ECOSTATUS		
				RQOs	June 2012	April-May June 2021
CROC-A24J-ROOIB		A2CROC-ROOIB	Crocodile	C/D		C/D
LIMP-A41D-SPANW	LmEWR01	A4LIMP-SPANW	Limpopo	C	C[2]	C
MATL-A41C-WDRAAI		A4MATL-PHOFU	Matlabas	C		C
LEPH-A50H-SEEKO		A5LEPH-SEEKO	Lephalale			C/D
LIMP-A63C-LIMPK		A6LIMP-LIMPK	Limpopo			C
MOGA-A63D-LIMPK		A6MOGA-LIMPK	Mogalakwena			D
SHAS-Y20B-TULIB			Shashe			**C**
LIMP-A71L-MAPUN	LmEWR02	A7LIMP-MAPUN	Limpopo		C/D[3]	C
UMZI-Y20C-BEITB			Umzimgwan			**C**
SAND-A71K-R508B		A7SAND-R508B	Sand			C
LUVU-A91K-OUTPO		A9LUVU-MUTAL	Luvuvhu			C
OLIF-B73C-MAMBA		B7OLIF-MAMB1	Olifants	C		C
OLIF-B73H-BALUL		B7OLIF-BALUL	Olifants	C		C
GLET-B81J-LRANC		B8GLET-IFR16	Great Letaba	C		C
LETA-B83A-LONEB		B8LETA-NGWEN	Letaba	C		C
ELEP-Y30C-SINGU		Y3ELEP-SINGU	Elephantes			C
SHIN-B90H-POACH	(LmEWR06)	B9SHIN-POACH	Shingwedzi		D	B/C

2 In the Dickens et al. 2012 LIMCOM report, the Ecological Category was 80% - Class B, but re-entering the data into the model a Class C was achieved for the June 2012 survey at this site (see TABLE 8.10).

3 In the Dickens et al. 2012 LIMCOM report, the Ecological Category was 87% - Class B, but re-entering the data into the model a Class C/D was achieved for the June 2012 survey at this site (see Table 8.24).

LIMP-Y30F-CHOKW	LmEwr07	Y3LIMP-CHOKW	Limpopo	D	C

Flow-depth data were not collected at the Shashe and Umzingwani sites (SHAS-Y20B-TULIB and UMZI-Y20C-BEITB) by the team during a July 2021 field survey. Budget constraints and Covid regulations only allowed for a small team with limited data collection time.

4.4 DISCUSSION

The site in the Crocodile River on Rooibokkraal is located the highest up in the basin, and is just above the Marico-Crocodile confluence, which is the start of the Limpopo River. The Crocodile River at the Rooibokkraal site was categorised during the April 2021 survey as moderate to largely impaired (C/D class), but thereafter, based on Ecostatus, the Limpopo River "improves" slightly to moderately impaired (C-class). At the sites sampled in the mainstem Limpopo River, the moderately impaired category (C-class) is then maintained all the way to the Chokwe site in Mozambique.

Habitat conditions naturally change in a river system from source to sea, with one of the main changes being substrates dominated by cobble-boulder to gravel-sand-mud. At the Mapungubwe site in the Limpopo River, there is a dramatic chance in substrate composition when compared to the Limpokwena site. In the Limpopo River at the Limpokwena site there is an abundance of bedrock-boulder and cobble-gravel biotopes, but at Mapungubwe downstream from the Shashe River confluence, dominant substrates are sand-gravel. This dramatic change in habitat influence the aquatic macroinvertebrate community composition, but where there are stable substrates in flowing water, taxa expected in cobble-boulder-bedrock substrates are still present. For example, in a tree-branch embedded in the sand with relatively fast to moderate velocity, the Epehemeroterans Tricorythidae and Oligoneuridae was present and abundant. Where there was one cobble in flow amongst sand-gravel, there were Hydropsychidae and Tricorythidae present in low abundance. This suggests that the limitations in physical habitat in the Limpopo River at Mapungubwe was driving abundance and presence for Tricorythidae, Oligoneuridae and Hydropsychidae, rather than water quality. The same was encountered at the furthest downstream site on the Limpopo (Chokwe), where Tricorythidae was present in a submerged branch in a flowing side channel.

The sites where the ecostatus was categorised as largely impaired (Mogalakwena) or moderately to largely impaired (Lephalale) are tributaries of the Limpopo, where flow conditions were dramatically altered.

The Shashe and Mzingwani streams in Zimbabwe are listed as naturally seasonal sand-bed rivers with highly variable rainfall (Van der Waal 1997), with species associated with these systems being potentially well adapted to survive with no surface flows and the apparent availability subsurface flows (Van der Waal 1997).

In the Olifants River, sampled during low flow in September 2020 and high flow in May 2021, there was a dramatic change in algal cover on substrates, and community composition within the in substrates in current. Tricorythidae, which was absent during low flow as nymphs, were extremely abundant during high flow. The exotic snail, Thiaridae: *Tarebia granifera*, was the most abundant taxa in every biotope sampled during low flow but was scarce during high flow. Both these responses are most likely driven by both flow and water quality, but this needs to be determined with supportive empirical evidence. The dominance of *Tarebia granifera* during low flow conditions provides some insight into what could be expected when low flow conditions are maintained. More research efforts should focus on how this exotic snail influence the stream community in terms of competition and functioning.

The absence of certain species historically recorded is of concern. In the Olifants River, Oberholzer & van Eeden (1967) recorded and mentioned earlier surveys when Unionidae and several other gastropod species were recorded. Most of the species recorded during these surveys have not been recorded since (De Kock et al. 2002; De Kock & Wolmarans 2010; Sithole et al. 2018), and the reason for their absence is unknown or speculative.

Similarly, Palaemonidae: *Macrobrachium* sp. have historically been reported in the Olifants and Sabie (Pienaar 1961; Taylor 1990), but is now presumed (because its not encountered) absent in both systems. Why is its absent, and what are the changes in the system that made a species which evolved with the ebbs and flows for millenia suddenly disappear? The concern is that such information is not highlighted or addressed during general surveys, and it barely affects the Ecostatus, suggesting everything is still acceptable (moderately impaired). The causes of a species disappearance should be investigated and possible causes addressed, especially since we have no idea of the implications on the ecosystem when a species is lost. If we do not address or attempt to understand these issues, ecostatus becomes an illusion, providing consolation through maintaining a false sense of security.

4.5 APPENDIX INVERTEBRATE DATA

Appendix C contains the raw data on which the above presentation is based.

De Kock, K. N., & Wolmarans, C. T. (2010, December). Verspreiding en habitats van Unio caffer Krauss, 1848 (Bivalvia: Unionoida: Unionidae) in Suid Afrika gebaseer ofp die rekords in die databasis van die Nasionale Varswaterslakversameling. Suid-Afrikaanse Tydskrif vir Natuurwetenskap en Tegnologie, 29(4), pp. 173-185.

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5 RIPARIAN VEGETATION

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5.1 INTRODUCTION

During April and May of 2021, 14 sites were surveyed and sampled along the main channel of the Limpopo River and some of its tributaries within South Africa. In June 2021 two assessments were conducted in Mozambique, the Limpopo River and the Elefantes, and the Sashe River in Zimbabwe was assessed during July of 2021. The biophysical survey for riparian vegetation at each site consisted of site and riparian zone delineation, determination of the present ecological status (PES) for riparian vegetation, and determination of indicator / environment links in order to determine Environmental Flows for riparian vegetation and definition and parameterisation of endpoints for inclusion in risk analyses using PROBFLO. This report outlines the ecostatus component of the assessment.

5.2 METHODS:

5.2.1 Study area and sampling regime

The Limpopo Basin encompasses portions of South Africa, Botswana, Zimbabwe and Mozambique. A total of 18 study sites were strategically selected in order to best represent the various sectors within the Limpopo Basin. Rivers sampled included the Crocodile, Limpopo, Matlabas, Lephalala, Mogalakwena, Sand, Luvuvu, Shingwedzi, Olifants, Letaba, Groot Letaba, Elephantes, Shashe and Umzingwani (Table 2.1FIGURE 2.2 RISK REGIONS IN THE LIMPOPO BASIN. THE GREEN STARS INDICATE SITE LOCATIONS.& FIGURE 2.2). Some rivers were sampled multiple times at different locations as they extended over larger areas.

5.2.2 In Situ Data Collection

In situ data collection was conducted with the use of cross-section transects perpendicular to flow. Cross-section locations were determined by on-site geomorphologist and riparian vegetation specialists. As far as possible, sites were placed across single or less complicated channels, perpendicular to flow and included vegetation species that represented flow-dependant community compositions (woody and non-woody).

Data collected along cross-section transects were assessed within a 1m^2 area from the base of the staff as a standard and included both biotic and abiotic data. Biotic data was vegetation-related and abiotic data included substrate, geomorphic feature, hydraulics, hydrology, water chemistry, ecotoxicology and elevation.

Cross-sections were surveyed using a Leica TCR403 Power total station (FIGURE 5.1). Intervals of recorded points along transects depended upon the variation of topography and vegetation composition along transects. During the setup process, permanent markers (benchmarks) were created in order to ensure future replication of transects. Benchmarks were created in the form of steel pegs inserted into the ground, pegs inserted into the base of large trees or drilled markers on large boulders, bedrock or infrastructure. The purpose of the benchmarks was to allow for the linking of future cross-section profiles to this study. In some cases, sites had been previously surveyed, therefore existing benchmarks were utilized in order to link historical cross-section data to transects surveyed during this study.

FIGURE 5.1. SURVEY SETUP - LEICA TCR403 POWER TOTAL **STATION ON TRIPOD.**

Several of the sites surveyed during this study were also surveyed in a study that took place in 2012. Some of these sites therefore had existing benchmarks that were utilized in order to link current data to the previously recorded profiles. These data was very useful as it allowed us to identify changes that took place over the nine-year period. Chokwe on the Limpopo River, Mozambique is an example of this (Figure 5.2). One such benchmark was recorded with current data, the benchmark in the form of a corner wall (Figure 5.3). With the use of previously recorded GPS coordinates, photographs and descriptions, we were able to identify the exact locations of the start and end of the previously recorded transect as seen in Figure 5.2 below.

FIGURE 5.2. LIMPOPO RIVER, CHOKWE IN MOZAMBIQUE. THE TOTAL STATION WAS POSITIONED ON-LINE WITH THE BASE OF THE LARGE FICUS SYCOMORUS INDICATED IN THE PHOTOGRAPH ABOVE AS THE END OF THE TRANSECT.

FIGURE 5.3. PREVIOUS BENCHMARK SURVEYED INTO CROSS-SECTION TRANSECT IN ORDER TO LINK 2012 DATA TO DATA COLLECTED DURING THIS SURVEY.

5.2.3 Biotic data collected:

Vegetation: Plant species were identified along cross-sections along with individual height and abundance (if woody classification) and cover percentage (if non-woody classification). The relative height of individual plants was recorded along transects with the use of a Leica TCR403 Power total station so that the relative elevation of the individual could be linked to water level and discharge values.

Algae: In addition to vegetation data, the percentage cover of algae was also recorded for additional data relating to in-stream conditions. The location was also recorded with the use of a Leica TCR403 Power total station for the determination of relative elevation according to water level and discharge values.

5.2.4 Driver / abiotic data collected:

Elevation: Elevation was recorded for each point along transects with the use of the Leica TCR403 Power total station. Elevation values translate to relative elevation according to the lowest recorded point along transects (Figure 5.4). In this Chokwe example (Figure 5.4) values indicated along the profile are elevation values relative to the lowest point on the transect (0,000 at approximately 200m from the start of transect on the left bank). Values; 1,293; 1,315; 1,241; 1,268; 1,276; 1,280; 1,270 and 1,277 on either side of the '0,000' represent water level values for each of the channel along the profile. Value 8,315 represents the start of the transect (which is 8,315m elevation relative to the lowest recorded point on the transect). The value 4,782 on the far-right hand point of the profile indicates the end of the profile as well as the height of the F. sycomorus illustrated in Figure 5.2. All other points shown on this profile indicate some of the plant species recorded along the transect and their relative elevation values.

Discharge: Discharge was measured using the OTT MF Pro handheld device and a SonTek, M9 River Surveyor. The MF Pro handheld device was utilized by default unless conditions were unfavourable (unwadable or unsafe) to do so. The accuracy of the M9 River Surveyor was limited when water depth was <0.3m. Under conditions where channel depth ranged <0.3m and >1m, channels were divided into sections and assessed with both the MF Pro and River Surveyor. Total discharges calculated by the separate devices were then added together in order to determine the total discharge. The correct usage of a SonTek, M9 River Surveyor includes a minimum of 4-6 runs, perpendicular to flow in order to determine the most accurate calculation of total discharge for a site or section. Preferably, runs were recorded in pairs, including the recording of discharge from Left to Right bank and then again from Right to Left bank (or visa-versa). Once the minimum number of runs were recorded, an average of the total discharge was utilized as the accepted discharge value.

Substrate characteristics: Dominant substrate was determined visually at each point along the transect and expressed as percentage cover. Substrate definition was according to the modified Wentworth classification of substrate types by size (Wentworth, 1922). This was also recorded in association with each individual vegetation point recorded along cross-sections in order to determine plant species substrate preferences.

Water quality: Water quality data will be applied to statistical analysis for individual plants and also community compositions at each of the study sites in order to determine whether water quality is a driving factor in riparian vegetation species and community composition. Components that were tested included; pH, temperature, turbidity, sulphate, ammonium, nitrates, nitrites, phosphates, chlorides, COD, thorium, magnesium and calcium.

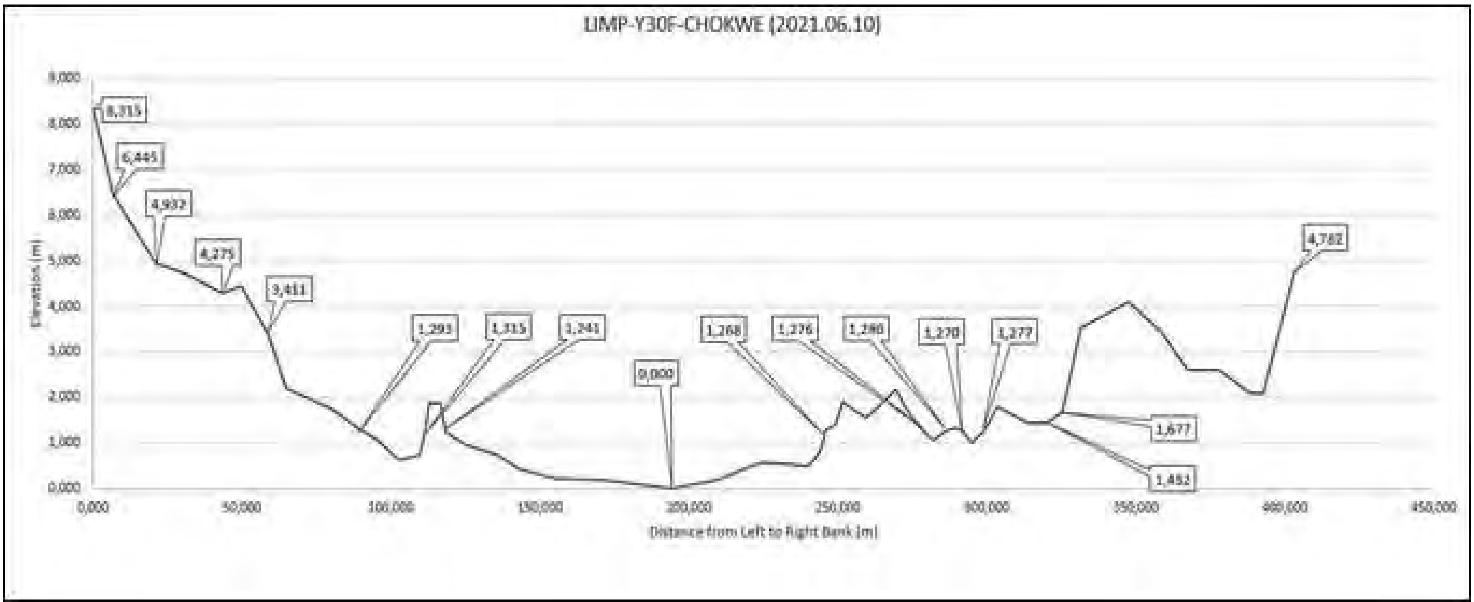


FIGURE 5.4. CROSS-SECTION PROFILE RECORDED ON 10 JULY 2021 AT CHOKWE ON THE LIMPOPO RIVER IN MOZAMBIQUE.

5.2.5 Present Ecological State

The Present Ecological State (PES) of riparian EWR zones was assessed using the Riparian Vegetation Response Assessment Index (VEGRAI) level 4 (Kleynhans et al., 2007), with simplification to 2 broad zones: the Macro-channel bank and the Macro-channel valley (floor). Since all VEGRAI assessments are relative to the natural unmodified conditions (reference state) it is necessary and important to define and describe the reference state for each site. This is done (in part) before going into the field using historic aerial imagery, present and historic species distributions, general vegetation descriptions of the area, any anecdotal data available, knowledge of the area and comparison of the site characteristics to other comparable sections of river that might be in a better state. Armed with this information the reference (and present state) is quantified on site whereby the assessor reconstructs and quantifies the reference state from the present state by understanding how visible impacts have caused the vegetation to change and respond.

Impacts on riparian vegetation at the site are then described and rated. It is important to distinguish between a visible / known impact (such as flow manipulation) and a response of riparian vegetation to said impact. If there is no response by riparian vegetation, the impact is noted but not rated since it has no visible / known effect. This is often the case with water quality for example. Ratings of impacts are as follows:

- No Impact = 0
- Small impact = 1
- Moderate impact = 2
- Large Impact = 3
- Serious impact = 4
- Critical impact = 5

Once the riparian zone has been delineated, the reference and present states has been described and quantified (aerial cover is used) and a species checklist for the site has been compiled, the VEGRAI metrics are rated and qualified. Table 5.1 outlines metrics that were assessed and Table 5.2 outlines the categories that may be the outcome.

TABLE 5.1. METRICS THAT ARE ASSESSED IN VEGRAI 4.

Vegetation Components	Level 4
Woody	Cover
	Abundance
	Species composition
	Recruitment
	Vertical structure
	Population structure
Non-woody (grasses, sedges, herbaceous vegetation)	Cover
	Species composition
Specialized category (reeds; palmiet)	Cover

5.3 RIPARIAN VEGETATION PRESENT ECOLOGICAL STATE

5.3.1 PES Summary

This section outlines the present ecological state (PES) of riparian vegetation on a site by site basis but starts with a summary of all sites: Table 5.3. Outlines the PES category for each site as a whole (Riparian zone) and separated into the macro-channel valley and bank.

TABLE 5.2. DESCRIPTIVE CATEGORIES USED TO DESCRIBE THE PRESENT ECOLOGICAL STATUS (PES) OF BIOTIC COMPONENTS (ADAPTED FROM KLEYNHANS, 1999).

Category	Description	% of Expected
A	Unmodified, or approximate natural conditions closely.	90 - 100
B	Largely natural with few modifications. A change in community characteristics may have taken place but species richness and presence of intolerant species indicate little modification.	80 - 89
C	Moderately Modified. A lower-than-expected species richness and presence of most intolerant species. Some impairment of health may be evident at the lower limit of this class.	60 - 79
D	Largely Modified. A clearly lower than expected species richness and absence or much lowered presence of intolerant and moderately intolerant species. Impairment of health may become more evident at the lower limit of this class.	40 - 59
E	Seriously Modified. A strikingly lower than expected species richness and general absence of intolerant and moderately intolerant species. Impairment of health may become very evident.	20 - 39
F	Critically Modified. An extremely lowered species richness and absence of intolerant and moderately intolerant species. Only tolerant species may be present with a complete loss of species at the lower limit of the class. Impairment of health generally very evident.	0 - 19

TABLE 5.3. SUMMARY OF RIPARIAN VEGETATION PES, EXPRESSED AS CATEGORIES.

River	Site	Macro channel valley	Macro channel bank	Rip Zone
Crocodile	CROC-A24J-ROOIB	C	C	C
Limpopo @ Spanwerk	LIMP-A41D-SPANW	C	C/D	C/D
Matlabas	MATL-A41D-WDRAAI	B/C	C	C
Lephalala	LEPH-A50H-SEEKO	C	C	C
Limpopo @ Limpokwena	LIMP-A36C-LIMPK	B/C	C	C
Mogalakwena	MOGA-A36D-LIMPK	C	B/C	C
Shashe	SHAS-Y20B-TULIB	D	D	D
Limpopo @ Poachers Corner	LIMP-A71L-MAPUN	C	B/C	C
Umzingwani	UMZI-Y20C-BEITB	D	D	D
Sand	SAND-A71K-R508B	C	B/C	B/C
Luvuvhu	LUVU-A91K-OUTPO	B/C	B	B
Olifants @ Mamba	OLIF-B73C-MAMBA	C/D	C	C
Olifants @ Balule	OLIF-B73H-BALUL	C	C	C
Groot Letaba	GLET-B81J-LRANC	C	C	C
Letaba @ Lonely Bull	LETA-B83A-LONEB	C	C	C
Elephantes Below Massingir	ELEP-Y30C-SINGU	C	D	C/D
Shingwedzi	SHIN-B90H-POACH	B/C	B	B
Limpopo @ Chokwe	LIMP-Y30F-CHOKW	D	D	D

5.3.2 Crocodile River (CROC-A24J-ROOIB):

The Crocodile River was a single confined channel at the site, mostly dominated by alluvial features, with consolidated banks and unconsolidated within-channel deposits of sand and gravel (open and vegetated). Banks were dominated by tall trees and shrubs, mostly riparian, but with some terrestrial species, flood benched were mixed woody and non-woody and alluvial bars were dominated by non-woody grasses and sedges and some with reedbeds. Alien vegetation was limited to annual weed species. Dominant species included Cynodon dactylon, Phragmites mauritianus, Panicum maximum, Combretum erythrophyllum, Vachellia gerardii, Ziziphus mucronata and Gymnosporia senegalensis. A schematic profile with associated vegetation and geomorphic features is shown in Appendix B (1) and a list of species observed at site is shown in Appendix B (2).

SITE PHOTOGRAPHS (LEFT) AND INDICATION OF SITE PLACEMENT ON GOOGLE EARTH © OVERLAY (RIGHT) FOR THE CROCODILE RIVER (CROC-A24J-ROOIB).

The site occurs along sub-quaternary A24J-00324. This sq was assessed as a category D overall (largely modified; DWS, 2014), but riparian zone continuity was moderately modified, and riparian zone modification was also moderate. The majority of the impacts were thus instream and flow related.

In 1836 W.C. Harris noted of the Crocodile River, from Bagobone River to the Ooli [Crocodile] River: "Three hours travelling between two ranges of the Cashan mountains brought us to the Ooli River, a pretty little stream... The banks of the Ooli are precipitous and clothed with extensive Mimosa [Acacia] groves... In order to drive the elephants into the plain, preparatory to hunting them next day, we set fire to the grass..." [p. 157] (Skead, 2009). This can be used as an indication that at least the banks were historically dominated by dense woody vegetation, notably Acacia (now Vachelia). The present state still reflects this mostly, with an overall PES score of 64.2% (category C, which is moderately modified from reference conditions). The table below outlines a summary of the PES ratings, score and ecological category of zones, and provides most notable reasons for the perturbation.

PES SCORE AND CATEGORY WITH MAIN REASONS FOR THE SCORE.

LEVEL 4 ASSESSMENT		Crocodile @ A24J_Rooik			21 April 2021
RIPARIAN VEGETATION EC METRIC GROUP	CALCULATED RATING	WEIGHTED RATING	CONFIDENCE	RANK	WEIGHT
Macro channel valley	69.5	20.2	3.4	2.0	29.1
Macro channel bank	62.1	44.0	3.2	1.0	70.9
	2.0				100.0
LEVEL 4 VEGRAI (%)				64.2	
VEGRAI EC				**C**	
AVERAGE CONFIDENCE				3.3	
	Zone				
	Macro channel valley		Macro channel bank		
VEGRAI % (Zone)	69.5		62.1		
EC (Zone)	C		C		
Confidence (Zone)	3.4		3.2		
Main cause of PES: The most notable impacts resulting in the ecoststus score, as observed at site, are elevated woody cover, facilitated by reduced flooding and almost complete exclusion from herbivory. A small amount of perennial alien species also occurred at site (Mellia azedarach and Arundo donax) as well as annual alien weeds species. Vegetation response to reduced flows along the valley floor, if any, was masked by recent flood disturbance. Abundant green filamentous algae also suggests elevated nutrient loading is possible.					

5.3.3 Matlabas River (MATL-A41D-WDRAAI):

The Matlabas River, at site, was a confined channel mostly dominated by well vegetated alluvial features, with consolidated banks with a distinct tree line by tall trees and shrubs, mostly riparian, but with some terrestrial species. Most of the channel valley was dominated by non-woody grasses (dominant), sedges and reeds. Alien vegetation was limited to annual weed species. Dominant species included Cynodon dactylon, Phragmites mauritianus, Setaria sphacelata, Eragrostis palna, Persicaria decipiens, Combretum erythrophyllum, Vachellia gerardii and V. erioloba. A schematic profile with associated vegetation and geomorphic features is shown in Appendix B (1).

SITE PHOTOGRAPHS (LEFT) AND INDICATION OF SITE PLACEMENT ON GOOGLE EARTH © OVERLAY (RIGHT) FOR THE MATLABAS RIVER (MATL-A41D-WDRAAI).

The site occurs along sub-quaternary A41D-00206. This sq was assessed as a category C overall (moderately modified; DWS, 2014), but riparian zone continuity was only slightly modified, and riparian zone modification was moderate. The majority of the impacts were flow related.

The present state still reflects this mostly, with an overall PES score of 70.8% (category C, which is moderately modified from reference conditions). The table below outlines a summary of the PES ratings, score and ecological category of zones, and provides most notable reasons for the perturbation.

PES SCORE AND CATEGORY WITH MAIN REASONS FOR THE SCORE.

LEVEL 4 ASSESSMENT		Matlabas_A41D_Wdraai			23 April 2021
RIPARIAN VEGETATION EC METRIC GROUP	CALCULATED RATING	WEIGHTED RATING	CONFIDENCE	RANK	WEIGHT
Macro channel valley	80.0	34.0	3.8	2.0	42.5
Macro channel bank	64.0	36.8	3.2	1.0	57.5
	2.0				100.0
LEVEL 4 VEGRAI (%)				70.8	
VEGRAI EC				**C**	
AVERAGE CONFIDENCE				3.5	
	Zone				
	Macro channel valley			Macro channel bank	
VEGRAI % (Zone)	80.0			64.0	
EC (Zone)	B/C			C	
Confidence (Zone)	3.8			3.2	

Main cause of PES:

The most notable impacts resulting in the ecostatus score, as observed at site: reduced flows and floods have facilitated an increase in reed cover. This was confirmed verbally by the farmer who has been living there for 40 years and recounts how few reeds there were at an earlier time. Some vegetation removal due to roads, fence lines and water pumps and the influence of the bridge. Invasion by alien species was minimal and limited to annual weeds. Benthic green algae in the channel suggests nutrients may have increased but this could also be due to less flows.

5.3.4 Limpopo River @ Spanwerk (LIMP-A41D-SPANW):

The Limpopo River, at the Spanwerk site, was a single confined alluvial dominated channel that flowed into a natural hydraulic control forming a bedrock anastomosing section (dyke) with resultant upstream pool or slower-flowing, deeper areas. As a result, the vegetation was more complex and diverse. Generally, the marginal zone was dominated by a mix of non-woody, well vegetated alluvial areas (mostly Cyperus longus, Cynodon dactylon and Digitaria eriantha along upstream banks or at mid-channel bar edges) and spares bedrock-controlled areas with scattered sedge (C. longus) and low shrub (Gomphostigma virgatum). Consolidated mid-channel bars and flood benched were well vegetated and supported good non-woody cover (sedge and grass) with scattered taller sub-adult trees (notably Combretum imberbe and Vachellia gerardii. A schematic profile with associated vegetation and geomorphic features is shown in Appendix B (1) and a list of species observed at site is shown in Appendix B (2).

SITE PHOTOGRAPHS (LEFT) AND INDICATION OF SITE PLACEMENT ON GOOGLE EARTH © OVERLAY (RIGHT) FOR THE LIMPOPO RIVER @ SPANWERK (LIMP-A41D-SPANW).

The site occurs along sub-quaternary A41D-00217. This sq was assessed as a category D overall (largely modified; DWS, 2014), but while riparian zone continuity was also largely modified, and riparian zone modification was moderate. The majority of the impacts were flow related.

Woody vegetation cover appears to be stable over the last 70 years (compare 1953 to 2005, Figure below) but some has been removed for agricultural lands. The present state however has an overall PES score of 62.0% (category C/D, which is moderately to slightly more modified from reference conditions). The table below outlines a summary of the PES ratings, score and ecological category of zones, and provides most notable reasons for the perturbation.

HISTORICAL AERIAL PHOTOGRAPHS SHOWING TEMPORAL CHANGES.

PES SCORE AND CATEGORY WITH MAIN REASONS FOR THE SCORE.

LEVEL 4 ASSESSMENT		**Limpopo_A41D_Spanwerk**		**2021/4/522**	
RIPARIAN VEGETATION EC METRIC GROUP	**CALCULATED RATING**	**WEIGHTED RATING**	**CONFIDENCE**	**RANK**	**WEIGHT**
Macro channel valley	62.2	27.4	3.4	2.0	44.0
Macro channel bank	61.9	34.7	3.2	1.0	56.0
	2.0				100.0
LEVEL 4 VEGRAI (%)				62.0	
VEGRAI EC				**C/D**	
AVERAGE CONFIDENCE				3.3	

	Zone	
	Macro channel valley	Macro channel bank
VEGRAI % (Zone)	62.2	61.9
EC (Zone)	C	C/D
Confidence (Zone)	3.4	3.2

Main cause of PES:

The most notable impacts resulting in the ecostatus score, as observed at site: well established woody component, some tall trees colonising valley features such as bars suggests reduced flooding frequency and/or magnitude. Alien species presence at the site was mostly annual weeds but with some established perennial aliens such as Mellia azedarach. Some vegetation clearing along banks and at some locations to the river was evident, mainly for installation and access to water pumps, but also for agriculture beyond the banks and livestock and fishermen access to the active channel. Abundant green benthic algae also suggests elevated nutrient loading is possible. The water column was green at the time of sampling.

5.3.5 Lephalala River (LEPH-A50H-SEEKO):

The Lephalala River, at site, was a single confined channel mostly dominated by alluvial features, with consolidated banks and unconsolidated within-channel deposits of sand and gravel (open and vegetated). Banks were dominated by tall trees and shrubs (some creeping shrubs), mostly riparian, but with some terrestrial and alien species, flood benched were mixed woody and non-woody and alluvial bars were dominated by non-woody grasses and sedges and some with linear reedbeds. Alien vegetation was common, especially along unconsolidated alluvial deposits, but was mostly limited to annual weed species (Notably Xanthium strumarium and Datura innoxia. Dominant species included Cynodon dactylon, Phragmites mauritianus, Panicum maximum, Combretum erythrophyllum, Vachellia gerardii, Ziziphus mucronata, Senegalia schweinfurthii, Faidherbia albida and Gymnosporia senegalensis. A schematic profile with associated vegetation and geomorphic features is shown in Appendix B (1) and a list of species observed at site is shown in Appendix B (2).

SITE PHOTOGRAPHS (LEFT) AND INDICATION OF SITE PLACEMENT ON GOOGLE EARTH © OVERLAY (RIGHT) FOR THE LEPHALALA RIVER (LEPH-A50H-SEEKO).

The site occurs along sub-quaternary A50H-00110. This sq was assessed as a category D overall (largely modified; DWS, 2014) and while riparian zone continuity was also largely modified, and riparian zone modification was moderately modified. The majority of the impacts were flow related, both in terms of quantity and quality.

The present ecological state has an overall PES score of 67.8% (category C, which is moderately modified from reference conditions). The table below outlines a summary of the PES ratings, score and ecological category of zones, and provides most notable reasons for the perturbation.

PES SCORE AND CATEGORY WITH MAIN REASONS FOR THE SCORE.

LEVEL 4 ASSESSMENT		Lephalala_A50H_Seeko			24 April 2021
RIPARIAN VEGETATION EC METRIC GROUP	CALCULATED RATING	WEIGHTED RATING	CONFIDENCE	RANK	WEIGHT
Macro channel valley	66.3	18.4	3.7	2.0	27.8
Macro channel bank	68.3	49.3	3.2	1.0	72.2
LEVEL 4 VEGRAI (%)				67.8	
VEGRAI EC				**C**	
AVERAGE CONFIDENCE				3.4	

	Zone	
	Macro channel valley	Macro channel bank
VEGRAI % (Zone)	66.3	68.3
EC (Zone)	C	C
Confidence (Zone)	3.7	3.2

Main cause of PES:

The most notable impacts resulting in the ecostatus score, as observed at site: reduced flows and floods have facilitated an increase in woody cover in the valley floor, notably Faidherbia albida, whose cohorts along the active channel suggest less frequent and smaller floods. Some vegetation removal due to roads, fence lines and the weir. Invasion by alien species was mostly limited to annual weeds, but these were widespread and dense, particularly within the valley bed. Benthic green algae in the channel suggests nutrients may have increased but this could also be due to less/lower flows.

5.3.6 Shashe River (SHAS-Y20B-TULIB):

The site was heavily browsed and grazed by goats and to a lesser degree donkeys. The goats came and went in a continuous stream throughout the day, browsing and grazing on almost every species they could reach. Very distinct browse lines were additional evidence of this feeding pressure. As a result of this intense feeding, trampling and traffic in the rivers and adjacent riparian zones, little to no new recruits were noticed. The only species that did not seem affected were the Hyphaene and Vachellia species. These were the only two species noted that had new recruits. Further damage that was noted was damage to the bark of large trees, suspected goats rubbing up against the trees causing damage.

Human movement through the area was also high but to a lesser degree than the goat pressure. Humans moved in and out of the river to fetch water for nearby crops that were planted within the riparian zones. These farms were mostly very small and seemed to have low impact in comparison. Children also moved in and out of the area playing in the sand and the water.

Cutting and burning of Croton was extensive and intensive on the floodplain of the left bank. Wood was used for animal enclosures and building of rural housing.

There was in intensive and extensive Xanthium invasion on the right bank in the lower and upper zone. Larger indigenous trees were present however Xanthium overtook entire undercover area in large masses. None of this was noted on the left bank. The right bank also had less goats, infrastructure and human traffic so this may be a contributing factor. There were also very small amount of new recruits of Argemone in the channel. These were the only species noted growing within the sandy channel (most of which was try, with a small, narrow trickle of water that did not flow).

Within the main channel there was almost no flow and had intensive and extensive algae in the water. The water also smelt of sewerage. The fish team also found very low abundances and diversity in the river. A possible reason for no now recruits was the fact that surface water was very far from lower done and consisted of only coarse sand, whereas the riparian vegetation belt consisting of the largest and most prevalent individuals were mostly growing on fine sands.

SITE PHOTOGRAPHS (LEFT) AND INDICATION OF SITE PLACEMENT ON GOOGLE EARTH © OVERLAY (RIGHT) FOR THE SHASHE RIVER (SHAS-Y20B-TULIB).

The present state has an overall PES score of 48.2% (category D, which is largely modified). The table below outlines a summary of the PES ratings, score and ecological category of zones, and provides most notable reasons for the perturbation.

PES SCORE AND CATEGORY WITH MAIN REASONS FOR THE SCORE.

LEVEL 4 ASSESSMENT		Shashe			01 September 2021
RIPARIAN VEGETATION EC METRIC GROUP	CALCULATED RATING	WEIGHTED RATING	CONFIDENCE	RANK	WEIGHT
Macro channel valley	50.0	27.7	2.5	1.0	55.3
Macro channel bank	46.0	20.6	2.6	2.0	44.7
LEVEL 4 VEGRAI (%)				48.2	
VEGRAI EC				**D**	
AVERAGE CONFIDENCE				2.5	
	Zone				
	Macro channel valley		Macro channel bank		
VEGRAI % (Zone)	50.0		46.0		
EC (Zone)	D		D		
Confidence (Zone)	2.5		2.6		
Main cause of PES: The most notable impacts resulting in the ecostatus score was extensive and intensive grazing and trampling pressure by livestock, as well as agricultural activities in the riparian zone.					

5.3.7 Mogalakwena River (MOGA-A36D-LIMPK):

The Mogalakwena River, at site, was a seasonal (with many weirs), single confined channel mostly dominated by alluvial features, with consolidated banks and unconsolidated within-channel deposits of sand and gravel. Banks were dominated by tall trees and shrubs, clearly riparian, with a distinct treeline and require strongly seasonal flows or permanent pools. Riparian forest was dominated by Schotia brachypetala, Ficus sycomorus, C. imberbe, Croton megalobotrys, F. albida, Philonoptera violacea and Colophospermum mopane. The alluvial channel bed was dominated by open areas, linear stretches of reed (P. mauritianus) and some tall shrub (notably Nuxia oppositifolia) stabilizing bank edges. The channel was dominated by filamentous green algae and sedges along the edge (C. longus). The site is known for its Pel's fishing owl occurrence and nesting. A schematic profile with associated vegetation and geomorphic features is shown in Appendix B (1).

SITE PHOTOGRAPHS (LEFT) AND INDICATION OF SITE PLACEMENT ON GOOGLE EARTH © OVERLAY (RIGHT) FOR THE MOGALAKWENA RIVER (MOGA-A36D-LIMPK).

The site occurs along sub-quaternary A63D-00034. This sq was assessed as a category C overall (moderately modified; DWS, 2014), but riparian zone continuity was only slightly modified, and riparian zone modification was moderately modified. The majority of the impacts were flow related (quantity).

From 1955 to 2018 there has been an overall increase in woody vegetation cover although multiple changes are evident with some areas reducing woody cover. Tributaries have a noticeable increase (see figure below). The present state has an overall PES score of 76.4% (category C, which is moderately modified from reference conditions). The table below outlines a summary of the PES ratings, score and ecological category of zones, and provides most notable reasons for the perturbation.

HISTORICAL AERIAL PHOTOGRAPHS SHOWING TEMPORAL CHANGES.

PES SCORE AND CATEGORY WITH MAIN REASONS FOR THE SCORE.

LEVEL 4 ASSESSMENT		Mogalakwena_A63D_Limpok			26 April 2021
RIPARIAN VEGETATION EC METRIC GROUP	**CALCULATED RATING**	**WEIGHTED RATING**	**CONFIDENCE**	**RANK**	**WEIGHT**
Macro channel valley	74.4	34.5	3.7	2.0	46.4
Macro channel bank	78.1	41.9	3.2	1.0	53.6
	2.0				100.0
LEVEL 4 VEGRAI (%)				76.4	
VEGRAI EC				**C**	
AVERAGE CONFIDENCE				3.4	

	Zone	
	Macro channel valley	Macro channel bank
VEGRAI % (Zone)	74.4	78.1
EC (Zone)	C	B/C
Confidence (Zone)	3.7	3.2

Main cause of PES:

The most notable impacts resulting in the ecostatus score, as observed at site, was the reduction and regulation of flow. Many weirs occur along this reach with extensive irrigation. Bank and flood feature denudation from severe grazing and trampling pressure which has led to erosion in some places. Some alien species presence but limited to annual weeds. Filamentous green algae severe which suggests possible elevated nutrients.

5.3.8 Limpopo River @ Limpokwena (LIMP-A36C-LIMPK):

The Limpopo River, at the Limpokwena site, was a complex channel, multiple thread in places, with some backwater areas and mixed alluvial / bedrock in nature. The riparian zone was intact with both lateral and longitudinal connectivity being good and with browsing and grazing pressure likely near natural. Some lee bars and other allivual deposits (notable unconsolidated allivia) were invaded by alien weed species, notably X. strumarium and D. innoxia. The marginal zone comprised mostly boulder, cobble or gravel with flowing water for the rheophyte, G. virgatum, and fragmented and scattered clumps of sedge and grass (C. longus and C. dactylon). Alluvial lee bars had formed, mostly in the lee of Mopane or Leadwood sub-adults and fringed by reeds (P. mauritianus). The high flow channel supported young fig trees (F. sycomorus), sand-paper figs (F. capreifolia), reeds and sedge while consolidated banks supported tall tree in places and shorter shrub. Dominant species included Schotia brachypetala, Ficus sycomorus, C. imberbe, Philonoptera violacea and Colophospermum mopane. A schematic profile with associated vegetation and geomorphic features is shown in Appendix B (1).

SITE PHOTOGRAPHS (LEFT) AND INDICATION OF SITE PLACEMENT ON GOOGLE EARTH © OVERLAY (RIGHT) FOR THE LIMPOPO RIVER @ LIMPOKWENA (LIMP-A36C-LIMPK).

The site occurs along sub-quaternary A63C-00033. This sq was assessed as a category D overall (largely modified; DWS, 2014), but riparian zone continuity was only slightly modified, and riparian zone modification was moderately modified. The majority of the impacts were flow related (quantity).

The present ecological state has an overall PES score of 71.1% (category C, which is moderately modified from reference conditions). The table below outlines a summary of the PES ratings, score and ecological category of zones, and provides most notable reasons for the perturbation.

PES SCORE AND CATEGORY WITH MAIN REASONS FOR THE SCORE.

LEVEL 4 ASSESSMENT		Limpopo_A63C_Limpok			25 April 2021
RIPARIAN VEGETATION EC METRIC GROUP	CALCULATED RATING	WEIGHTED RATING	CONFIDENCE	RANK	WEIGHT
Macro channel valley	77.9	44.4	3.7	2.0	56.9
Macro channel bank	76.0	32.7	3.2	1.0	43.1
	2.0				100.0
LEVEL 4 VEGRAI (%)				77.1	
VEGRAI EC				**C**	
AVERAGE CONFIDENCE				3.4	
	Zone				
	Macro channel valley		Macro channel bank		
VEGRAI % (Zone)	77.9		76.0		
EC (Zone)	B/C		C		
Confidence (Zone)	3.7		3.2		
Main cause of PES: The most notable impacts resulting in the ecostatus score, as observed at site were bank and flood feature denudation from severe grazing and trampling pressure which has led to erosion in several places. Some alien species presence but limited to annual weeds.					

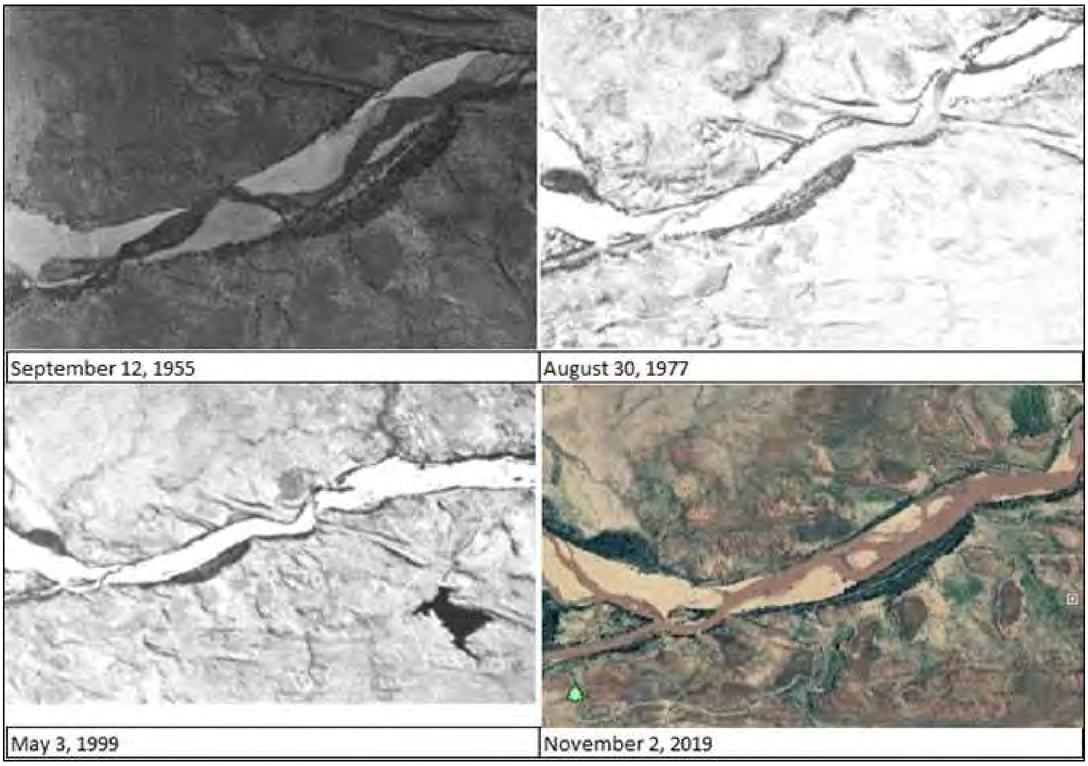
5.3.9 Limpopo River @ Poachers Corner (LIMP-A71L-MAPUN):

The Limpopo River, at the Poachers Corner (Mapumgubwe site), was a wide, open alluvial channel with a distinct, mostly tall woody riparian zone along its length. There was no marginal zone and the active channel was characterized by wide open unconsolidated alluvia, mostly course sand, with no vegetation, or some recruitment of annual weeds, and filamentous green algae in the channel. Bank vegetation was well established with tall shrub (C. megalobotrys and N. oppositifolia) and figs (F. sycomorus) lining the edge of banks, while tall trees dominated the remained of the riparian forest. Dominant woody species included Xanthocercis zambesiaca (some of notable size), P. violacea, C. microphyllum, Grewia bicolor, Phylanthus reticulatus and Hyphaene coriacea. Unshaded areas on banks were dominated by weed species, notably X. strumarium, D. innoxia, Bidens Pilosa and Argemone Mexicana. A schematic profile with associated vegetation and geomorphic features is shown in Appendix B (1).

SITE PHOTOGRAPHS (LEFT) AND INDICATION OF SITE PLACEMENT ON GOOGLE EARTH © OVERLAY (RIGHT) FOR THE LIMPOPO RIVER @ POACHERS CORNER (LIMP-A71L-MAPUN).

The site occurs along sub-quaternary A71L-00005. This sq was assessed as a category C overall (moderately modified; DWS, 2014), but while riparian zone continuity was also moderately modified, and riparian zone modification was only slightly modified. The majority of the impacts were flow related (quantity).

Comparing 1955 to 2019 there appears to be some channel migration within the macro-channel valley, but the position and density of trees appears to be largely unchanged. (figure below). The present state has an overall PES score of 77.3% (category C, which is moderately modified from reference conditions). The table below outlines a summary of the PES ratings, score and ecological category of zones, and provides most notable reasons for the perturbation.



HISTORICAL AERIAL PHOTOGRAPHS SHOWING TEMPORAL CHANGES.

PES SCORE AND CATEGORY WITH MAIN REASONS FOR THE SCORE.

LEVEL 4 ASSESSMENT	Mapungubwe_A71L				27 April 2021
RIPARIAN VEGETATION EC METRIC GROUP	CALCULATED RATING	WEIGHTED RATING	CONFIDENCE	RANK	WEIGHT
Macro channel valley	75.8	48.3	3.8	2.0	63.6
Macro channel bank	80.0	29.1	3.2	1.0	36.4
	2.0				100.0
LEVEL 4 VEGRAI (%)				77.3	
VEGRAI EC				**C**	
AVERAGE CONFIDENCE				3.5	

	Zone	
	Macro channel valley	Macro channel bank
VEGRAI % (Zone)	75.8	80.0
EC (Zone)	C	B/C
Confidence (Zone)	3.8	3.2

Main cause of PES:

The most notable impacts resulting in the ecostatus score, as observed at site, were the reduction in flows, which while known, do not appear to illicit a response from the vegetation since the channel floor is wide and sandy and it's unlikely that a more established marginal zone would have developed under reference flows. Removal of vegetation is small, limited to tourist roads and is mainly caused by wildlife, presumably in near natural densities, although some bank erosion (scouring) has occurred. Some nutrient loading may be prevalent sine the water column had high levels of algae. Invasion by alien plant species was relatively high but limited to annual weed species, particularly along flood features and to a lesser degree banks.

5.3.10 Umzingwani (UMZI-Y20C-BEITB):

This site was equally affected by goats and donkey feeding pressure, however donkeys seemed in larger abundances here in addition to the goats. Similar pressures were noted with little to no new recruits and water quality was just as bad, with a terrible sewerage smell to the water with intensive algae compositions. Here however tiny amounts of *Ludwigia* and *Ishaemum* were noted but in very small quantities. Some other species were present here too that seemed not to be affected by feeding pressure, including Nicotiana and Cassia. Ziziphus was also noticed here but it was unclear as to whether they were affected by feeding pressure as they were in such low abundances at the site. This site also contained large *Schotia* individuals but did not notice any new recruits. There were also very low abundances of *P. mauritianus*. Grazing lawns of *Cynodon* were maintained by donkeys who we noticed grazing on these small patches.

SITE PHOTOGRAPHS (LEFT) AND INDICATION OF SITE PLACEMENT ON GOOGLE EARTH © OVERLAY (RIGHT) FOR THE UMZINGWANI (UMZI-Y20C-BEITB).

The present state has an overall PES score of 50.9% (category D, which is largely modified). The table below outlines a summary of the PES ratings, score and ecological category of zones, and provides most notable reasons for the perturbation.

PES SCORE AND CATEGORY WITH MAIN REASONS FOR THE SCORE.

LEVEL 4 ASSESSMENT		Umzongwani			03 September 2021
RIPARIAN VEGETATION EC METRIC GROUP	CALCULATED RATING	WEIGHTED RATING	CONFIDENCE	RANK	WEIGHT
Macro channel valley	50.0	27.7	2.5	1.0	55.3
Macro channel bank	52.1	23.3	2.6	2.0	44.7
LEVEL 4 VEGRAI (%)				50.9	
VEGRAI EC				D	
AVERAGE CONFIDENCE				2.5	
	Zone				
	Macro channel valley		Macro channel bank		
VEGRAI % (Zone)	50.0		52.1		
EC (Zone)	D		D		
Confidence (Zone)	2.5		2.6		
Main cause of PES: The most notable impacts resulting in the ecostatus score was extensive and intensive grazing and trampling pressure by livestock, as well as agricultural activities in the riparian zone.					

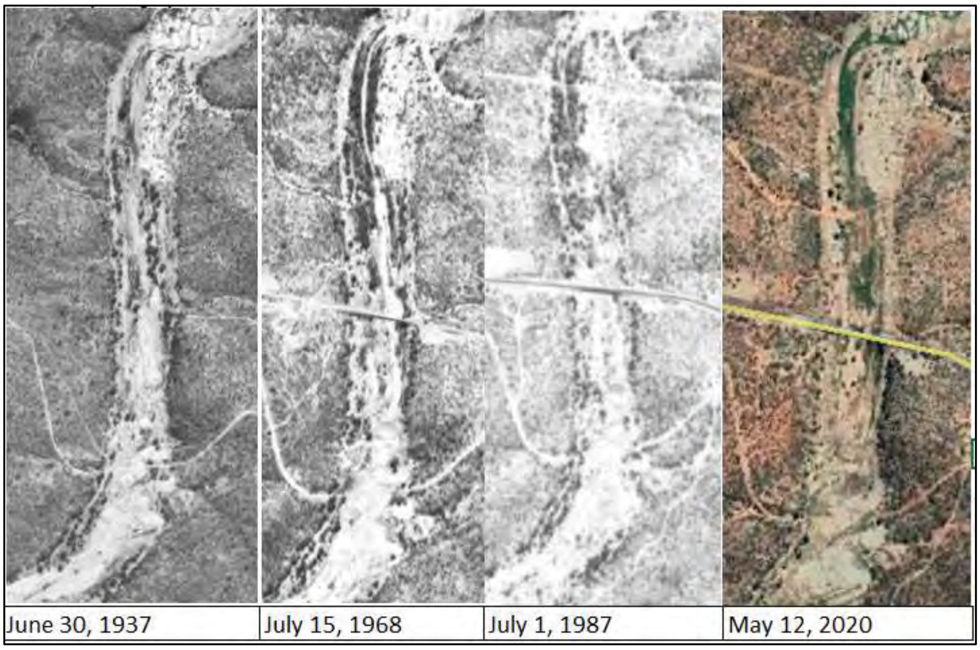
5.3.11 Sand River (SAND-A71K-R508B):

The Sand River, at site, was a single alluvial channel. Banks were gentle, merging into the upland and dominated by mostly terrestrial woody shrubs and trees (notably V. tortilis), but with some ripariuan indicators (P. violacea, C. imberbe, S. brachypetala and F. sycomorus). The macro-channel valley was undulating, with denuded alluvial high flow and flood channels, with dense vegetation on alluvial deposits, mainly sedges (C. sexangularis) and shrubs (Pluchea dioscoridis) but with some tree recruitment in places (F. albida). The active channel was narrow and with substrate covered by algae, lined by sedges and shrubs in places, otherwise open. The presence of Cyperus sexangularis near the active channel suggests the river is seasonal. A schematic profile with associated vegetation and geomorphic features is shown in Appendix B (1).

Site photographs (left) and indication of site placement on Google Earth © overlay (right) for the Sand River (SAND-A71K-R508B).

The site occurs along sub-quaternary A71K-00019. This sq was assessed as a category B overall (Largely natural; DWS, 2014), riparian zone continuity was only slightly modified, and riparian zone modification was also largely natural. The majority of the impacts were flow related (quantity).

From 1937 to 1987 there was an increase in tree density and coverage and then a reduction to 2020 where tree cover and density was less than in 1937. The channel does however appear to be stable (figure below). The present state has an overall PES score of 78.3% (category B/C, which is slightly modified from reference conditions). The table below outlines a summary of the PES ratings, score and ecological category of zones, and provides most notable reasons for the perturbation.



Historical aerial photographs showing temporal changes.

PES SCORE AND CATEGORY WITH MAIN REASONS FOR THE SCORE.

LEVEL 4 ASSESSMENT		Sand_A71K_R508			28 April 2021
RIPARIAN VEGETATION EC METRIC GROUP	CALCULATED RATING	WEIGHTED RATING	CONFIDENCE	RANK	WEIGHT
Macro channel valley	75.6	30.3	1.8	2.0	40.0
Macro channel bank	80.0	48.0	3.2	1.0	60.0
	2.0				100.0
LEVEL 4 VEGRAI (%)				78.3	
VEGRAI EC				**B/C**	
AVERAGE CONFIDENCE				2.5	
	Zone				
	Macro channel valley		Macro channel bank		
VEGRAI % (Zone)	75.6		80.0		
EC (Zone)	C		B/C		
Confidence (Zone)	1.8		3.2		

Main cause of PES:

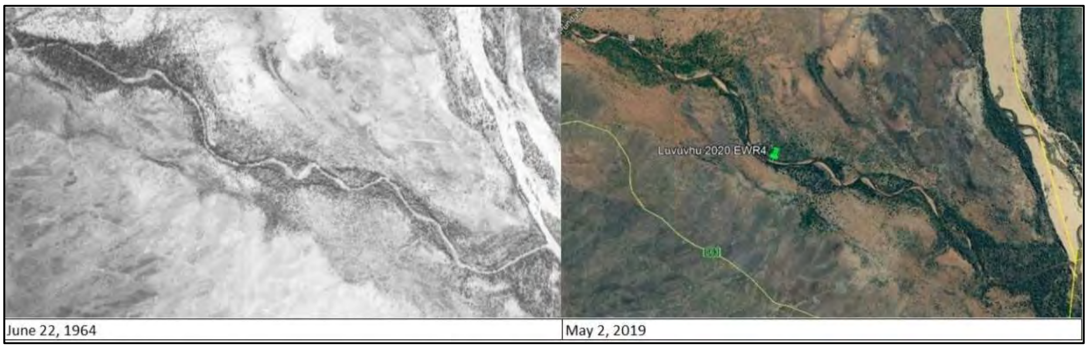
The most notable impacts resulting in the ecostatus score, as observed at site included some vegetation removal for roads, fences and people and livestock access was observed, and some invasion by alien plant species, particularly along the macro channel valley, although the majority were annual weed species.

5.3.12 Levuhvu River (LUVU-A91K-OUTPO):

The Levuhvu River, at site, was a single confined channel mostly dominated by alluvial features, with consolidated banks and unconsolidated within-channel deposits of sand and gravel (open and vegetated), and with an extensive gravel / cobble point bar downstream of the site. Looking upstream from the site the channel was single, bank full and with tall trees to the water's edge. Looking downstream the channel rounded a gravel /cobble point bar with some shrub (P. dioscoridis) and flood-damaged trees (F. albida, Syzygium gerardii). The marginal zone was either open unvegetated, woody (tall tree and shrub, notably P. dioscoridis, S. gerardii, F. sycomorus, Breonadia salicina) or lined by reeds, sedges and grasses, inundated at the time (P.mauritianus, G. fruticosus, C. longus, C. dactylon). The floodplain was mostly open sand with some cobble deposits, supporting younger trees, C. imberbe and F. albida, with tall trees at the edge (Figs, Nyala trees, Apple Leaf and Leadwoods). Banks were alluvial, mostly woody and steep with some open sandy areas. A schematic profile with associated vegetation and geomorphic features is shown in Appendix B (1).

SITE PHOTOGRAPHS (LEFT) AND INDICATION OF SITE PLACEMENT ON GOOGLE EARTH © OVERLAY (RIGHT) FOR THE LEVUHVU RIVER (LUVU-A91K-OUTPO).

The site occurs along sub-quaternary A91K-00039. This sq was assessed as a category B overall (Largely natural; DWS, 2014), riparian zone continuity was largely natural, and riparian zone modification was also largely natural. The majority of the impacts were flow related (quantity). Woody abundance and cover appears to be stable over the last 50 years (1964 to 2019; figure below). The present state has an overall PES score of 83.5% (category B, which is largely natural). The table below outlines a summary of the PES ratings, score and ecological category of zones, and provides most notable reasons for the perturbation.



HISTORICAL AERIAL PHOTOGRAPHS SHOWING TEMPORAL CHANGES.

PES SCORE AND CATEGORY WITH MAIN REASONS FOR THE SCORE.

LEVEL 4 ASSESSMENT		Luvu_A91K_Outp			29 April 2021
RIPARIAN VEGETATION EC METRIC GROUP	**CALCULATED RATING**	**WEIGHTED RATING**	**CONFIDENCE**	**RANK**	**WEIGHT**
Macro channel valley	81.2	44.7	2.5	2.0	55.1
Macro channel bank	86.3	38.7	3.2	1.0	44.9
	2.0				100.0
LEVEL 4 VEGRAI (%)				83.5	
VEGRAI EC				**B**	
AVERAGE CONFIDENCE				2.8	

	Zone	
	Macro channel valley	Macro channel bank
VEGRAI % (Zone)	81.2	86.3
EC (Zone)	B/C	B
Confidence (Zone)	2.5	3.2

Main cause of PES:

The site is mostly natural in terms of riparian vegetation but with some presence of alien annual weeds.

5.3.13 Olifants River @ Mamba (OLIF-B73C-MAMBA):

The marginal zone was dominated by non-woody Ranunculus baurii, Schoenoplectus brachyceras and Phragmites mauritianus. At the transect location, the active channel consisted of four splits (as depicted in satellite image above). The splits in the channel were a result of the build-up of sand bars dominated by sand, cobble and bedrock.

The lower and upper zones were dominated by a non-woody component (same as species mentioned above), including Gomphocarpus fruticosus. Woody component was dominated by Nuxia oppositifolia and Breonadia salicina. There was evidence of scouring of channel bank in the upper zone as a result of the 2000 and 2012 flood events. A schematic profile with associated vegetation and geomorphic features is shown in Appendix B (1).

SITE PHOTOGRAPHS (LEFT) AND INDICATION OF SITE PLACEMENT ON GOOGLE EARTH © OVERLAY (RIGHT) FOR THE OLIFANTS RIVER @ MAMBA (OLIF-B73C-MAMBA).

The site occurs along sub-quaternary B73H-00311. This sq was assessed as a category C overall (Moderately modified; DWS, 2014), while the riparian zone continuity and riparian zone modification were largely natural. The majority of the impacts were flow related (quantity).

From 1944 to 2021 there appears to be a slight increase in woody bank vegetation cover which may be due to individual growth or reduced flooding disturbance, but along in-channel features there has been a loss of woody vegetation cover (figure below). The present state has an overall PES score of 66.5% (category C, which is Moderately modified). The table below outlines a summary of the PES ratings, score and ecological category of zones, and provides most notable reasons for the perturbation.

HISTORICAL AERIAL PHOTOGRAPHS SHOWING TEMPORAL CHANGES.

PES SCORE AND CATEGORY WITH MAIN REASONS FOR THE SCORE.

LEVEL 4 ASSESSMENT		Olifants_B73C_Mamba			05 May 2021
RIPARIAN VEGETATION EC METRIC GROUP	**CALCULATED RATING**	**WEIGHTED RATING**	**CONFIDENCE**	**RANK**	**WEIGHT**
Macro channel valley	61.9	41.2	2.8	2.0	66.5
Macro channel bank	74.2	24.8	3.2	1.0	33.5
LEVEL 4 VEGRAI (%)				66.0	
VEGRAI EC				**C**	
AVERAGE CONFIDENCE				3.0	

	Zone	
	Macro channel valley	Macro channel bank
VEGRAI % (Zone)	61.9	74.2
EC (Zone)	C/D	C
Confidence (Zone)	2.8	3.2

Main cause of PES:

The site had been heavily scoured from recent flood disturbance making it difficult to discern vegetation responses, but flood features supported high densities of alien weeds and remnant pockets of Sesbanea punicea persisted on consolidated features.

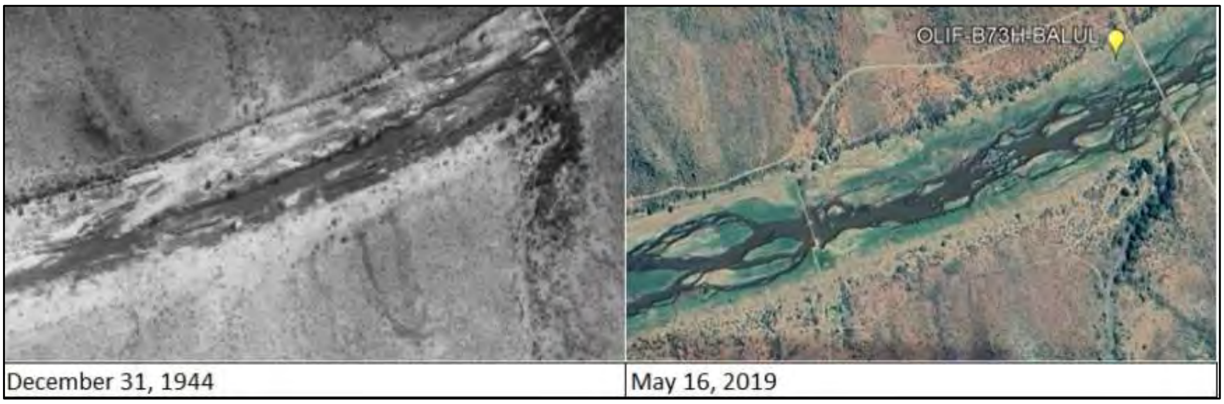
5.3.14 Olifants River @ Balule (OLIF-B73H-BALUL):

The marginal zone was dominated by alluvial soils and bedrock, controlled by bedrock with alluvial deposits. The zone was well grassed and supported Phragmites clumps. The zone consisted of large, saturated open sandy areas with Schoenoplectus brachyceras in high densities on the lower bars. The lower and upper zones consisted of lateral bars dominated by mixed alluvial bedrock with flood channels. The zones were dominated by non-woody vegetation consisting of mostly grasses, some low density Phragmites in place, scattered shrubs dominated by Gomphocarpus fruticosus and alien invasive species. The macro-channel bank consisted of scattered shrubs with a distinct treeline. Dominating species included Philenoptera violacea and Nuxia oppositifolia. A schematic profile with associated vegetation and geomorphic features is shown in Appendix B (1).

SITE PHOTOGRAPHS (LEFT) AND INDICATION OF SITE PLACEMENT ON GOOGLE EARTH © OVERLAY (RIGHT) FOR THE OLIFANTS RIVER @ BALULE (OLIF-B73H-BALUL).

The site occurs along sub-quaternary B73H-00311. This sq was assessed as a category C overall (Moderately modified; DWS, 2014), while the riparian zone continuity and riparian zone modification were largely natural. The majority of the impacts were flow related (quantity).

The weir has been installed since 1944, but otherwise woody bank vegetation has become more defined and woody cover has increased. Woody vegetation along the macro-channel valley however has been removed by flooding disturbance (compare 1944 to 2019; figure below). The present state has an overall PES score of 66.5% (category C, which is Moderately modified). The table below outlines a summary of the PES ratings, score and ecological category of zones, and provides most notable reasons for the perturbation.



HISTORICAL AERIAL PHOTOGRAPHS SHOWING TEMPORAL CHANGES.

PES SCORE AND CATEGORY WITH MAIN REASONS FOR THE SCORE.

LEVEL 4 ASSESSMENT		Olifants_B73H_Balule			03 May 2021
RIPARIAN VEGETATION EC METRIC GROUP	**CALCULATED RATING**	**WEIGHTED RATING**	**CONFIDENCE**	**RANK**	**WEIGHT**
Macro channel valley	65.0	45.7	2.8	2.0	70.3
Macro channel bank	70.2	20.9	3.2	1.0	29.7
LEVEL 4 VEGRAI (%)				66.5	
VEGRAI EC				**C**	
AVERAGE CONFIDENCE				3.0	
	Zone				
	Macro channel valley		Macro channel bank		
VEGRAI % (Zone)	65.0		70.2		
EC (Zone)	C		C		
Confidence (Zone)	2.8		3.2		
Main cause of PES: The site had been heavily scoured from recent flood disturbance making it difficult to discern vegetation responses, but flood features supported high densities of alien weeds and remnant pockets of Sesbanea punicea persisted on consolidated features.					

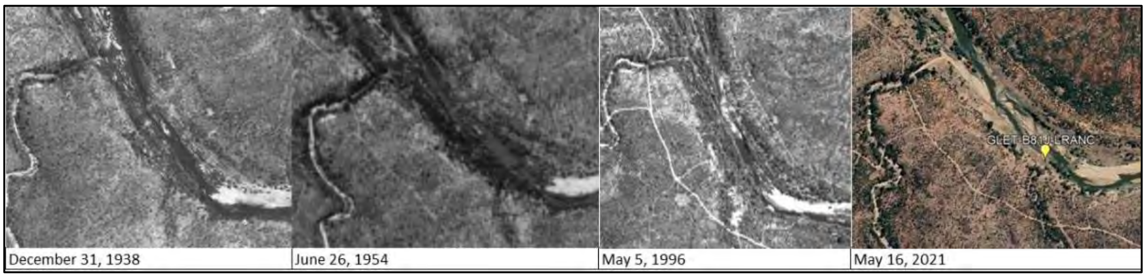
5.3.15 Groot Letaba River (GLET-B81J-LRANC):

The Groot Letaba River, at site, was a braded channel with both bedrock and alluvial areas, making for complex habitats and diverse vegetation. The Macro-channel banks were dominated by taller tress, mostly P. violacea and Senegalia nigrescens, with terrestrial gasses and shrubs and high densities of agricultural weeds (X. strumarium). Flood benches were dominated by a shrub/grass mixture, mostly G. senegalensis and Sprobolus fimbriatus. In the macro-channel valley, scattered Nuxia oppositifolia were associated with bedrock core bars upstream of the riffle areas where sand deposits occurred. The alluvial flood bench was dominated by a dense clear line of Combretum erythrophyllum. Backwater pools and gravel and sand bars supported grassed areas, mostly Ishaemum fasciculatum and C. dactylon lawns and scattered and fragmented reeds. Bedrock, boulder and course gravel habitats supported high densities of Breonadia salicina and Gomphocarpus fruticosus. A schematic profile with associated vegetation and geomorphic features is shown in Appendix B (1).

SITE PHOTOGRAPHS (LEFT) AND INDICATION OF SITE PLACEMENT ON GOOGLE EARTH © OVERLAY (RIGHT) FOR THE GROOT LETABA RIVER (GLET-B81J-LRANC).

The site occurs along sub-quaternary B81J-00219. This sq was assessed as a category C overall (Moderately modified; DWS, 2014), while the riparian zone continuity and riparian zone modification were largely natural. The majority of the impacts were flow related (quantity).

From 1938 to 1996 woody cover and density steadily increased and was then noticeably reduced by 2021, presumably from flood scouring during the 2000 floods (**Error! Reference source not found.**). The present state has an overall PES score of 70.4% (category C, which is Moderately modified). The table below outlines a summary of the PES ratings, score and ecological category of zones, and provides most notable reasons for the perturbation.



HISTORICAL AERIAL PHOTOGRAPHS SHOWING TEMPORAL CHANGES.

PES SCORE AND CATEGORY WITH MAIN REASONS FOR THE SCORE.

LEVEL 4 ASSESSMENT	Gletaba_B81J-Lranch				06 May 2021
RIPARIAN VEGETATION EC METRIC GROUP	CALCULATED RATING	WEIGHTED RATING	CONFIDENCE	RANK	WEIGHT
Macro channel valley	70.8	27.2	2.8	2.0	38.5
Macro channel bank	70.2	43.2	3.2	1.0	61.5
LEVEL 4 VEGRAI (%)				70.4	
VEGRAI EC				**C**	
AVERAGE CONFIDENCE				3.0	

	Zone	
	Macro channel valley	Macro channel bank
VEGRAI % (Zone)	70.8	70.2
EC (Zone)	C	C
Confidence (Zone)	2.8	3.2

Main cause of PES:

The site had been heavily scoured from recent flood disturbance making it difficult to discern vegetation responses, but flood features supported high densities of alien weeds and remannt pockets of *Sesbanea punicea* persisted on consolidated features.

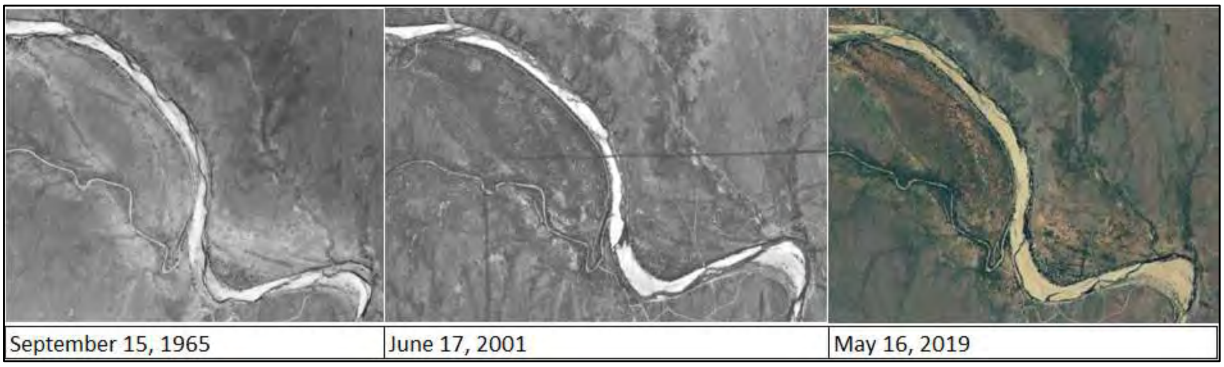
5.3.16 Letaba River @ Lonely Bull (LETA-B83A-LONEB):

The Letaba River, at the “Lonely Bull” site, was a wide, braided type channel with a clear but not dense woody riparian zone along the banks and sparse and clumped, mostly non-woody vegetation scattered across the macro-channel valley. Tall bank species included C. megalobotrys, P. violacea, C. imberbe and Trichilea emetica. Vegetated bars along the active channel were mostly covered by creeping grass, Notably C. dactylon and Ishaemum fasiculatum with patches of reeds disturbed by floods and grazed. Nuxia oppositifolia shrubs formed woody “islands” scattered across the macro-channel floor and surrounded some backwater or pool areas. A schematic profile with associated vegetation and geomorphic features is shown in Appendix B (1).

SITE PHOTOGRAPHS (LEFT) AND INDICATION OF SITE PLACEMENT ON GOOGLE EARTH © OVERLAY (RIGHT) FOR THE LETABA RIVER @ LONELY BULL (LETA-B83A-LONEB).

The site occurs along sub-quaternary B83A-00235. This sq was assessed as a category C overall (Moderately modified; DWS, 2014), while the riparian zone continuity and riparian zone modification were largely natural. The majority of the impacts were flow related (quantity).

From 1965 to 2019 there appears to have been an increase in woody cover and density, particularly along tributaries (figure below). The present state has an overall PES score of 71.3% (category C, which is Moderately modified). The table below outlines a summary of the PES ratings, score and ecological category of zones, and provides most notable reasons for the perturbation.



HISTORICAL AERIAL PHOTOGRAPHS SHOWING TEMPORAL CHANGES.

PES SCORE AND CATEGORY WITH MAIN REASONS FOR THE SCORE.

LEVEL 4 ASSESSMENT	Letaba_B83A_Loneb				04 May 2021
RIPARIAN VEGETATION EC METRIC GROUP	**CALCULATED RATING**	**WEIGHTED RATING**	**CONFIDENCE**	**RANK**	**WEIGHT**
Macro channel valley	70.0	55.7	3.3	2.0	79.5
Macro channel bank	76.5	15.7	3.2	1.0	20.5
LEVEL 4 VEGRAI (%)				71.3	
VEGRAI EC				**C**	
AVERAGE CONFIDENCE				3.2	

	Zone	
	Macro channel valley	Macro channel bank
VEGRAI % (Zone)	70.0	76.5
EC (Zone)	C	C
Confidence (Zone)	3.3	3.2

Main cause of PES:

The site had been heavily scoured from recent flood disturbance making it difficult to discern vegetation responses, but flood features supported high densities of alien weeds and remannt pockets of *Sesbanea punicea* persisted on consolidated features.

5.3.17 Elefantes River below Massingir (ELEP-Y30C-SINGU):

The Elefantes River, at Massingir, was a sinuous, braided and confined channel mostly dominated by alluvial features, with consolidated banks and unconsolidated within-channel deposits of sand and gravel (open and vegetated) with some backwater and pool areas that were deeper than the main channel and with silt over sand. The macro-channel floor was extensive, alluvial and mostly non-vegetated or with scattered small trees or shrubs. The macro-channel bank was steep, and dominated by tall riparian trees. Secondary channels were characterized by Phragmites mauritianus and Schoenoplectus corymbosus. Deep pool areas along secondary channels had thick layers of fine sand deposits which support marginal and aquatic vegetation such as Ludwigia adscendense, Potomogeton crispus, Azolla pinnata and Ceratophyllum demersum. Portions of the active channel were undercut with overhanging reeds and other macrophytes (C. demersum and L. adscendence). The marginal zone was open or lined by reeds, dense and overhanging in paces and provided shelter for some aquatic species. The floodplain is extensive (>1 km wide), heavily disturbed by agricultural activities, but with some remnant large riparian trees. Large figs (F. sycomorus in particular) indicate floodplain flood channels. A schematic profile with associated vegetation and geomorphic features is shown in Appendix B (1).

SITE PHOTOGRAPHS (LEFT) AND INDICATION OF SITE PLACEMENT ON GOOGLE EARTH © OVERLAY (RIGHT) FOR THE ELEFANTES RIVER BELOW MASSINGIR (ELEP-Y30C-SINGU).

The present state has an overall PES score of 59.9% (category C/D, which is moderately to slightly more modified). The table below outlines a summary of the PES ratings, score and ecological category of zones, and provides most notable reasons for the perturbation.

PES SCORE AND CATEGORY WITH MAIN REASONS FOR THE SCORE.

LEVEL 4 ASSESSMENT		Elefantes @ Massingir			09 June 2021
RIPARIAN VEGETATION EC METRIC GROUP	**CALCULATED RATING**	**WEIGHTED RATING**	**CONFIDENCE**	**RANK**	**WEIGHT**
Macro channel valley	63.0	34.9	3.4	1.0	55.3
Macro channel bank	56.0	25.0	3.4	2.0	44.7
LEVEL 4 VEGRAI (%)					59.9
VEGRAI EC					**C/D**
AVERAGE CONFIDENCE					3.4
	Zone				
	Macro channel valley		Macro channel bank		
VEGRAI % (Zone)	63.0		56.0		
EC (Zone)	C		D		
Confidence (Zone)	3.4		3.4		
Main cause of PES: The most notable impacts resulting in the ecostatus score, as observed at site, are extensive agricultural activities on the macro channel banks, floodplain and upper zone valley features, wood and reed removal and invasive alien weed species on flood features.					

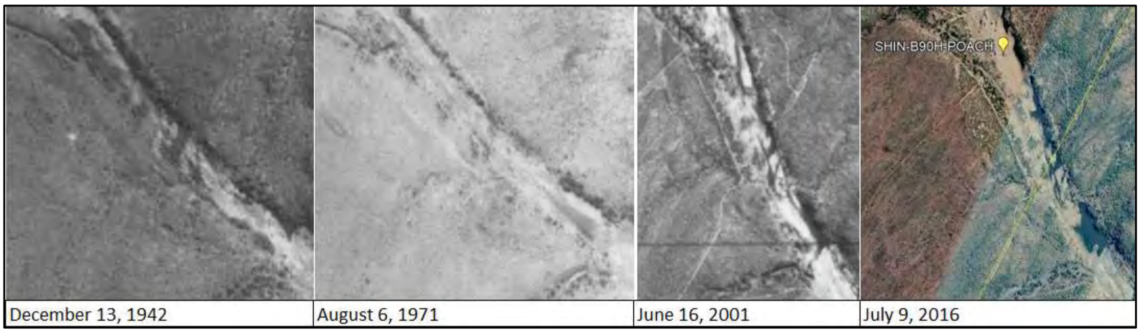
5.3.18 Shingwedzi River (SHIN-B90H-POACH):

The Shingwedzi River, at site, was mixed bedrock and alluvial and mostly with no marginal vegetation or scattered pockets of low shrub or sedge. Banks were well wooded in places, notably near or associated with deeper pools, possibly perennial pools. The mixed bedrock / gravel riffle areas supported a notable population of Gomphocarpus fruticosus but this areas was also influenced by the confluence of a small tributary to the Shingwedzi. The extensive gravel flood bench was sparse mostly unvegetated by with some shrub. Notably Gymnosporia senegalensis, a species associated with seasonal or drier conditions. Pool edges supported the only marginal zone vegetation, mixed woody (Nuxia oppositifolia, Vachellia xanthophloea, Phoenix reclinate and Hyphaene coriacea) and non-woody, mostly P. mauritianus, Cyperus sexangularis. The macro-channel bank supported tall phreatophytic trees where pools persisted the longest or were perennial. Dominant species included Spirostachys africana, P. violacea, C. imberbe and Diospyros mespiliformis. A schematic profile with associated vegetation and geomorphic features is shown in Appendix B (1).

SITE PHOTOGRAPHS (LEFT) AND INDICATION OF SITE PLACEMENT ON GOOGLE EARTH © OVERLAY (RIGHT) FOR THE SHINGWEDZI RIVER (SHIN-B90H-POACH).

The site occurs along sub-quaternary B90H-00145. This sq was assessed as a category B overall (Largely natural; DWS, 2014), riparian zone continuity was largely natural, and riparian zone modification was also largely natural. The majority of the impacts were flow related (quantity).

From 1942 to 2016 in-channel pools seem to have expanded / deepened, but woody vegetation density and distribution appears stable along the main channel and has increased slightly along smaller tributaries (figure below). The present state has an overall PES score of 83.0% (category B, which is largely natural). The table below outlines a summary of the PES ratings, score and ecological category of zones, and provides most notable reasons for the perturbation.



HISTORICAL AERIAL PHOTOGRAPHS SHOWING TEMPORAL CHANGES.

PES SCORE AND CATEGORY WITH MAIN REASONS FOR THE SCORE.

LEVEL 4 ASSESSMENT		Shin_B90H-Poach			01 May 2021
RIPARIAN VEGETATION EC METRIC GROUP	CALCULATED RATING	WEIGHTED RATING	CONFIDENCE	RANK	WEIGHT
Macro channel valley	80.4	45.4	3.6	2.0	56.5
Macro channel bank	86.3	37.5	3.2	1.0	43.5
	2.0				100.0
LEVEL 4 VEGRAI (%)				83.0	
VEGRAI EC				**B**	
AVERAGE CONFIDENCE				3.4	
	Zone				
	Macro channel valley		Macro channel bank		
VEGRAI % (Zone)	80.4		86.3		
EC (Zone)	B/C		B		
Confidence (Zone)	3.6		3.2		
Main cause of PES: The site is mostly natural in terms of riparian vegetation but with some presence of alien annual weeds, particularly where flood disturbance occurs.					

5.3.19 Limpopo River @ Chokwe (LIMP-Y30F-CHOKW):

The Limpopo River at Chokwe was mostly a single channel within an expansive channel bed dominated by alluvial features, with consolidated gentle-sloping banks. Banks were dominated by tall trees (Mostly Ficus sycomorus) and shrubs, mostly riparian, but with some terrestrial species, flood benches were mostly unvegetated or non-woody and alluvial bars were dominated by non-woody grasses and sedges and some with reedbeds. Shrubs such as Pluchea and Faidherbia albida saplings were scattered within. Some areas were characterized by silt over sand with no vegetation but usually near areas where aquatic vegetation was common within the water column. The marginal zone was either non-vegetated or characterized by dense overhanging reed. Secondary channels were a mixture of sandy beds or reeds, variously scant. Backwater pools areas were characterised by slower flowing water and dominated by dense aquatic vegetation, mainly Ludwigia adscendence, Commelina africana and Nymphae nouchali.

Alien vegetation was limited to annual weed species, but these were common, dense and dominant on alluvial flood features. In places, flood features and channel banks were heavily disturbed by a myriad of vegetable gardens. A schematic profile with associated vegetation and geomorphic features is shown in Appendix B (1).

SITE PHOTOGRAPHS (LEFT) AND INDICATION OF SITE PLACEMENT ON GOOGLE EARTH © OVERLAY (RIGHT) FOR THE LIMPOPO RIVER @ CHOKWE (LIMP-Y30F-CHOKW).

The present state has an overall PES score of 55.1% (category D, which is largely modified). The table below outlines a summary of the PES ratings, score and ecological category of zones, and provides most notable reasons for the perturbation.

PES SCORE AND CATEGORY WITH MAIN REASONS FOR THE SCORE.

LEVEL 4 ASSESSMENT		**Limpopo @ Chokwe**			**10 June 2021**
RIPARIAN VEGETATION EC METRIC GROUP	**CALCULATED RATING**	**WEIGHTED RATING**	**CONFIDENCE**	**RANK**	**WEIGHT**
Macro channel valley	54.1	26.8	3.4	1.0	49.5
Macro channel bank	56.0	28.3	3.4	2.0	50.5
LEVEL 4 VEGRAI (%)				55.1	
VEGRAI EC				**D**	
AVERAGE CONFIDENCE				3.4	
	Zone				
	Macro channel valley		Macro channel bank		
VEGRAI % (Zone)	54.1		56.0		
EC (Zone)	D		D		
Confidence (Zone)	3.4		3.4		
Main cause of PES: The most notable impacts resulting in the ecostatus score, as observed at site, are intense and extensive agricultural activities on the macro channel banks and upper zone valley features, and invasive alien weed species in high densities on flood features.					

5.4 APPENDIX FOR RIPARIAN VEGETATAION

Appendix B contains raw data for the vegetation assessment.

5.5 RIPARIAN VEGETATION REFERENCES

Department of Water and Sanitation. 2014. A Desktop Assessment of the Present Ecological State, Ecological Importance and Ecological Sensitivity per Sub Quaternary Reaches for Primary Catchments in South Africa. Primary: catchments A and B. Compiled by RQIS-RDM: https://www.dwa.gov.za/iwqs/rhp/eco/peseismodel.aspx accessed on [July 2021].

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Water Affairs and Forestry report. "

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6 ECOSYSTEM SERVICES

Contributor: Vuyisile Dlamini

6.1 INTRODUCTION

The Limpopo River Basin is home to an estimated 18 million people from Botswana, Zimbabwe, South Africa and Mozambique. According to UN-HABITAT/UNEP, (2007), the basin supports an estimated 5200 human settlements with different seasonal ecosystem services. According to Nhassengo, Somura and Wolfe, (2021) the Limpopo River Basin (LRB) sustains ecosystems and provide ecosystem services critical to the human livelihoods of local communities and economic activities. This report presents the different observed ecosystem services (ES) and benefits of the Limpopo Basin in different sites of the basin.

Ecosystem services are defined by Costanza et al. (1997); Nelson et al. (Modelling multitude ecosystem services , biodiversity conservation, commodity production and tradeoffs at landscape scales., 2009); Jenkins et al. (Valuing ecosystem services from wetlands restoration in the Mississipi Alluvial Valley, 2010) and Braat and de Groot (2010) as a range of characteristics, goods and services generated by ecosystems that are of benefit to human well-being. This definition shows that people derive these 'benefits' from ecosystems. The MA categorized ES into provisioning (food, fresh water, fuel); regulating (water purification, climate regulation); cultural (recreation, spirituality); and supporting services (nutrient cycling, soil formation), which are important for the production of all other ecosystem services. Supporting and regulating services are often combined as their functions and processes can be interdependent. All these different categories of ecosystem services are linked to human livelihoods and ecosystems functions. Ecosystem services that benefit human livelihood can be both directly and indirectly. Direct use, includes human use of products from the river e.g. medicinal plants, food products, etc.) and indirectly include functions ecosystems perform that are used and valued by human societies, such as the provision of clean water. Such indirect services are linked to the functionality of ecosystem processes of river basins.

Ecosystem services in the Limpopo Basin based on field observations and interactions with community members

The following table shows the different ecosystem services observed in different parts of the Limpopo River Basin.

TABLE 6.1: ECOSYSTEM SERVICES OBSERVED IN DIFFERENT PARTS OF THE LIMPOPO BASIN

Site	Ecosystem services observed
CROC-A24J-ROOIK	Site is upstream associated with a number of commercial farms. The main ecosystem services are provisioning (water for irrigation in the farms for vegetables and cash crops, water supply to municipality and communities). Supporting services are also important for the life cycle of many fish species in the river which depend on the natural variability in the river flow.
LIMP-A41D-SPANW	A number of commercial farms are found around this sites and most with instream irrigation pump houses. Some parts of this site are used for cultural and spiritual rituals. Flow is regarded as an important attribute in this site for water supply to the farms and for the cultural rituals as some rituals only take place at high flow.
MATL-A41D-WDRAAI	The main ecosystem service in this site is commercial irrigated agriculture mainly for cash crops which prefer dry conditions e.g. tobacco and beans. The farms are allocated about 200l/sec to irrigate 120 ha. Subsistence fishing is also an important ecosystem service in this part of the catchment .
LIMP-A36C-LIMPK	The site is situated within the Limpokwena nature reserve and the main ecosystem services are the aesthetics services from ecotourism and and provisioning of water for farm irrigation within the reserve
MOGA-A36D-LIMPK	The Mogalakwena River system was identified as a floodplain system, which is attributed for fishing, farming services and enhancement of water quality with the removal of phosphates as well as by removing nitrates and toxicants. The water is also used for household and small hold agriculture.
LIMP-A71L-MAPUN	Site is within the Mapungupwe Transfrontier park shared by Zimbabwe, and South Africa. In South Africa, the main ecosystem services are the maintenance and refugee for fish as a variety of fish species depends on the natural variability in river flows in this site and maintaining the site for aesthetics(tourism). However, this site has competing ecosystem services demands as the Shashe village in Zimbabwe also derive provisioning ecosystem services which include water for domestic use, fishing.
SAND-A71K-R508B	Site is downstream of the Musina town. This is an important part of the catchment that supports the population from Musina for water provisioning, fishing and agriculture. Community members fish a number of species in this site which includes Tilapia, Carp and Tigerfish. Further downstream of this site, subsistence and commercial irrigation farming (tomatoes, beans) in downstream villages(Masisi) is common. Fresh produce shops around Masisi village, rely on groundwater (adverts for groundwater drilling). Cultural and spiritual ecosystem services were observed in this part of the catchment as burnt candles from these rituals were observed. This sites is also used to harvest medicinal plants.

Site	Ecosystem services observed
LUVU-A91K-OUTP	The site is within the Kruger National Park, the flow regime in this site is important to maintain the site's aesthetics which is an important feature for the Outpost Lodge tourists. It also supports the delivery of a range of different provisioning services such as clean water and supporting services which is maintaining aquatic plants and fish habitats within the Kruger park
SHIN-B90H-POACH	The site is within the Kruger National Park, so it is most important for tourists' attraction (aesthetics) as it is along a tourist road to camping sites. The site also supports fish diversity.
LETA-B83E-KNPBR	The site is within the Kruger National Park, site is upstream of villages and commercial farms. The main ecosystem services in this part of the catchment is the maintenance of the area' aesthetics and provision of irrigation water downstream.
OLIF-B73H-BALUL	Site is within Balule nature reserve, the main ecosystem service in this site is maintenance of the area's aesthetics for tourists' attraction, maintenance and supporting of river' riparian zones and instream biodiversity.
OLIF-B73C-MAMBA	Site is at Mamba Kruger national park and the main ecosystem services are to support and maintain the ecosystem for conservation and aesthetics for tourists attraction
GLET-B81J-LRANC	Site is in the Groot-Letaba River, upstream of the Kruger National park. This site is downstream of Seloane community which use the river for fishing, abstract commercial and subsistence agriculture irrigation water. The riparian vegetation is over-utilised, mainly for firewood, fence construction, furniture, medicinal purposes and food.
LIMP-Y30F-CHOKWE	In this part of the catchment, the river's flow is mostly important for irrigation. This site is within a community who fish, fetch water and practise subsistence farming. This site is in the lowest part of the Limpopo Basin, which means it is a sink region.

Based on the different ecosystem services observed from the different sites along the Limpopo as presented in Table 6.1, the basin' ecosystem services can be categorised into; cultural, regulating, provisioning and supporting services as shown in Table 6.2. The river's flow contributes directly to the maintenance of aesthetics value, fisheries, provisioning of products and raw material, educational/research and cultural use of the river as categorised and described in Table 6.2.

TABLE 6.2 CATEGORIES OF THE ECOSYSTEM SERVICES OBSERVED AND DERIVED IN THE LIMPOPO BASIN

Types of services		Description
Provision	Water	Provision of water for irrigation, domestic use and livestock.
	Food, medicine	Wild fruits
	Livestock grazing	Flood plains and riverbank livestock grazing
	Raw material	Medicinal plants, craft material, ornamental artefacts
Regulation	Waste treatment	
Supporting services	Refugia	Breeding for fish and feeding for water population
Cultural		Cultural activities, spiritual and wellbeing rituals, social interaction Recreational use-ecotourism Research and education

6.2 PROVISIONING

The provisioning ecosystem services identified in the basin include: irrigation agriculture water, fishing, sand mining, grazing of livestock along riparian area, and use of riverine trees for medicinal purposes.

6.2.1 Provisioning of water for commercial irrigation

The provisioning services were the most commonly observed ecosystem services in the catchment because of their tangible nature. Abstraction of irrigation water for commercial agriculture is the most prevalent provision ecosystem services in the most upstream parts of the basin from the headwaters to Mogalakwena River. Irrigation has been identified as the major water use in the Limpopo basin (Qwist-hoffman,2013). The provisioning of water for irrigation within the Limpopo River Basin is supported by natural and built infrastructure(dams), as most of the commercial farms have dams to store irrigation water in the most upstream parts of the catchment. According to LBPTC (2010), there are over 160 major dams in South Africa within the Limpopo River basin with storage capacities ranging between 10 Mm^3 and 100 Mm^3. FAO, (2004) reports that, run-of-river abstractions for irrigation are most common along the main stem of the Limpopo River, in the

South African side of the basin with increase in irrigation water abstractions in the dry season. Nhassengo, Somura and Wolfe, (2021) attributed the dams and over abstraction of water upstream to water shortages in the lower catchments, affecting downstream ecosystems and people with a high socio-economic dependence on these basin's ecosystems. As a result, the Limpopo River which was initially a perennial river in Mozambique, is sometimes dry as a consequence of the abstractions and this has a major effect on the provision of ecosystem services in the Lower parts of the basin.

6.2.2 Provisioning of water for subsistence agriculture and livelihoods

Besides using the Limpopo River water for commercial irrigation, most of the rural communities adjacent to river systems in the basin rely on the river for provisioning of water for subsistence livelihoods like agriculture . The irrigation water is supplied through irrigation schemes or individually. The Chókwè irrigation scheme is the largest irrigation scheme in Mozambique and several irrigation schemes in South Africa along the Groot Letaba. Based on field visits and observation in the Groot-Letaba most of the subsistence farmers pump less than 200 litres of water for a hectare of land under irrigation. Water from the different parts of the basin is drawn through canals and water pumps. Along the Groot-Letaba River, the Prieska 17km water canal diversion supply subsistence irrigation water to all the communities' farms adjacent to the Groot-Letaba River. The provision of water for subsistence agriculture irrigation in the catchment provides food security, income generation and alleviate poverty which are all important for human well-being (FAO 2004).

Observation from the field also showed that, downstream of Musina town along the Sand River site, communities from the Masisi village irrigate their subsistence farms (tomatoes, beans). Most parts of the river along the Chokwe site in Mozambique, are filled with sand and communities abstract water from wells in the sand beds along the river banks to irrigate their household gardens and for water supply. The fresh produce are major sources of income for the communities. However, the high abstraction of irrigation water upstream leaves the downstream parts of the catchment most of the time dry and the communities downstream of the basin vulnerable as they do not have sufficient coping mechanisms to cushion them against the threats of low flow (Qwist-hoffman, 2013). As a result, on average, subsistence farmers in the basin only produce enough food to feed their families adequately for less than 8 months of the year (Cunguara and Darnhofer, 2011). Surface water for irrigation and households in the basin is conjunctively used to sustain the water quantity and quality requirements of users in the catchment.

6.2.3 Livestock grazing

Livestock production in the basin is both socially and financially important to smallholder farmers in the Limpopo River basin. Based on observation, the most common livestock are cattle and goats which usually graze along the basin rivers' banks. During community interactions the residents highlighted that cattle and goats are most preferred because of their high returns. Most of the livestock farmers openly graze as opposed to buying fodder which is expensive. In some parts of the catchment e.g. Mapungupwe where South Africa and Zimbabwe share the river, the river is mostly used for predominately livestock (riparian zone grazing) and domestic use.

6.2.4 Fisheries

Subsistence fishing is another provisioning service that is common in the basin. Along the GLET-B81J-LRANC site, Sand River and Chokwe sites smallholder fisheries were observed and the most preferred fish species were clarius gariepinus, tilapia and carp. The fishers used different fishing techniques and in summer they can get about 200 fish of more than 200 mm in length. The local communities fish for food and income. However, there are other parts of the catchment where recreational fishing takes place. However, the fishing in the Groot Letaba is a regulated activity with only neighbouring community members allowed to fish in the designated fishing sites. According to fishers found in the Groot Letaba and Sand River fishing sites, fishing in the area is usually preferred in summer as they are likely to find more fish compared to winter. The fishers characterised winter fishing as high effort but with low fish catch rate which renders the activity time consuming.

6.2.5 Medicinal plants, fuelwood and sand mining

The river systems long the Limpopo basin also provide households with goods and services that are not related to crop production but are used for building, medicinal plants and household fuel. In the middle part of the catchment in Gwa-Selwana the community harvest the Mimusops zeyheri which is called nhlantswa in Xitsonga and mmupudu (Northern Sotho) to treat gastritis diseases. According to Du Preez et al., (2003) and Amusa, (2009), the roots of Mimusops zeyheri are of ethnomedicinal use to treat ulcers and wounds. Mimusops zeyheri is mostly found in the Limpopo province and other areas towards the north of South Africa, in rocky hillsides, riverine boundaries and in dry open woodland and bushveld (Du Preez, 2003; Palgrave 2002).

Besides using the plants for medicinal use, some plant found along the rivers' riparian zones are harvested for firewood. Evidence from the field showed that villages around the Shashe River, Groot-Letaba River and Chokwe harvest some trees for household firewood. Observation from the field also showed that sand mining is prevalent in some parts of the basin. Sand mining was observed downstream of site GLET-B81J-LRANC along the Groot-Letaba River. The sand mining takes place along the river bank and it is sold to local communities for building their houses.

6.3 REGULATING SERVICES

Regulating services are those ecosystem services that regulate water flow, maintain biodiversity, nutrient recycling and bank stability. These services control runoff and pollutants which could be distractive.

6.3.1 Flow and water quality regulation

In the Limpopo Basin, flood plains, wetlands and river's riparian zone play a major regulating service to the river's ecosystems. The Mogalakwena River system was identified as a floodplain system. The majority of the ecological services provided by the Mogalakwena River floodplain are important for the enhancement of water quality with the removal of phosphates as well as by removing nitrates and toxicants from neighbouring agriculture farms. Also vegetation alongside rivers, may remove some of these anthropogenic inputs before they enter systems, thus ameliorating these damages. Elevated loads of nutrients from commercial farms and suspended sediments entering reservoirs lead to algal blooms and increased turbidity, increasing the costs of potable water supply. So, the floodplains and wetlands work as sinks for waterflow and nutrients. Turpie et al., (2017) explains that, wetlands have a sink capacity, which includes water stored in saturated soils. The Mogalakwena's flood plain which is close to site MOGA-A36D-LIMPK is of relatively level alluvial made of sand or gravel adjacent to the river channel which also works as a sink which regulates flow. According to Marneweck and Batchelor (2002) the floodplains regularly work as sinks for water overflows during floods and periods of high rainfall in the catchment.

6.4 SUPPORTING SERVICES

The River basin's flow also plays a role in sustaining and supporting freshwater-dependent habitats e.g riparian zone and flood pans which are breeding grounds for biodiversity. The riparian zones play an important role as nursery areas for riparian vegetation. The Limpopo and the Luvuvhu rivers has a number of landscape features such as the riverine, riparian floodplain, floodplain grassland, river channels and flood pans which all provide food, shelter and nesting sites to a large number of bird and aquatic species. The pans are important as a stopover for migratory water birds in the basin. There are 31 flooded pans supported by river flows of the Limpopo River and Luvuvhu, and the flood pans provide food, shelter and nesting sites to a large number of bird species making the site a biodiversity hotspot in the basin. Nhassengo, Somura and Wolfe, (2021) explains that the variation of hydrological regimes in the river systems is vital to support biodiversity and aquatic ecosystem integrity in these hotspots. According to Ramulifho et al., (2019) all elements of a river's flow regime (i.e., magnitude, frequency, duration, timing) are important in structuring and supporting aquatic communities. The area surrounding the confluence of the Mutshindudi and the Luvuvhu River is also regarded as a diversity hotspot for fish and invertebrates which is supported by constant river flow from these systems. However, the biodiversity of this hotspot is under threat due to diminishing in-stream habitat.

6.5 CULTURAL

Different parts of the Limpopo Basin's ecosystems are recognised for their aesthetics, spiritual, educational, cultural and recreational values. CSIR, (2003) reported that, the various conservation areas in the Limpopo Basin cover an area of 57 538 km2 , and most of this is in South Africa. The protected areas serve as areas of research and tourist attractions.

6.5.1 Ecotourism, research and education.

In the middle of the Limpopo River, the sites are predominately within protected areas, thus the main ecosystem services are to maintain the area's aesthetics, riparian zone and for tourist attraction. In the Kruger National Park, the Luvuvhu, Letaba, Olifants and Sabie-Sand are important river systems that support the Kruger National Park ecosystem for ecotourism and to improve the park' aesthetics. Observation from sites in the Kruger National Park showed that, the rivers' flow regimes are important to maintain the area aesthetics which is an important feature for tourists' attraction. The Limpopo / Shashe River confluence is a great tourist attraction area. According to SANPARKS (2019) the confluence uniquely integrates with the Mapungubwe Cultural Landscape, Vhembe Biosphere and Greater Mapungubwe Transfrontier Conservation Area to increase the area's aesthetics and attract tourists. This area has become an important conservation area in the Limpopo River as it links both river banks.

Beyond tourism and aesthetics values, some parts of the Limpopo basin are important for scientific research and education. Several studies to understand the biodiversity and ecosystems of the Limpopo basin have taken place, in most parts of the basin e.g Livuvhu, Letaba, Olifants Rivers. Scientists and students derive educational value and knowledge about the riverine ecosystems that exists and can be enjoyed by future generations in the basin.

6.6 ECOSYSTEM SERVICE FLOWS IN THE BASIN

Villamagna et al., (2013) explains that the typical flow of ecosystem services is from upstream where they are produced to where they are received by beneficiaries. Figure 6.1Simple illustration of how provisioning service flows in the basin catchment (Bagstad et al., 2013) illustrate how ecosystem services flow within space. Ecosystem services benefits flow across the Limpopo Basin from upstream to downstream, locally or interregional inundated with several sinks (e.g. dams, pollution, drought). Interregional flows are defined as flows between countries, which is between the riparian countries in this case. Based on observation, the provisioning ecosystem services flow in the basin is influenced by several barriers or sinks leading to their degradation and absorption upstream and limited flow to downstream users.

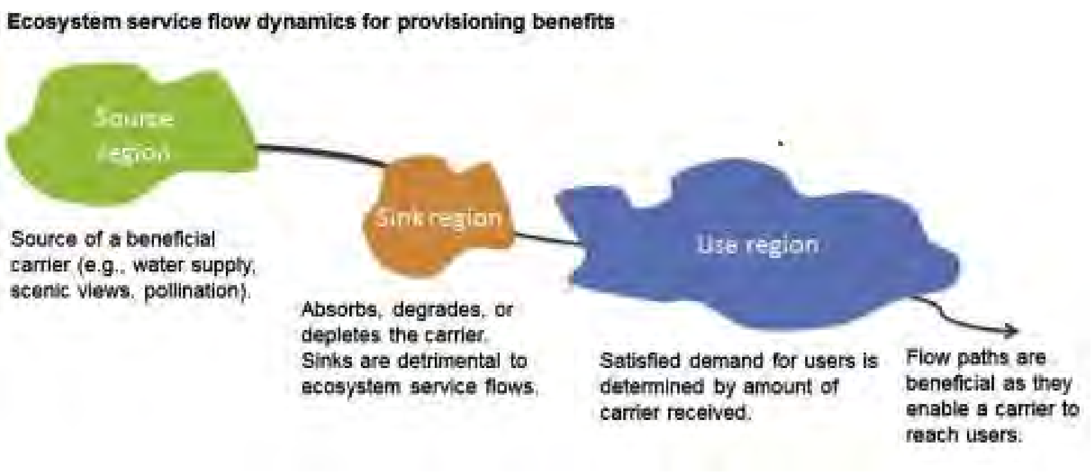

FIGURE 6.1SIMPLE ILLUSTRATION OF HOW PROVISIONING SERVICE FLOWS IN THE BASIN CATCHMENT (BAGSTAD ET AL., 2013)

The basin provisioning services source location (ecosystems that generate an ecosystem service carrier) are mostly in different parts of the basin with raw water provisioning source locations mostly upstream. The upstream in this basin also have several provisioning ecosystem services' sinks e.g dams (features that can absorb, degrade) as most of water upstream is used for commercial irrigation. These sinks (dams and other pressures) limit the quantity available for "downstream" users and the ecosystem services flow paths are blocked by these sinks. FAO-SAFR (2004) reported increases in water demand and abstraction in the upper parts of the catchment due to increasing irrigation water demands which led to major shortages in the lower reaches especially in the dry season. According to Chapman and Parker, (2014) river flow in most parts of the basin is at risk, and this will have a major impact on the delivery of flow dependent ecosystem services. According to USAID (2013) ecosystem services in most parts of the basin are threatened by reduced flow as a result of increase in temperature. In this case, increased temperature, is identified as the "sink" as it reduces water flow a carrier for other provisioning ecosystem services e.g. fish.

Literature also shows that the Limpopo River' flows frequently cease during drought periods mainly in the middle and lower reaches of the river, thus ecosystem services available vary per season (Ashton et al., 2001). Drought is a sink as it depletes the water flow which is detrimental to the flow of ecosystem services. There have been reported severe water shortages in the lower parts of the basin which have negatively affected downstream ecosystems and delivery of ecosystem services.

6.7 SUMMARY OF FINDINGS

At most of the sites, there is major competition between uses and ecosystem services in the basin. In the upper reaches of the catchment (Lephalale, Marico) irrigation and commercial agriculture competes with smallholder livelihoods like fishing, subsistence agriculture. In the middle parts of the basin (Levhuvhu, Mogalekwena, Olifants) cultural services(eco-tourism) are the most common and compete with small holder provision services e.g fishing , household water use. In the lower reaches of the basin (Chokwe), the major competition is between irrigation and subsistence water use and fishing. Most of the rural local communities rely on the ecosystem services for subsistence needs, food security and livelihood activities. However, their degree of dependency differs across communities and regions, with very high dependence in Mozambique and Zimbabwe. Magombeyi, Taigbenu and Barron, (2013) reported uneven distribution of wealth, resources and opportunities across the basin and identified Botswana and South Africa as more advanced with their economic development compared to Zimbabwe and Mozambique. Theses socio-economic differences were identified as a major contributor to the uneven capacity to utilize the resources in the basin.

Based on interactions with communities, there has been loss of ecosystem services at some sites e.g. Chokwe and Groot-Letaba where unpredictable low flows were identified as the main reason for loss of ecosystem services affecting their livelihoods. Communities along the Groot-Letaba explained that they have experienced some periods of water shortage during their agriculture growing season which have resulted in lower-than-expected yields. This is also reported by Nhassengo, Somura and Wolfe, (2021) who interviewed local communities in the Chokwe area and identified declines in water quality, water shortages between August and November as the major reasons for loss of ecosystem services like fishing and agriculture.   Since these rural communities are highly dependent on the basin ecosystem goods and services, changes in the supply of these services would have major impacts on the sustainability of local livelihoods, and human well-being.

6.8 ECOSYSTEM SERVICES REFERENCES

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7 CONCLUSIONS

This report contains a detailed description of the present ecological state of the response indicators chosen for the e-flow study, with the present ecological state reflecting the present state of the driver variables (hydrology, water quality and geomorphology). The response variables include fish, benthic macroinvertebrates and riparian vegetation. It also summarises the ecosystem services associated with these ecological components.

The information contained here is used to guide the population of the Conceptual Models, provide details into the Conditional Probability Tables and ultimately into the Bayesian Networks that are used to map the probability of each one of these response variables changing in relation to the driver variables, and how these in turn will impact on the ecosystem services and endpoints.

8 DATA APPENDICES

8.1 APPENDIX A: INVERTEBRATES

Below is the data describing the water quality as it affects the invertebrates, the instream habitat and the invertebrate diversity and health.

8.1.1 CROC-A24J-ROOIB (A4CROC-ROOIB)

Flow conditions were high, and the water colour olive green. Instream habitat was limited to gravel beds, mud, and sand. Marginal vegetation was limited to reeds (Phragmites sp.). Hydraulic biotopes were represented by shallow riffles, deep and shallow runs, backwater pools, and eddies. Photographs taken at the site are included in FIGURE 4.1.

8.1.1.1 Water Quality

Water at the time of sampling was categorised as cool alkaline freshwater. The pH and dissolved oxygen levels were elevated at the time of sampling, but more data is required to determine the extent. Water quality samples analysed indicated elevated levels of phosphates and potassium.

TABLE 8.1. IN SITU WATER QUALITY RESULTS FOR THE CROCODILE RIVER SITE AT ROOIBOKKRAAL.

Date	Time	In & Out of Current	Temp (°C)	pH	DO (%)	DO (mg/L)	EC (µS/cm)	TDS (mg/L)
21-iv-2021	11:30	IC	21.6	9.19	138.3	12.52	792	552
		OOC	23.2	9.24	104.4	8.99	771	532
		Average	22.4	9.2	121	10.8	782	542

8.1.1.2 Instream Habitat

Five sampling efforts were carried out in available gravel, vegetation, and sand-mud-silt biotopes. Habitat heterogeneity for the site was visually estimated as low, and the habitats sampled also suggests low heterogeneity (46% - TABLE 8.2).

Rocky substrates were limited, confined to very few cobbles, with the streambed dominated by gravel, and fair amounts of sand-silt (TABLE 8.3). The low turbulence (TABLE 8.2) and volume occupied by the two gravel-cobble squares sampled further highlights the low habitat heterogeneity.

The marginal vegetation sampled were mainly grass and reeds.

TABLE 8.2. INFIELD HABITAT MEASUREMENTS AT THE CROCODILE ROOIBOKKRAAL SITE FOR EACH BIOTOPE SAMPLED.

Effort	Category			Hydraulic Biotope	Dominant Substrates and/or Vegetation
	Turbulence	Depth	Flow		
1	Mod-Low	Moderate	Intermediate	Run	Gravel
2	Ext-Low	Deep	Stagnant	Eddy-glide	Grass-mud
3	Ext-Low	Intermediate	Stagnant	Glide	Reeds-mud
4	Low	Intermediate	Slow	Run	Gravel
5	Ext-Low	Shallow	Stagnant	Glide	Mud-silt
Habitat Heterogeneity					46%

TABLE 8.3. A SUMMARY OF THE OCCUPIED VOLUME OF THE SUBSTRATES MEASURED IN THE VOLUME-AREA OF THE SAMPLED BIOTOPE.

Effort	% Of Volume Sampled4					TOTAL
	Cobble	Coarse gravel	Gravel	Sand	Mud-silt	
1	0.06%	1.55%	0.04%			2%
4	0.05%	0.40%	0.07%			1%

8.1.1.3 Aquatic macroinvertebrates

Information used to determine taxa previously recorded was extracted from the Freshwater Biodiversity Information System (FBIS). Sites from which data were used are listed (TABLE 8.4). Reference conditions were based on taxa previously recorded and from the Reach PESEIS (Department of Water and Sanitation, 2014).

4 Only loose substrates (not embedded) ≥5 mm collected and measured. Volume = width x length x depth and % occupied by measured substrates.

TABLE 8.4. DETAILS OF SITES ON THE CROCODILE-WEST RIVER OF WHICH INVERT DATA WERE USED. THE MONITORING DATA FOR THIS SURVEY IS INDICATED IN BLUE FONT.

Site Code	Latitude (S)	Longitude (E)	Elevation (M a.s.l.)	Quat. Catch.	Aq. Ecoregion Lev II	Date	Season
A2CROC-SWEET	-24.58768	27.24967	912	A24J	7.03	19/v/2004	Autumn
A2CROC-MAKOP	-24.58768	27.2467	890	A24J	1.04	15/v/2013	Autumn
						20/ix/2014	Spring
A2CROC-ROOIB	-24.31417	27.04614	885	A24J	1.03	21/iv/21	Autumn
A2CROC-MORGE	-24.29253	27.02800	879	A24J	1.03	19/v/2004	Autumn

In TABLE 8.5, colour codes for MIRAI symbols refers to categories indicated in Table 5.2, while the light red and light green indicates whether RQO (if available) targets were met or not. Light red indicates non-conformance, and light green conformance. Discharge at the A2H128 gauging station at the day of sampling is also indicated, as is the RQO Maintenance and drought flow requirements. Where there are no discharge values, no data was available from the Hydrology website.

TABLE 8.5. A SUMMARY OF THE RQO NUMERICAL LIMITS FOR THE CROCODILE RIVER IN QUATERNARY SUB CATCHMENT A24J, AND RESULTS FOR THE AVAILABLE DATA SETS. A2CROC-ROOIB IS CROC-A24J-ROOIB. DISCHARGE AT A2CROC-ROOIB WAS MEASURED AT THE SITE.

Quaternary Sub-catchment	River		RQOs	A2CROC-SWEET 19/v/04	A2CROC-MAKOP 15/v/13	A2CROC-MAKOP 20/ix/14	A2CROC-MORGE 19/v/04	**A2CROC-ROOIB 21/iv/21**	Target Achieved
A24J	Crocodile	MIRAI	≥58%	56%	68%	50%	40%	**60%**	40%
			C/D	D	C	D	D/E	**C/D**	40%
		SASS4	≥120	91	126	78	62	**111**	20%
		ASPT	≥5.0	5.1	5.0	4.1	4.8	**4.8**	40%
A2H128	Discharge (m^3/s)				5.341			**7.212***	
RQOs	Maintenance Flow (m^3/s)			1.548	1.548	1.287	1.548	**1.791**	
	Drought Flow (m^3/s)			1.303	1.303	1.091	1.303	**1.503**	

Conditions was rated as moderately to largely impaired. The highest percentage of SASS rated sensitive taxa was recorded at the A2CROC-ROOIB site during April 2021, with flow sensitive taxa present but not dominant.

Taxa associated with slow and stagnant waters dominated, followed by moderate to fast flows. Most taxa were associated with the vegetation biotope, followed by cobble-gravel and sand mud.

8.1.2 LIMP-A41D-SPANW (A4LIMP-SPANW)

Flow conditions were visually rate as high, and the water colour clear with a slight green tint. Instream habitat was diverse, with bedrock, boulders, cobble, gravel, sand, mud, silt substrates all in abundance, with a variety of stream velocities (68% - TABLE 8.7). Some bank scouring occurred following recent high flow events, but the marginal vegetation variety was diverse with patches with marginal vegetation represented by grasses, sedges, herbaceous plants, shrubs, and algae. Hydraulic biotopes were represented by shallow and deep riffles and rapids, deep and shallow runs, large pools, glides, backwater pools, and eddies. Photographs taken at the site are included in FIGURE 4.2.

8.1.2.1 Water Quality

Water at the time of sampling was categorised as cool discoloured alkaline freshwater. The turbidity, potassium, pH and dissolved oxygen levels were elevated at the time of sampling, but more data is required to determine the extent.

TABLE 8.6. IN SITU WATER QUALITY RESULTS FOR THE LIMPOPO RIVER SITE AT SPANWERK.

Date	Time	In & Out of Current	Temp (°C)	pH	DO (%)	DO (mg/L)	EC (µS/cm)	TDS (mg/L)
21-iv-2021	11:30	IC	21.3	8.74	122.2	10.73	779	536
		OOC	22.8	8.72	138.5	11.95	895	574
		Average	22.1	8.7	130	11.3	837	554

8.1.2.2 Instream Habitat

Six sampling efforts were carried out in available boulder-cobble, cobble-gravel, vegetation, gravel-sand, and sand-mud-silt biotopes. Habitat heterogeneity for the site was visually estimated as very high. Available habitat represented considerably more diversity than what could be sampled in the time spend at the site. Habitats sampled still suggests high habitat heterogeneity (68% - TABLE 8.7).

A variety of different rocky substrates were present at different velocities and depths, but sampling time was limited. Sampled substrates included boulders, cobble, gravel, and sand-mud-silt. The higher turbulence categories (TABLE 8.7) and volume occupied (TABLE 8.8) by the two stones in current squares and the gravel in current highlights the high habitat heterogeneity.

TABLE 8.7. INFIELD HABITAT CATEGORIES FOR EACH BIOTOPE SAMPLED IN THE LIMPOPO RIVER AT SPANWERK.

Effort	Category			Hydraulic Biotope	Dominant Substrates and/or Vegetation
	Turbulence	Depth	Flow		
1	V High	Intermediate	Moderate	Riffle	Cobble-gravel
2	High	Intermediate	Moderate	Run	Gravel-cobble
3	V Low	Intermediate	Stagnant	Glide-pool	Grass-reeds-mud
4	Ex-Low	Shallow	Stagnant	Run	Sedge-grass-gravel
5	Mod-high	Shallow	Moderate	Riffle	Gravel-sand
6	V Low	Intermediate	Slow	Glide	Mud-sand
Habitat Heterogeneity					68%

TABLE 8.8. A SUMMARY OF OCCUPIED VOLUME OF THE SUBSTRATES MEASURED IN THE VOLUME-AREA OF THE SAMPLED BIOTOPE.

Effort	% Of Volume Sampled					TOTAL
	Small Boulder	Large Cobble	Cobble	Coarse Gravel	Gravel	
1	40.14%	1.89%	4.43%	0.56%		47%
2		19.89%	0.77%	0.50%	0.01%	21%
5			7.04%	7.57%	0.01%	15%

8.1.2.3 Aquatic Macroinvertebrates

Information used to determine taxa previously recorded was extracted from the Freshwater Biodiversity Information System (FBIS). Sites from which data were used are listed (TABLE 8.9). Reference conditions were based on taxa previously recorded and from the Reach PESEIS (Department of Water and Sanitation, 2014), and presented as a summary in TABLE 8.9.

TABLE 8.9. DETAILS OF SITES ON THE LIMPOPO RIVER FROM WHICH INVERT DATA WERE USED. THE MONITORING DATA FOR THIS SURVEY IS INDICATED IN BLUE FONT.

Site Code	Latitude (S)	Longitude (E)	Elevation (M a.s.l.)	Quat. Catch.	Aq. Ecoregion Lev II	Date	Season
A4LIMP-CAMBR	-23.41708	27.43052	815	A41E	1.02	16/iii/2011	Autumn
A2LIMP-SPANW	-23.94185	26.93123	857	A41D	1.02	05/vi/2012	Winter
						22/iv/2021	Autumn

Data was captured and run in the MIRAI model to determine Ecological Status. In the table, colour codes for MIRAI symbols refers to Table 5.2. The indigenous mollusc Thiaridae: Melanoides tuberculata (Müler, 1774) was encountered in abundance, with the exotic invasive species, Tarebia granifera (Lamarck, 1816), absent.

TABLE 8.10. A SUMMARY OF THE RQO NUMERICAL LIMITS FOR THE LIMPOPO RIVER IN QUATERNARY SUB CATCHMENT A41D, AND RESULTS FOR THE AVAILABLE DATA SETS. A4LIMP-SPANW IS LIMP-A41D-SPANW. DISCHARGE AT A4LIMP-SPANW FOR BOTH SURVEYS WAS MEASURED AT THE SITE.

Quaternary Sub-catchment	River		RQOs	A4LIMP-CAMBR 16/iii/11	A4LIMP-SPANW 05/vi/12	A4LIMP-SPANW 22/iv/21	Target Achieved
A41D	Limpopo	MIRAI		69%	65%	63%	
				C	C	C	
		SASS5		131	112	121	
		ASPT		5.2	5.3	5.3	
	Discharge (m^3/s)				1.426*	6.586*	

Conditions were rated as moderately impaired. SASS taxa considered sensitive were present but not dominant, despite the high habitat diversity. Rheophilic taxa such as Tricorythidae: Tricorythus sp., Libellulidae: Zygonyx natalensis, two species of Hydropsychidae and Simuliidae were present and abundant.

8.1.3 MATL-A41C-WDRAAI (A4MATL-PHOFU)

Flow conditions were visually rate as high, and the water clear with a tannin tint, potentially from ion-oxides and/or high dissolved organic plant material. Instream habitat was rated as moderate to low, with cobble present and gravel, sand, mud, silt substrates all in abundance. Velocity-depth categories were limited, as were hydraulic biotopes. The marginal vegetation was dominated by reeds, with sedges and grasses present but limited. Site photographs are included in FIGURE 4.3.

8.1.3.1 Water Quality

Water at the time of sampling was categorised as cool neutral freshwater. The electrical conductivity (73.8 mS/m) was elevated on 23 April 2021 when compared to background data for gauging station A4H004 (1.5 – 58.6 mS/m) (Dickens et al. 2020). More data is required to determine the extent.

TABLE 8.11. IN SITU WATER QUALITY RESULTS FOR THE MATLABAS RIVER SITE AT PHOFU.

Date	Time	In Current	Temp (°C)	pH	DO (%)	DO (mg/L)	EC (µS/cm)	TDS (mg/L)
23-iv-2021		IC	22.3	7.1	108	9.3	738	539
RQOs				6.5-8.5		≥6	≤400	

8.1.3.2 Instream Habitat

Six sampling efforts were carried out in available cobble, gravel, vegetation, and sand-mud-silt biotopes. Habitat heterogeneity for the site was visually estimated as moderate, and the habitats sampled suggested moderate to low heterogeneity (51% - TABLE 8.12).

TABLE 8.12. INFIELD HABITAT CATEGORIES FOR EACH BIOTOPE SAMPLED IN THE MATLABAS RIVER AT PHOFU.

Effort	Category			Hydraulic Biotope	Dominant Substrates and/or Vegetation
	Turbulence	Depth	Flow		
1	Mod-High	Intermediate	Moderate	Run	Cobble
2	V Low	Intermediate	Slow	Run-glide	Cobble-gravel
3	Ex-Low	Shallow	Stagnant	Glide-pool	Reeds-sand
4	Ex-Low	Intermediate	Stagnant	Glide-pool	Reeds-mud-sand
5	Ex-Low	Intermediate	Stagnant	Glide-pool	Sand
6	V Low	Intermediate	Slow	Glide-run	Gravel-sand

Habitat Heterogeneity	51%

Cobble was dominant in the Effort 1 and 2 biotopes (6.7% and 5.1%) but occupied only 7% and 3% of the total area sampled, which is considered low (Table 8.13).

TABLE 8.13. A SUMMARY OF THE OCCUPIED VOLUME OF THE SUBSTRATES MEASURED IN THE VOLUME-AREA OF THE SAMPLED BIOTOPE.

Effort	% Of Volume Sampled					TOTAL
	Small Boulder	Large Cobble	Cobble	Coarse Gravel	Gravel	
1		2.73%	3.98%	0.72%		7%
2		2.08%	3.03%	0.53%		3%

8.1.3.3 Aquatic Macroinvertebrates

Information used to determine taxa previously recorded was extracted from the Freshwater Biodiversity Information System (FBIS). Sites from which data were used are listed (Table 8.14). Reference conditions were based on taxa previously recorded and from the Reach PESEIS (Department of Water and Sanitation, 2014).

TABLE 8.14. DETAILS OF SITES ON THE MATLABAS RIVER FROM WHICH INVERT DATA WERE USED. THE MONITORING DATA FOR THIS SURVEY IS INDICATED IN BLUE FONT.

Site Code	Latitude (S)	Longitude (E)	Elevation (M a.s.l.)	Quat. Catch.	Aq. Ecoregion Lev II	Date	Season
A4MATL-HOOPD	-24.30800	27.51600	988	A41A	1.03	23/vii/08	Winter
A4MATL-PHOFU	-24.05158	27.35925	916	A41C	1.02	25/vii/08	Winter
						23/iv/21	Autumn
A4MATL-MATJE	-23.97563	27.17709	889	A41C	1.03	22/vii/08	Winter

TABLE 8.15. A SUMMARY OF THE RQO NUMERICAL LIMITS FOR THE MATLABAS RIVER IN QUATERNARY SUB CATCHMENT A41C, AND RESULTS FOR THE AVAILABLE DATA SETS. A4MATL-PHOFU IS MATL-A41C-WDRAAI. DISCHARGE AT A4MATL-PHOFU FOR THE 2021 SURVEY WAS MEASURED AT THE SITE.

Quaternary Sub-catchment	River		RQOs	A4MATL-HOOPD 23/vii/08	A4MATL-MATJE 22/vii/08	A4MATL-PHOFU 25/vii/08	A4MATL-PHOFU 23/iv/21	Target Achieved
A41C	Matlabas	MIRAI	$\geq$62%	61%	58%	62%	64%	50%
			C	C	D	C	C	75%
		SASS4	$\geq$120	78	75	83	90	0%
		ASPT	$\geq$5.0	4.9	4.2	5.2	5.3	50%
A4H004	Discharge (m^3/s)			0.115	0.123	0.114	0.181*	
RQOs	Maintenance Flow (m^3/s)						0.266	
	Drought Flow (m^3/s)						0.077	

Conditions were rated as moderately impaired. Sensitive taxa are present, but some expected sensitive taxa (e.g., Heptageniidae, and Tricorythidae), were absent. Taxa considered tolerant dominated the stream community, which could also be related to available habitat. Rheophilic taxa were present and dominant in the flowing portions of the stream. Historical results for the stream also indicate low SASS scores for a 2008 survey.

8.1.4 LEPH-A50H-SEEKO

Flow conditions were visually rate as high, and the water colour was visually rated light to greenish brown. Instream habitat was rated as moderate to low, with boulders, cobble, and bedrock abundant downstream from the weir, but sand-mud and less often gravel dominant further downstream. Velocity-depth categories were well represented below the weir, but variety diminished further downstream. The marginal vegetation was dominated by reeds, with sedges and grasses present but very limited. Site photographs are included in FIGURE 4.4.

8.1.4.1 Water Quality

Water at the time of sampling was categorised as cool circum-neutral freshwater, with elevated phosphorus (PO4). The electrical conductivity (85.7 mS/m) was elevated compared to historical data (Dickens et al. 2020).

Table 8.16. In situ water quality results for the Lephalale River site at Seekoeigat.

Date	Time	IC -OOC	Temp (°C)	pH	DO (%)	DO (mg/L)	EC (µS/cm)	TDS (mg/L)
24-iv-2021	11:45	IC	21.7	7.68	108.8	9.72	855	590
		OOC	21.5	7.60	104.7	9.00	859	593
Average			21.6	7.6	107	9.4	857	592

8.1.4.2 Intream Habitat

Six sampling efforts were carried out in available cobble, gravel, vegetation, and sand-mud-silt biotopes. Habitat heterogeneity for the site was high downstream from the weir, and homogenous further downstream. Overall habitat sampled was rated to have moderate to low heterogeneity (59% - Table 8.17).

Table 8.17. Infield habitat categories for each biotope sampled in the Lephalale River at Seekoeigat.

Effort	Category			Hydraulic Biotope	Dominant Substrates and/or Vegetation
	Turbulence	Depth	Flow		
1	V Low	Shallow	Slow	Riffle	Cobble
2	High	Intermediate	Fast	Rapid	Cobble-gravel
3	Ex-Low	Intermediate	Stagnant	Pool-glide	Reeds-mud-sand
4	Ex-Low	Intermediate	Slow	Glide-run	Reeds-sand
5	Ex-Low	Intermediate	Stagnant	Glide-eddy	Sand
6	High	Shallow	Fast	Riffle-run	Gravel-sand
Habitat Heterogeneity					59%

Cobble represented a relatively large portion (28.7% and 26%) of the stones in current biotopes sampled, indicating high quality cover for rheophilics Table 8.18.

Table 8.18. A summary of the occupied volume of the substrates measured in the volume-area of the sampled biotope.

Effort	% Of Volume Sampled					TOTAL
	Small Boulder	Large Cobble	Cobble	Coarse Gravel	Gravel	
1		14.76%	12.98%	2.80%	0.01%	31%
2		25.51%	1.50%	2.31%	0.01%	29%

6	50.79%	49.21	6%

8.1.4.3 Aquatic Macroinvertebrates

Information used to determine taxa previously recorded was extracted from the Freshwater Biodiversity Information System (FBIS). Sites from which data were used are listed (Table 8.19). Reference conditions were based on taxa previously recorded and from the Reach PESEIS (Department of Water and Sanitation, 2014).

TABLE 8.19. DETAILS OF SITES ON THE LEPHALALE RIVER FROM WHICH INVERT DATA WERE USED. THE MONITORING DATA FOR THIS SURVEY IS INDICATED IN BLUE FONT.

Site Code	Latitude (S)	Longitude (E)	Elevation (M a.s.l.)	Quat. Catch.	Aq. Ecoregion Lev II	Date	Season
A5LEPH-BUFFE	-23.61506	28.11862	857	A50G	1.02	12/v/2005	Autumn
A5LEPH-KROON	-23.58112	28.11706	854	A50G	1.02	11/v/2005	Autumn
A5LEPH-ABBOT	-23.46216	28.09566	841	A50G	1.02	13/v/2005	Autumn
A5LEPH-BEAUT	-23.21732	27.89103	803	A50H	1.02	12/v/2005	Autumn
A5LEPH-SEEKO	-23.14187	27.88321	794	A50H	1.02	24/iv/2021	Autumn

TABLE 8.20. A SUMMARY OF THE ECOSTATUS DERIVED FROM MIRAI FOR THE AVAILABLE DATA OF SITES (TABLE 8.19) ON THE LEPHALALE RIVER. DISCHARGE AT A4LEPH-SEEKO SITE FOR THE 2021 SURVEY WAS MEASURED AT THE SITE.

Quaternary Sub-catchment	River		RQOs	A5LEPH-BUFFE 12/v/05	A5LEPH-KROON 11/v/05	A5LEPH-ABBOT 13/v/05	A5LEPH-BEAUT 12/v/05	A5LEPH-SEEKO 24/iv/21	Target Achieved
A50G & H	Lephalala	MIRAI		57%	60%	74%	63%	**61%**	
				D	C/D	C	C	**C/D**	
		SASS4		112	135	159	128	**115**	
		ASPT		4.7	5.4	5.1	5.6	**6.4**	
	Discharge (m^3/s)							**3.506***	

Conditions were rated as moderately to largely impaired. Taxa diversity was low in 2021, with several expected taxa absent. Taxa rated as sensitive in SASS5 were present but not dominant. Flow sensitive taxa were dominant in cobble biotopes in current.

8.1.5 LIMP-A63C-LIMPK

Flow conditions were visually rate as high, and the water colour was visually rated as light to red brown. Instream habitat was rated as moderate to high, with bedrock, boulders, cobble, gravel, and sand-mud-silt present and abundant. Velocity-depth categories were relatively well represented, but deeper water was not sampled. The marginal vegetation was limited due to bank scouring and high sand-mud deposition. Reeds, sedges grasses and grass roots were sampled on the opposite riverbank. Site photographs are included in FIGURE 4.5.

8.1.5.1 Water Quality

Water at the time of sampling was categorised as cool alkaline freshwater, with elevated nutrients. The electrical conductivity (93.6 mS/m) and dissolved oxygen levels were elevated.

TABLE 8.21. IN SITU WATER QUALITY RESULTS FOR THE LIMPOPO RIVER SITE AT LIMPOKWENA.

Date	Time	IC -OOC	Temp (°C)	pH	DO (%)	DO (mg/L)	EC (µS/cm)	TDS (mg/L)
25-iv-2021	09:30	IC	22.2	8.60	116.0	10.32	1 095	763
		OOC	22.8	8.32	120.5	10.51	777	543
Average			22.5	8.4	118	10.4	936	653

8.1.5.2 Instream Habitat

Eight sampling efforts were carried out in available bedrock, cobble, gravel, vegetation, and sand-mud-silt biotopes. Habitat heterogeneity for the site was high (70% - Table 8.22).

TABLE 8.22. INFIELD HABITAT CATEGORIES FOR EACH BIOTOPE SAMPLED IN THE LIMPOPO RIVER AT LIMPOKWENA.

Effort	Category			Hydraulic Biotope	Dominant Substrates and/or Vegetation
	Turbulence	Depth	Flow		
1	Mod-Low	Intermediate	Slow	Riffle-run	Boulder-cobble
2	Mod-High	Intermediate	Moderate	Riffle	Bedrock-cob-gravel
3	Mod-Low	Shallow	Slow	Run	Sand-gravel-cob
4	Ex-Low	Shallow	Stagnant	Glide-run	Sand
5	Ex-Low	Intermediate	Stagnant	Glide-pool	Roots-reed-mud
6	Ex-Low	Intermediate	Stagnant	Glide-Pool	Shrub-silt-sand
7	Low	Intermediate	Moderate	Riffle-run	Boulder

8	Mod-High	Intermediate	Moderate	Rapid riffle	Cobble-bedrock
Habitat Heterogeneity					70%

The first effort sampled was dominated by a large boulder, limiting other substrates. Several of the cobble present were embedded and were therefore not considered. Lower occupied volume of rocky substrates indicates reduced available cover (Table 8.23).

TABLE 8.23. A SUMMARY OF THE OCCUPIED VOLUME OF THE SUBSTRATES MEASURED IN THE VOLUME-AREA OF THE SAMPLED BIOTOPE.

Effort	% Of Volume Sampled					TOTAL
	Small Boulder	Large Cobble	Cobble	Coarse Gravel	Gravel	
1	75.98%		3.09%	0.63%	0.01%	16%
2		3.55%	2.29%	1.32%	0.01%	7%
3			2.21%	1.27%	0.01%	3%
8			6.03%	1.38%		7%

8.1.5.3 Aquatic Macroinvertebrates

No aquatic macroinvertebrate information was available from the Freshwater Biodiversity Information System (FBIS). Reference conditions were based on taxa recorded at the site, up and downstream taxa presence, and taxa listed for the reach on the Reach PESEIS (Department of Water and Sanitation, 2014).

TABLE 8.24. A SUMMARY OF THE ECOSTATUS DERIVED FROM MIRAI COMPARING COLLECTED DATA TAXA EXPECTED. DISCHARGE AT A6LIMP-LIMPK SITE FOR THE 2021 SURVEY WAS MEASURED AT THE SITE.

Quaternary Sub-catchment	River		RQOs	A6LIMP-LIMPK 25/iv/21	Target Achieved
A63C	Limpopo	MIRAI		75% C	
		SASS4		141	
		ASPT		5.9	
Discharge (m^3/s)				10.038*	

Conditions were rated as moderately impaired. Taxa considered sensitive were represented in the total sample, while flow sensitive taxa were present but not abundant.

8.1.6 MOGA-A63D-LIMPK

Flow was restricted to a trickle close to the weir wall, with no areas with any visible flow. The water colour was clear, with substrates at the site dominated by bedrock, cobble, gravel, and sand. Instream habitat was rated as low due to the lack of hydraulic biotope and flow-depth diversity. There was no marginal vegetation at the site, linked to recent bank scouring during high flows and the now absent flow. Site photographs are included in FIGURE 4.6.

8.1.6.1 Water Quality

Water at the time of sampling was categorised as cool-warm circum-neutral subsaline water, with elevated nutrients, sulphates, sodium, magnesium, and calcium.

TABLE 8.25. IN SITU WATER QUALITY RESULTS FOR THE MOGALAKWENA RIVER SITE AT LIMPOKWENA.

Date	Time	IC -OOC	Temp (°C)	pH	DO (%)	DO (mg/L)	EC (µS/cm)	TDS (mg/L)
26-iv-2021	10:00	IC	22.4	7.80	94.3	8.14	2 160	1 500
		OOC	22.8	7.26	213.6	17.4	2 670	1 810
Average			23.6	7.5	154	12.8	2 415	1 655

8.1.6.2 Instream Habitat

Eight sampling efforts were carried out in the trickle, in stones out of current, and in a sandy pool. Due to the limited flow and lack of any marginal vegetation, habitat heterogeneity was rated low (41% - Table 8.26.

TABLE 8.26. INFIELD HABITAT CATEGORIES FOR EACH BIOTOPE SAMPLED IN THE MOGALAKWENA RIVER AT LIMPOKWENA.

Effort	Category			Hydraulic Biotope	Dominant Substrates and/or Vegetation
	Turbulence	Depth	Flow		
1	Ex-Low	V shallow	Stagnant	Trickle	Cobble-gravel
2	Ex-Low	Intermediate	Stagnant	Pool	Gravel-Cob-Sand
3	Ex-Low	Shallow	Stagnant	Pool	Sand-Gravel-Silt
Habitat Heterogeneity					41%

Due to the shallowness of the trickle, the rocky substrates occupied a considerable volume of the area sampled (Table 8.27).

TABLE 8.27. A SUMMARY OF THE OCCUPIED VOLUME OF THE SUBSTRATES MEASURED IN THE VOLUME-AREA OF THE SAMPLED BIOTOPE.

Effort	% Of Volume Sampled					TOTAL
	Small Boulder	Large Cobble	Cobble	Coarse Gravel	Gravel	
1			14.43%	9.93%	0.01%	24%
2			1.45%	5.26%	0.02%	7%

8.1.6.3 Aquatic Macroinvertebrates

No aquatic macroinvertebrate information was available from the Freshwater Biodiversity Information System (FBIS). Reference conditions were based on taxa previously recorded and from the Reach PESEIS (Department of Water and Sanitation, 2014).

TABLE 8.28. A SUMMARY OF THE ECOSTATUS DERIVED FROM MIRAI COMPARING COLLECTED DATA TAXA EXPECTED. DISCHARGE AT A6MOGA-LIMPK SITE FOR THE 2021 SURVEY WAS MEASURED AT THE SITE.

Quaternary Sub-catchment	River		RQOs	A6MOGA-LIMPK 26/iv/21	Target Achieved
A63D	Mogalakwena	MIRAI		49%	
				D	
		SASS4		71	
		ASPT		4.7	
Discharge (m^3/s)				0.000*	

Conditions were rated as largely impaired. One flow sensitive taxon, Trichoptera: Hydropsychidae, was surviving the available flow, but its speculative whether it will complete it life cycle. Other expected flow sensitive taxa were all absent. No SASS-rated sensitive taxa were present.

8.1.7 SHAS-Y20B-TULIB

Flow was visually rated as very low, and very shallow over sandy substrates. Instream habitat was rated as low due to the lack of substrate other than sand, hydraulic biotope, and flow-depth diversity. High quantities of algal growth, with marginal vegetation absent. Measured discharge on 23 July 2021 was 0.000 m^3/s, representing no change from the natural median for July.

8.1.7.1 Instream Habitat

Sampling was carried out in stagnant waters over sandy-mud substrates. Habitat heterogeneity was rated low.

8.1.7.2 Aquatic Macroinvertebrates

No aquatic macroinvertebrate information was available from the Freshwater Biodiversity Information System (FBIS). Reference conditions were derived from taxa encountered in the region and collected during this July 2021 survey.

TABLE 8.29. A SUMMARY OF THE ECOSTATUS DERIVED FROM MIRAI COMPARING COLLECTED DATA TAXA EXPECTED. DISCHARGE AT SHAS-Y20B-TULIB SITE FOR THE 2021 SURVEY WAS MEASURED AT THE SITE.

Quaternary Sub-catchment	River		RQOs	SHAS-Y20B-TULIB 23/vii/21	Target Achieved
Y20B	Shashe	MIRAI		75%	
				C	
		SASS5		61	
		ASPT		5.1	
Discharge (m^3/s)				0.000*	

Taxa encountered were those expected in stagnant pools with sand-muddy substrates. The zero surface flow conditions appear to be natural for this time of the year, with taxa present adapted over millennia to survive these conditions.

8.1.8 LIMP-A71L-MAPUN

Flow was visually rated as moderate, mainly shallow over sandy substrates. The water colour was light brown, with cobble limited, fine gravel to coarse sand dominant, and silt-mud-sand dominating slower flowing portions. Instream habitat was rated as low due to the lack of substrate, hydraulic biotope, and flow-depth diversity. Marginal vegetation was present but limited. Site photographs are included in FIGURE 4.7.

8.1.8.1 Water Quality

Water at the time of sampling was categorised as warm alkaline freshwater, with elevated ammonium, and dissolved oxygen. Water temperature is linked to dominantly the shallow streambed, and it's likely that temperature fluctuate as a result.

TABLE 8.30. IN SITU WATER QUALITY RESULTS FOR THE LIMPOPO RIVER SITE AT MAPUNGUBWE.

Date	Time	IC -OOC	Temp (°C)	pH	DO (%)	DO (mg/L)	EC (µS/cm)	TDS (mg/L)
27-iv-2021	09:30	IC	25.4	8.73	129.6	10.84	421	287

	OOC	27.1	8.83	134.2	11.93	423	289
Average		26.3	8.8	132	11.4	422	288

8.1.8.2 Instream Habitat

Seven sampling efforts were carried out across a wide channel, mainly in the sandy-gravel substrates. A branch in the flowing water was included as biotope, which produced several flow sensitive taxa usually associated with stones biotopes. Habitat heterogeneity was rated low (46% - Table 8.31).

Table 8.31. Infield habitat categories for each biotope sampled in the Limpopo River at Mapungubwe.

Effort	Category			Hydraulic Biotope	Dominant Substrates and/or Vegetation
	Turbulence	Depth	Flow		
1	Low	Intermediate	Moderate	Run	Gravel-sand
2	Mod-Low	Shallow	Slow	Run	Sand-mud
3	Ex-low	Shallow	Stagnant	Pool	Herb-branch-mud
4	Mod-Low	Intermediate	Slow	Run	Branch-sand-gravel
5	Low	Shallow	Moderate	Run	Sand
6	Ex-Low	Shallow	Stagnant	Pool	Mud-sand
7	Mod-High	Shallow	Moderate	Run	Gravel-Sand-Cob
Habitat Heterogeneity					46%

There was limited habitat cover for the invertebrates in the two biotope efforts sampled. Most flow sensitive taxa were encountered attached to woody branches in current, effort 4.

Table 8.32. A summary of the occupied volume of the substrates measured in the volume-area of the sampled biotope.

Effort	% Of Volume Sampled					TOTAL
	Small Boulder	Large Cobble	Cobble	Coarse Gravel	Gravel	
5				0.14%	0.28%	0.4%
7			0.91%	1.30%	0.01%	2%

8.1.8.3 Aquatic Macroinvertebrates

No aquatic macroinvertebrate information was available from the Freshwater Biodiversity Information System (FBIS). Reference conditions were derived from the June 2012 survey (Dickens et al. 2012), this April 2021 survey, and from the PESEIS Reach (A71L-00005) (Department of Water and Sanitation, 2014).

TABLE 8.33. A SUMMARY OF THE ECOSTATUS DERIVED FROM MIRAI USING DATA COLLECTED THIS SURVEY, THE 2012 SURVEY, AND TAXA EXPECTED AS REFERENCE. DISCHARGES AT A7LIMP-MAPUN SITE FOR THE 2012 AND 2021 SURVEYS WERE MEASURED AT THE SITE.

Quaternary Sub-catchment	River		RQOs	A7LIMP-MAPUN 07/vi/12	A7LIMP-MAPUN 27/iv/21	Target Achieved
A71L	Limpopo	MIRAI		59%	74%	
				C/D	C	
		SASS5		96	137	
		ASPT		4.8	5.5	
Discharge (m^3/s)				0.081*	9.739*	

Conditions was rated as moderately impaired. Flow sensitive taxa were present but limited to suitable habitats which were severely limited. SASSS rated sensitive taxa were present but not dominant. A branch sampled in current produced several individuals of the Ephemeropterans Tricorythidae and Oligoneuridae. No Hydropsychidae were encountered.

8.1.9 UMZI-Y20C-BEITB

Flow was visually rated as a trickle (<30 cm width) with floating algae over shallow sandy substrate. Coarse sand was dominant, with bedrock boulders present but not submerged. Instream habitat during sampling was rated as low due to the lack of substrate, hydraulic biotope, and flow-depth diversity. Measured discharge on 25 July 2021 was 0.000 m^3/s, representing no change from the natural median for July.

8.1.9.1 Instream Habitat

Sampling efforts were restricted to sandy-mud-silt substrates. Filamentous green algae were also sampled on the shallow sand bed. Marginal vegetation was absent. Habitat heterogeneity was rated low.

8.1.9.2 Aquatic Macroinvertebrates

No aquatic macroinvertebrate information was available from the Freshwater Biodiversity Information System (FBIS). Reference conditions were derived from taxa encountered in the region and collected during this July 2021 survey.

TABLE 8.34. A SUMMARY OF THE ECOSTATUS DERIVED FROM MIRAI COMPARING COLLECTED DATA TAXA EXPECTED. DISCHARGE AT UMZI-Y20C-BEITB SITE FOR THE 2021 SURVEY WAS MEASURED AT THE SITE.

Quaternary Sub-catchment	River		RQOs	UMZI-Y20C-BEITB 23/vii/21	Target Achieved
Y20C	Mzingwani	MIRAI		71%	
				C	
		SASS5		64	
		ASPT		5.3	
	Discharge (m^3/s)			0.000*	

Taxa encountered were those expected in stagnant pools with sand-muddy substrates. The zero surface flow conditions appear to be natural for this time of the year, with taxa present adapted to survive these conditions.

8.1.10 SAND-A71K-R508B

Flow was visually rated as very low, predominantly shallow over sandy substrates. Water in the stream was categorised as warm, alkaline and subsaline. The water colour was clear to light brown, with cobbles limited, large boulders present, fine gravel to coarse sand dominant, and silt-mud-sand dominating slower flowing portions. Instream habitat was rated as low due to the lack of hydraulic biotope, and flow-depth diversity. Marginal vegetation was present but limited. Site photographs are included in FIGURE 4.8.

8.1.10.1 Water Quality

Water at the time of sampling had elevated nutrients, chlorine, sulphates, sodium, potassium, and magnesium. Water temperature was high probably due to shallow riverbed, with elevated pH and dissolved oxygen.

TABLE 8.35. IN SITU WATER QUALITY RESULTS FOR THE SAND RIVER AT THE R508 BRIDGE.

Date	Time	IC -OOC	Temp (°C)	pH	DO (%)	DO (mg/L)	EC (µS/cm)	TDS (mg/L)
28-iv-2021	13:00	IC	26.4	8.58	189.7	15.78	2 580	1 750
		OOC	29.0	8.71	212.1	10.22	2 580	1 800
Average			27.7	8.6	201	16.2	2 580	1 775

8.1.10.2 Instream Habitat

Six sampling efforts were carried out across a narrow channel, mainly in the sandy-gravel substrates. Cobbles were present but limited, with large boulder-bedrock and sand the dominant substrates. Only cobble-gravel-sand-mud substrates were sampled. Habitat heterogeneity was rated low (49% - Table 8.36).

TABLE 8.36. INFIELD HABITAT CATEGORIES FOR EACH BIOTOPE SAMPLED IN THE SAND RIVER AT THE R508 BRIDGE.

Effort	Category			Hydraulic Biotope	Dominant Substrates and/or Vegetation
	Turbulence	Depth	Flow		
1	V Low	Shallow	Slow	Run	Boulder-gravel
2	Ex-Low	Very shallow	Stagnant	Glide	Cobble-gravel
3	Ex-Low	Very shallow	Stagnant	Glide	Roots-branches
4	Ex-Low	Shallow	Stagnant	Pool	Sedges-sand
5	Ex-Low	Very shallow	Slow	Run	Sand-gravel
6	Ex-Low	Shallow	Stagnant	Glide	Mud-sand-silt
Habitat Heterogeneity					49%

Habitat cover for macroinvertebrates were relatively good where available (Effort 1 - Table 8.37), but those habitats were limited.

TABLE 8.37. A SUMMARY OF THE OCCUPIED VOLUME OF THE SUBSTRATES MEASURED IN THE VOLUME-AREA OF THE SAMPLED BIOTOPE.

Effort	% Of Volume Sampled	TOTAL

	Small Boulder	Large Cobble	Cobble	Coarse Gravel	Gravel	
1	36.29%		1.02%	1.90%	0.02%	39%
2			5.09%	1.00%	0.01%	6%

8.1.10.3 Aquatic Macroinvertebrates

No aquatic macroinvertebrate information was available from the Freshwater Biodiversity Information System (FBIS). Reference conditions were derived from this April 2021 survey, and from the PESEIS Reach (A71K-00019) (Department of Water and Sanitation, 2014).

TABLE 8.38. A SUMMARY OF THE ECOSTATUS DERIVED FROM MIRAI USING DATA COLLECTED THIS SURVEY, AND TAXA EXPECTED AS REFERENCE. DISCHARGE AT A7SAND-R508B SITE FOR THE 2021 SURVEY WAS MEASURED AT THE SITE.

Quaternary Sub-catchment	River		RQOs	A7SAND-R508B 28/iv/21	Target Achieved
A71K	Sand	MIRAI		72% C	
		SASS5		106	
		ASPT		5.6	
Discharge (m^3/s)				0.009*	

Stream conditions were categorised as moderately impaired. Taxa diversity was relatively low, with sensitive taxa mostly absent. Flow sensitive taxa were scare and dominated by two Hydropsychidae species. Impaired conditions are attributed to limited instream habitat linked to subsaline conditions, with low flow-velocity-depth habitat and substrate diversity.

8.1.11 LUVU-A91K-OUTPO

Flow was visually rated as very high, with high availability of stable substrates restricted to deep areas during this high flow sampling event. Water in the stream was categorised as cool-warm alkaline freshwater. The water colour was clear to light brown, with cobbles-boulders the dominant habitat. Instream habitat was rated as high, and the inundation period of wadeable habitat unknown. Site photographs are included in FIGURE 4.9.

8.1.11.1 Water Quality

Measures water parameters in the 2021 survey suggested elevated pH and dissolved oxygen, but more data is required to determine.

TABLE 8.39. IN SITU WATER QUALITY RESULTS FOR THE LUVUVHU RIVER DOWNSTREAM FROM THE MUTALE CONFLUENCE.

Date	Time	IC -OOC	Temp (°C)	pH	DO (%)	DO (mg/L)	EC (µS/cm)	TDS (mg/L)
29-iv-2021	11:15	IC	24.4	8.30	122.60	10.22	381	262
		OOC	25.4	8.38	114.30	9.76	381	262
Average			24.9	8.3	118	10.0	381	262

8.1.11.2 Instream Habitat

Six sampling efforts were carried out limited to shallower flows in the channel. Boulders and cobbles were the dominant substrate, with a high variety of hydraulic biotopes, velocities and depth classes present, but not wadeable. Habitat heterogeneity at the site is high, but habitat sampled was rated moderate to high (62% - TABLE 4.7)

TABLE 8.40. INFIELD HABITAT CATEGORIES FOR EACH BIOTOPE SAMPLED IN THE LUVUVHU RIVER DOWNSTREAM FROM THE MUTALE CONFLUENCE.

Effort	Category			Hydraulic Biotope	Dominant Substrates and/or Vegetation
	Turbulence	Depth	Flow		
1	Ex-High	Intermediate	Fast	Rapid	Boulder-cobble
2	V High	Intermediate	Fast	Rapid riffle	Boulder-cobble
3	Ex-Low	Shallow	Stagnant	Glide	Roots-algae
4	Ex-Low	Intermediate	Stagnant	Pool	Grass-roots-algae
5	Ex-Low	Intermediate	Stagnant	Pool	Silt-mud
6	Mod-Low	Shallow	Slow	Run	Gravel-sand
Habitat Heterogeneity					62%

Habitat cover (interstitial spaces) was considerable in the accessible fast flowing boulder-cobble biotopes.

TABLE 8.41. A SUMMARY OF THE OCCUPIED VOLUME OF THE SUBSTRATES MEASURED IN THE VOLUME-AREA OF THE SAMPLED BIOTOPE.

Effort	% Of Volume Sampled					TOTAL
	Small Boulder	Large Cobble	Cobble	Coarse Gravel	Gravel	
1	14.31%	15.71%	11.93%	2.97%	0.04%	45%
2		1.221%	10.82%	3.84%	0.05%	16%
6			1.33%	0.73%	0.22%	2%

8.1.11.3 Aquatic Macroinvertebrates

Aquatic macroinvertebrate information was supplied by SANPARKS from their Kruger National Park Rivers Biomonitoring Programme. Other information (Oct 1999 data) was collected from the Freshwater Biodiversity Information System (FBIS). Reference conditions are made up of all the available data for the Luvuvhu Outpost site and supplemented with taxa listed for the PESEIS Reach (A71K-00039) (Department of Water and Sanitation, 2014).

TABLE 8.42. DETAILS OF THE SITE ON THE LUVUVHU RIVER BELOW THE MUTALE CONFLUENCE AND THE SAMPLING DATES FOR WHICH DATA WAS MADE AVAILABLE. THE MONITORING DATA FOR THIS SURVEY IS INDICATED IN BLUE FONT.

Site Code	Latitude (S)	Longitude (E)	Elevation (M a.s.l.)	Quat. Catch.	Aq. Ecoregion Lev II	Date	Season
A9LUVU-MUTAL	-22.44460	31.083502	249	A91J	2.02	19 Oct 1999	Spring
						Sep 2010	Spring
						Sep 2011	Spring
						Sep 2012	Spring
						Sep 2012	Spring
						Sep 2013	Spring
						Sep 2014	Spring
						Sep 2015	Spring
						Sep 2016	Spring
						Sep 2017	Spring
						Sep 2018	Spring
						11 Sep 2018	Spring
						Sep 2019	Spring
						Sep 2020	Spring
						29 Apr 2021	Autumn

Conditions at the site in 2021 was categorised as moderately impaired. Taxa considered sensitive to water quality (e.g., Heptageniidae, Tricorythidae, Philopotamidae) dominated the stream community, as did those associated with moderate to fast flows. Freshwater prawns, Palaemondiae: Macrobrachium sp., were encountered during the fishing efforts. They are frequently encountered at the site during electrofishing (Robin Petersen 2018, personal communication, 11 September). SASS records presented less frequent encounters.

TABLE 8.43. A SUMMARY OF THE ECOSTATUS DERIVED FROM MIRAI USING HISTORICAL DATA COLLECTED AND DATA FOR THIS SURVEY. DISCHARGE AT A9LUVU-MUTAL SITE FOR THE 2021 SURVEY WAS MEASURED AT THE SITE.

Quaternary Sub-catchment	River		RQOs	A9LUVU-OUTPO	A9LUVU-OUTPO	A9LUVU-OUTPO	A9LUVU-OUTPO	A9LUVU-OUTPO	A9LUVU-OUTPO	A9LUVU-OUTPO	A9LUVU-OUTPO	A9LUVU-OUTPO	A9LUVU-OUTPO	A9LUVU-OUTPO	A9LUVU-OUTPO	**A9LUVU-OUTPO**
				19/x/99	Sep-10	Sep-11	Sep-12	Sep-13	Sep-14	Sep-15	Sep-16	Sep-17	Sep-18	11/ix/18	Sep-19	**29/iv/21**
A91J	Luvuvhu	MIRAI		75%	63%	52%	73%	75%	70%	65%	53%	53%	82%	82%	69%	**63%**
				C	C	D	C	C	C	C	D	D	B/C	B/C	C	**C**
		SASS		172	123	100	191	156	136	145	119	107	191	199	141	**141**
		ASPT		6.1	5.9	6.3	6.0	5.2	5.4	5.6	5.0	5.1	5.8	6.4	4.9	**6.7**
	Discharge (m^3/s)															**17.433***

8.1.12 OLIF-B73C-MAMBA (B7OLIF-MAMB1)

Flow was visually rated as very high, with high habitat diversity. Water in the river during the 2021 survey was categorised as cool alkaline subsaline. The water colour was clear to olive-brown, with cobbles-boulders, bedrock, gravel, and sandy substrates abundant. Instream habitat diversity was rated as high (62% - Table 8.45). Site photographs are included in FIGURE 4.10.

8.1.12.1 Water Quality

Measures water parameters in the 2020 and 2021 survey suggested elevated pH, while dissolved oxygen and electrical conductivity was elevated in 2021.

TABLE 8.44. IN SITU WATER QUALITY RESULTS FOR THE OLIFANTS RIVER DOWNSTREAM FROM THE KLASERIE CONFLUENCE.

Date	Time	IC -OOC	Temp (°C)	pH	DO (%)	DO (mg/L)	EC (µS/cm)	TDS (mg/L)
30-ix-2020		IC	20.8	8.44	107.36		742	520
05-v-2021	11:30	IC	22.8	8.73	127.90	11.42	1 278	907
		OOC	22.6	8.85	123.10	10.54	1 293	892

8.1.12.2 Instream Habitat

Six sampling efforts were carried out, in a variety of substrates and velocity classes. Large boulders-bedrock are common in the channel, but this biotope was not sampled. Cobbles, gravel, and sand were very dominant, with a high variety of hydraulic biotopes, velocities, and depth classes. Habitat heterogeneity at the site is high, but habitat sampled was rated moderate to high (62% - TABLE 4.7).

TABLE 8.45. INFIELD HABITAT CATEGORIES FOR EACH BIOTOPE SAMPLED IN THE OLIFANTS RIVER DOWNSTREAM FROM THE KLASERIE CONFLUENCE.

Effort	Category			Hydraulic Biotope	Dominant Substrates and/or Vegetation
	Turbulence	Depth	Flow		
1	Ex-High	Intermediate	Fast	Riffle	Cobble-gravel
2	High	Intermediate	Fast	Riffle	Cobble
3	Ex-Low	Shallow	Stagnant	Pool-glide	Grass-sand
4	Ex-Low	Intermediate	Stagnant	Pool	Gravel-sand
5	V Low	Intermediate	Moderate	Run	Grass-silt
6	Ex-Low	Intermediate	Stagnant	Pool-glide	Gravel-mud
Habitat Heterogeneity					62%

Although the cobble-gravel-boulder substrates were present and abundant, a large quantity was embedded in a bed of sand-gravel, therefore the lower volume occupied.

TABLE 8.46. A SUMMARY OF THE OCCUPIED VOLUME OF THE SUBSTRATES MEASURED IN THE VOLUME-AREA OF THE SAMPLED BIOTOPE.

Effort	% Of Volume Sampled					TOTAL
	Small Boulder	Large Cobble	Cobble	Coarse Gravel	Gravel	
1		8.74%	7.91%	1.45%	0.004%	18%
2		26.49%	2.34%	0.44%		29%
6			1.33%	2.93%	0.04%	4%

8.1.12.3 Aquatic Macroinvertebrates

Aquatic macroinvertebrate information was supplied by SANPARKS from their Kruger National Park Rivers Biomonitoring Programme. Other information (July 1993 data) was collected from the Freshwater Biodiversity Information System (FBIS). Sampling dates for available information is included in able 8.47. Reference conditions are made up of all the available data for the Mamba site and supplemented with taxa listed for the PESEIS Reach (B73C-00332) (Department of Water and Sanitation, 2014).

ABLE 8.47. DETAILS OF THE SITE ON THE OLIFANTS RIVER BELOW THE KLASERIE CONFLUENCE AND THE SAMPLING DATES FOR WHICH DATA WAS MADE AVAILABLE. THE MONITORING DATA FOR THIS SURVEY IS INDICATED IN BLUE FONT.

Site Code	Latitude (S)	Longitude (E)	Elevation (M a.s.l.)	Quat. Catch.	Aq. Ecoregion Lev II	Date	Season
B7OLIF-MAMBA	-24.08642	31.25094	278	B73C	3.03	30 Aug 2010	Winter
						07 Sep 2011	Spring
						03 Sep 2012	Spring
						06 Sep 2013	Spring
						14 Aug 2014	Spring
						07 Sep 2015	Spring
						14 Sep 2016	Spring
						11 Sep 2017	Spring
						14 Sep 2018	Spring

	08 Sep 2019	Spring
	30 Sep 2020	Spring
	05 May 2021	Autumn

Conditions in 2021 was rated as moderately Impaired. Previous data indicate that condition vary mostly between moderate and largely impaired (Table 8.48). Taxa rated in SASS as tolerant dominated the stream community, with taxa associated with moderate to fast flows present but not dominant.

TABLE 8.48. A SUMMARY OF THE ECOSTATUS DERIVED FROM MIRAI USING HISTORICAL DATA COLLECTED AND DATA FOR THIS SURVEY. DISCHARGE AT B7OLIF-MAMB1 SITE FOR THE 2021 SURVEY WAS MEASURED AT THE SITE.

Quaternary Sub-catchment	River		RQOs	B7OLIF-MAMBA 30/viii/10	B7OLIF-MAMBA 07/ix/11	B7OLIF-MAMBA 03/ix/12	B7OLIF-MAMBA 06/ix/13	B7OLIF-MAMBA 14/viii/14	B7OLIF-MAMBA 07/ix/15	B7OLIF-MAMBA 14/ix/16	B7OLIF-MAMBA 11/ix/17	B7OLIF-MAMBA 14/ix/18	B7OLIF-MAMBA 08/ix/19	B7OLIF-MAMBA 30/ix/20	**B7OLIF-MAMBA 29/iv/21**	Target Achieved
B73C	Olifants	MIRAI		63%	45%	79%	45%	43%	50%	63%	64%	61%	63%	74%	**61%**	
				C	D	B/C	D	D	D	C	C	C/D	C	C	**C**	
		SASS		112	72	188	77	61	67	124	121	124	121	161	**145**	
		ASPT		5.1	5.1	5.5	5.1	5.1	4.5	5.2	5.3	5.4	5.8	6.7	**5.0**	
B7H015	Discharge (m^3/s)			3.426	8.022	3.667	6.395	11.757	5.331	1.195	2.500	1.571	1.063	1.692	**9.862***	

8.1.13 OLIF-B73H-BALUL (B7OLIF-BALUL)

Flow was visually rated as very high, with high habitat diversity. Water in the river during the 2021 survey was categorised as cold-cool alkaline freshwater. The water colour was clear to brownish, with cobbles-boulders, bedrock, gravel, and sandy substrates abundant. Instream habitat diversity was rated as high (68% - Table 8.50).

8.1.13.1 Water Quality

Measures water parameters in the 2020 and 2021 survey suggested elevated pH, while electrical conductivity levels decreased when compared to the upstream site, B7OLIF-MAMB1. There is also in increase in nutrients between the Mamba and Bulule sites.

TABLE 8.49. IN SITU WATER QUALITY RESULTS FOR THE OLIFANTS RIVER DOWNSTREAM FROM THE BALULE WEIR

Date	Time	IC -OOC	Temp (°C)	pH	DO (%)	DO (mg/L)	EC (µS/cm)	TDS (mg/L)
04-x-2020		IC	26.1	8.3	98		860	994
03-v-2021	09:00	IC	20.7	8.56	112.90	10.10	552	387
		OOC	22.6	8.85	123.10	10.20	543	897

8.1.13.2 Instream Habitat

Six sampling efforts were carried out, in a variety of substrates and velocity classes. Large boulders-bedrock are common below the low-level crossing, and cobble-gravel upstream from the crossing. Most of the stone biotopes were sampled upstream from the bridge. in the channel, but this biotope was not sampled. Cobbles, gravel, and sand were very dominant, with a high variety of hydraulic biotopes, velocities, and depth classes. Habitat heterogeneity at the site is high (68% - Table 8.50).

TABLE 8.50. INFIELD HABITAT CATEGORIES FOR EACH BIOTOPE SAMPLED IN THE OLIFANTS RIVER DOWNSTREAM FROM THE BALULE GAUGING WEIR.

Effort	Category			Hydraulic Biotope	Dominant Substrates and/or Vegetation
	Turbulence	Depth	Flow		
1	V High	Intermediate	Fast	Riffle	Cobble
2	Ex-Low	Intermediate	Stagnant	Glide-pool	Reeds-Grass
3	Ex-High	Shallow	Fast	Rapid	Cobble-gravel
4	V Low	Intermediate	Slow	Glide-pool	Grass
5	Mod-Low	V Shallow	Slow	Riffle	Gravel-sand
6	Ex-Low	Shallow	Stagnant	Pool	Silt-mud-sand

Habitat Heterogeneity	68%

TABLE 8.51. A SUMMARY OF THE OCCUPIED VOLUME OF THE SUBSTRATES MEASURED IN THE VOLUME-AREA OF THE SAMPLED BIOTOPE.

Effort	% Of Volume Sampled					TOTAL
	Small Boulder	Large Cobble	Cobble	Coarse Gravel	Gravel	
1		20.21%	1.68%	1.17%	0.003%	23%
3		3.33%	7.27%	5.46%	0.02%	16%

The bridge causes an impoundment when overtopping, resulting in deposition in the upstream channels. Loose cobble-gravel-boulder substrates are therefore present, but most is embedded within a layer of sand-gravel-cobble.

8.1.13.3 Aquatic Macroinvertebrates

Aquatic macroinvertebrate information was supplied by SANPARKS from their Kruger National Park Rivers Biomonitoring Programme. Information was also collected from the Freshwater Biodiversity Information System (FBIS). Additional information is available for the Balule site on Molluscs (Oberholzer & van Eeden, 1967; De Kock et al. 2002; De Kock & Wolmarans 2010), Hirudinea (Oosthuizen 1991), and Decapoda (Pienaar 1961; Taylor 1990). Sampling dates for available information is included in Table 8.52. Reference conditions are made up of all the available data for the Balule site and supplemented with taxa listed for the PESEIS Reach (B73H-00311) (Department of Water and Sanitation, 2014).

TABLE 8.52. DETAILS OF THE SITE ON THE OLIFANTS RIVER BELOW THE BALULE WEIR AND THE SAMPLING DATES FOR WHICH DATA WAS MADE AVAILABLE. THE MONITORING DATA FOR THIS SURVEY IS INDICATED IN BLUE FONT.

Site Code	Latitude (S)	Longitude (E)	Elevation (M a.s.l.)	Quat. Catch.	Aq. Ecoregion Lev II	Date	Season
B7OLIF-BALUL	-24.05305	31.72990	185	B73H	3.06	01 Oct 2010	Winter
						07 Sep 2011	Spring
						03 Sep 2012	Spring
						06 Sep 2013	Spring
						19 Aug 2014	Spring

07 Sep 2015	Spring
12 Sep 2016	Spring
12 Sep 2017	Spring
11 Sep 2018	Spring
09 Sep 2019	Spring
01 Oct 2020	Spring
03 May 2021	Autumn

Conditions slightly improved at the Balule site when comopared to the upstream Mamba site, but was categorsied as moderately impaired. Both the sensitive Ephemeroptera Tricorythidae and Oligoneuridae were present, as was the Tricoptera famileies Hydropsychidae (2 species), and Philopotamidae. Taxa historicaly recorded but abset in datasets since 1993 included Unionidae: Unio caffer, and Palemoniodae: Macrobrachium sp.

TABLE 8.53. A SUMMARY OF THE ECOSTATUS DERIVED FROM MIRAI USING HISTORICAL DATA COLLECTED AND DATA FOR THIS SURVEY. DISCHARGE AT B7OLIF-BALUL SITE FOR THE 2021 SURVEY WAS MEASURED AT THE SITE.

Quaternary Sub-catchment	River		RQOs	B7OLIF-BALUL 1/x/10	B7OLIF-BALUL 07/ix/11	B7OLIF-BALUL 03/ix/12	B7OLIF-BALUL 06/ix/13	B7OLIF-BALUL 19/viii/14	B7OLIF-BALUL 07/ix/15	B7OLIF-BALUL 12/ix/16	B7OLIF-BALUL 12/ix/17	B7OLIF-BALUL 11/ix/18	B7OLIF-BALUL 09/ix/19	B7OLIF-BALUL 01/x/20	**B7OLIF-BALUL 03/v/21**	Target Achieved
B73H	**Olifants**	**MIRAI**		54%	44%	78%	69%	54%	62%	41%	54%	70%	67%	74%	**70%**	
				D	D	C	C	D	C	D/E	D	C	C	C	**C**	
		SASS		89	80	156	78	82	112	66	100	111	135	149	**150**	
		ASPT		5.2	3.3	5.4	4.9	4.3	4.9	5.1	4.8	5.3	5.4	5.1	**6.0**	
B7H026	Discharge (m^3/s)			2.620	7.710	Na	Na	Na	6.312	1.283	2.697	1.079	1.767	2.537	**10.670***	
RQOs	Maintenance Flow (m^3/s)															
	Drought Flow (m^3/s)															

8.1.14 GLET-B81J-LRANC

Flow was visually rated as low, with high habitat diversity. Water in the river during the 2021 survey was categorised as cool alkaline subsaline. The water colour was clear to brownish, with sand-gravel dominant, and cobble and boulders present but limited to specific points. Instream habitat diversity was rated as high (65% - Table 8.55). Site photographs are included in FIGURE 4.12.

8.1.14.1 Water Quality

Measured pH, dissolved oxygen, and electrical conductivity was elevated, but more data is needed to determine relevance.

TABLE 8.54. IN SITU WATER QUALITY RESULTS FOR THE GREAT LETABA RIVER AT LONE RANCH.

Date	Time	IC -OOC	Temp (°C)	pH	DO (%)	DO (mg/L)	EC (µS/cm)	TDS (mg/L)
06-v-2021	11:30	IC	22.4	8.17	121.8	10.73	1 001	679
		OOC	22.1	8.34	108.5	9.61	1 013	542
Average			22.3	8.3	115	10.2	1 007	611
RQOs				6.5–8.4			300	

8.1.14.2 Instream Habitat

Six sampling efforts were carried out, in a variety of substrates and velocity classes. Large boulders-bedrock were present but very limited, with cobble-gravel more abundant and sand-gravel dominant. Habitat heterogeneity at the site was rated as high (65% - Table 8.55).

TABLE 8.55. INFIELD HABITAT CATEGORIES FOR EACH BIOTOPE SAMPLED IN THE GREAT LETABA RIVER AT THE LONE RANCH SITE.

Effort	Category			Hydraulic Biotope	Dominant Substrates and/or Vegetation
	Turbulence	Depth	Flow		
1	V High	Intermediate	Fast	Riffle-run	Cobble-gravel
2	Low	Intermediate	Moderate	Run	Cobble-gravel
3	V High	Shallow	Moderate	Rapid	Boulder-gravel
4	Ex-Low	Shallow	Stagnant	Glide	Grass-mud-sand
5	Ex-Low	Shallow	Stagnant	Pool	Grass-reed-sand
6	Ex-Low	Shallow	Stagnant	Pool	Sand-silt
Habitat Heterogeneity					65%

The best habitat cover was measured in effort 3, in a boulder-cobble dominant rapid. At the two other stone biotopes, the gradient was lower and cobble-boulders more embedded in sand-gravel Table 8.56.

TABLE 8.56. A SUMMARY OF THE OCCUPIED VOLUME OF THE SUBSTRATES MEASURED IN THE VOLUME-AREA OF THE SAMPLED BIOTOPE.

Effort	% Of Volume Sampled					TOTAL
	Small Boulder	Large Cobble	Cobble	Coarse Gravel	Gravel	
1		5.10%	3.18%	4.01%	0.01%	12%
2			5.49%	1.64%	0.004%	7%
3	28.88%	12.13%		0.18%	0.003%	41%

8.1.14.3 Aquatic Macroinvertebrates

The site is located at an existing IFR (Instream Flow Requirement) site, with data collected in 2001, 2003 and 2007 (Table 8.57). This information was extracted from the Freshwater Biodiversity Information System (FBIS). Reference conditions were based on taxa previously recorded and from the Reach PESEIS (Department of Water and Sanitation, 2014).

TABLE 8.57. DETAILS OF THE SITE ON THE GREAT LETABA RIVER AT LONE RANCH AND THE SAMPLING DATES FOR WHICH DATA WAS AVAILABLE. THE MONITORING DATA FOR THIS SURVEY IS INDICATED IN BLUE FONT.

Site Code	Latitude (S)	Longitude (E)	Elevation (M a.s.l.)	Quat. Catch.	Aq. Ecoregion Lev II	Date	Season
B8GLET-IFR16	-23.67708	31.09833	311	B81J	3.03	01 Oct 2001	Spring
						09 May 2003	Autumn
						20 Jun 2007	Winter
						06 May 2021	Autumn

Conditions were continuously rated as moderatly impaired during the four sampling events since 2001. Both flow sensitive taxa and SASS rated sensitive taxa were present and dominant in stones in current biotopes. Historically the Ephemerotera: Tricorythidae is not regularly encountered, and the exotic mollusc Thiaridae: Tarebia granifera was recorded for the first time in June 2007.

TABLE 8.58. A SUMMARY OF THE ECOSTATUS DERIVED FROM MIRAI USING HISTORICAL DATA COLLECTED AND DATA FOR THIS SURVEY. THE COMPLIANCE TO RESOURCE QUALITY OBJECTIVES IS INDICATED AS RED (FAILED) OR GREEN (ACHIEVED), AND THE PERCENTAGE OF TIME ACHIEVED ARE PRESENTED. DISCHARGE AT B8GLET-IFR16 SITE FOR THE 2021 SURVEY WAS MEASURED AT THE SITE.

Quaternary Sub-catchment	River		RQOs	B8GLET-IFR16 01/x/01	B8GLET-IFR16 09/v/03	B8GLET-IFR16 20/iv/07	B8GLET-IFR16 06/v/21	Target Achieved
B81J	Great Letaba	MIRAI	≥62%	66%	77%	68%	**67%**	100%
			C	C	C	C	**C**	
		SASS		132	139	125	**120**	
		ASPT		6.6	5.1	5.0	**5.7**	
B8H008	Discharge (m^3/s)			0.683	0.321	0.485	**1.788***	50%
RQOs	90%			0.523	0.688	1.339	**0.688**	
	60%			0.554	1.354	1.856	**1.354**	

8.1.15 LETA-B83A-LONELY BULL

Flow was visually rated as low, with high habitat diversity. The water colour was clear to greenish brown, with cobble-boulder present, and sand-gravel dominant. Instream habitat diversity was rated as high (62% - Table 8.60). Site photographs are included in FIGURE 4.13.

8.1.15.1 Water Quality

The water during the 2021 site visit was categorised as cool, alkaline freshwater. The pH and electrical conductivity were elevated in the out of current measurements.

TABLE 8.59. IN SITU WATER QUALITY RESULTS FOR THE LETABA RIVER AT LONELY BULL.

Date	Time	IC -OOC	Temp (°C)	pH	DO (%)	DO (mg/L)	EC (µS/cm)	TDS (mg/L)
04-v-2021	10:15	IC	21.2	7.98	103.6	9.30	378	259
		OOC	24.2	8.86	122.7	10.12	1 231	858
Average			22.7	8.4	113	9.7	805	559

8.1.15.2 Instream Habitat

Six sampling efforts were carried out, in a variety of substrates and velocity classes. At the site, large boulders, bedrock, cobble, gravel, and sand-mud substrates were well represented. Habitat heterogeneity at the site was rated as high (65% - Table 8.60), with hydraulic biotopes and different velocity classes sampled.

TABLE 8.60. INFIELD HABITAT CATEGORIES FOR EACH BIOTOPE SAMPLED IN THE LETABA RIVER AT THE LONELY BULL SITE.

Effort	Category			Hydraulic Biotope	Dominant Substrates and/or Vegetation
	Turbulence	Depth	Flow		
1	Low	Intermediate	Fast	Rapid	Cobble-gravel
2	High	Intermediate	Fast	Riffle	Cobble-gravel
3	Low	Shallow	Slow	Run	Grass
4	Ex-Low	Intermediate	Stagnant	Pool-glide	Grass
5	Ex-High	Shallow	Fast	Riffle	Gravel
6	Ex-Low	Shallow	Stagnant	Pool	Sand-mud-silt
Habitat Heterogeneity					62%

Habitat cover in the substrates were limited, with embeddednes reducing the volume occupied in the area sampled (Table 8.61). Cobble substrates dominated the first and second sampling efforts.

TABLE 8.61. A SUMMARY OF THE OCCUPIED VOLUME OF THE SUBSTRATES MEASURED IN THE VOLUME-AREA OF THE SAMPLED BIOTOPE.

Effort	% Of Volume Sampled					TOTAL
	Small Boulder	Large Cobble	Cobble	Coarse Gravel	Gravel	
1		9.16%	5.30%	2.81%	0.006%	17%
2		4.20%	2.49%	1.13%		8%
3			0.31%	4.26%	0.10%	5%

8.1.15.3 Aquatic Macroinvertebrates

Aquatic macroinvertebrate information was supplied by SANPARKS from their Kruger National Park Rivers Biomonitoring Programme. Additional information is available for the Letaba River on Molluscs (Oberholzer & van Eeden, 1967; De Kock et al. 2002; De Kock & Wolmarans 2010), Hirudinea (Oosthuizen 1991), and Decapoda (Pienaar 1961; Taylor 1990). Sampling dates for available information is included in Table 8.62. Reference conditions are made up of all the available data for the Letaba River in the Kruger national Park and supplemented with taxa listed for the PESEIS Reach (B83A-00235) (Department of Water and Sanitation, 2014).

TABLE 8.62. DETAILS OF THE SITE ON THE LETABA RIVER ABOVE THE H14 BRIDGE AND THE SAMPLING DATES FOR WHICH DATA WAS MADE AVAILABLE. THE MONITORING DATA FOR THIS SURVEY IS INDICATED IN BLUE FONT.

Site Code	Latitude (S)	Longitude (E)	Elevation (M a.s.l.)	Quat. Catch.	Aq. Ecoregion Lev II	Date	Season
B7LETA-LBULL	-23.75833	31.36997	264	B83A	3.03	01 Oct 2010	Winter
						05 Sep 2012	Spring
						05 Sep 2013	Spring
						19 Aug 2014	Spring
						08 Sep 2015	Spring
						12 Sep 2016	Spring
						12 Sep 2017	Spring
						11 Sep 2018	Spring
						01 Oct 2020	Spring
						04 May 2021	Autumn

Conditions at the Lonely Bull site on the Letaba River was as moderately impaired. Since 2010, the targeted Resource Quality Objective in terms of the aquatic macroinverebrates have been achieved 70% of the time, while discharge was only achieved 44% of the time. Discharge however, need to be assessed in terms of timing, intensity, frequency and duration to be able to improve interpretation of potential responses.

Taxa associated with moderate to fast flowing habitats and water of moderate to high quality was well represented in 2021, with some (e.g. Tricorythidae, Oligoneuridae, and Hydropsychidae) abundant.

No Freshwater prawns (Macrobrachium sp.) has been encountered during electrofishing (Robin Petersen, 2018, personal communication, 11 September) or SASS monitoring since collected from 2010 onwards. Historically the were encountered in the Letaba River (1959, 1960) but were also not encountered in 1987 and 1988 surveys (Taylor 1990). Old empty shell of Potamididae were picked in the deposition flood bench near the site.

TABLE 8.63. A SUMMARY OF THE ECOSTATUS DERIVED FROM MIRAI USING HISTORICAL DATA COLLECTED AND DATA FOR THIS SURVEY. THE COMPLIANCE TO RESOURCE QUALITY OBJECTIVES IS INDICATED AS RED (FAILED) OR GREEN (ACHIEVED), AND THE PERCENTAGE OF TIME ACHIEVED ARE PRESENTED. DISCHARGE AT LETA-B83A-LBULL SITE FOR THE 2021 SURVEY WAS MEASURED AT THE SITE.

Quaternary Sub-catchment	River		RQOs	B8LETA-LBULL 1/x/10	B8LETA-LBULL 05/ix/12	B8LETA-LBULL 05/ix/13	B8LETA-LBULL 19/viii/14	B8LETA-LBULL 08/ix/15	B8LETA-LBULL 12/ix/16	B8LETA-LBULL 12/ix/17	B8LETA-LBULL 11/ix/18	B8LETA-LBULL 10/ix/19	**B8LETA-LBULL 04/v/21**	Target Achieved
B83A	Letaba	MIRAI	≥62%	67%	73%	64%	66%	59%	64%	56%	58%	73%	**75%**	70%
			C	C	C	C	C	C/D	C	D	C/D	C	**C**	
		SASS		104	137	130	117	118	123	92	105	158	**178**	
		ASPT		4.5	5.1	5.7	5.6	5.4	4.9	4.4	5.0	4.9	**5.9**	
	Discharge (m^3/s)			0.096	1.198	0.000	1.435	0.858	0.217	0.561	0.528	0.000	**1.656***	44%
	RQOs	90%		0.497	0.594	0.594	0.597	0.594	0.594	0.594	0.594	0.594	**0.571**	
		60%		0.597	0.598	0.598	0.597	0.598	0.598	0.598	0.598	0.598	**0.597**	

8.1.16 ELEP-Y30C-SINGU

Flow was visually rated as high, with low habitat diversity. The water colour was clear, with sand-gravel substrates dominant. The water during the 2021 survey was categorised as cool, alkaline freshwater. Instream habitat diversity was rated as moderate (57% - Table 8.65). Site photographs are included in FIGURE 4.14.

8.1.16.1 Water Quality

Nutrients, pH, and dissolved oxygen were slightly elevated, but more data is required to determine relevance.

TABLE 8.64. IN SITU WATER QUALITY RESULTS FOR THE ELEPHANTES RIVER IN MOZAMBIQUE DOWNSTREAM FROM MASSINGIHR DAM.

Date	Time	IC -OOC	Temp (°C)	pH	DO (%)	DO (mg/L)	EC (µS/cm)	TDS (mg/L)
09-iv-2021	12:30	IC	22.6	8.08	114	12.68	413.6	392.1

9 Instream Habitat

Six sampling efforts were carried out, limited in terms of substrates, velocity classes and hydraulic biotopes. Habitat heterogeneity at the site was rated as moderate (57% - Table 8.65).

TABLE 8.65. INFIELD HABITAT CATEGORIES FOR EACH BIOTOPE SAMPLED IN THE ELEPHANTES RIVER AT THE SITE IN MOZAMBIQUE.

Effort	Category			Hydraulic Biotope	Dominant Substrates and/or Vegetation
	Turbulence	Depth	Flow		
1	Low	Intermediate	Moderate	Run	Gravel-sand
2	Ex-low	Intermediate	Stagnant	Pool	Herb
3	Low	Intermediate	Fast	Run	Sand
4	Ex-Low	Deep	Stagnant	Pool	Aq. Veg-Mud-Detritus
5	Low	Intermediate	Moderate	Riffle-run	Gravel-sand-mud
6	Ex-Low	Intermediate	Slow	Glide	Reeds-Aq. Veg
Habitat Heterogeneity					57%

Cover for aquatic invertebrates in the gravel-sand dominated streambed was limited (Table 8.66), with most taxa encountered in the marginal and aquatic vegetation biotopes.

TABLE 8.66. A SUMMARY OF THE OCCUPIED VOLUME OF THE SUBSTRATES MEASURED IN THE VOLUME-AREA OF THE SAMPLED BIOTOPE.

Effort	% Of Volume Sampled					TOTAL
	Small Boulder	Large Cobble	Cobble	Coarse Gravel	Gravel	
1				0.41%		0.4%
5				0.74%	0.05%	0.8%

9.1.1.1 *Aquatic Macroinvertebrates*

Aquatic macroinvertebrate information was supplied by Nepid Consultants from a 2005 low flow and 2006 high flow survey conducted in the Elephantes and Limpopo Rivers in Mozambique. Sampling dates for available information is included in Table 8.67.

TABLE 8.67. DETAILS OF SITES ON THE ELEPHANTES AND LIMPOPO RIVERS IN THE VICINITY OF THE 2021 SAMPLING SITES. THE MONITORING DATA FOR THIS SURVEY IS INDICATED IN BLUE FONT.

Site Code	Latitude (S)	Longitude (E)	Elevation (M a.s.l.)	Quat. Catch.	Aq. Ecoregion Lev II	Date	Season
Y3ELEP-MASSI	-23.88011	32.25380	88	Y30C	Na	01 Aug 2005	Winter
						18 May 2006	Autumn
Y3ELEP-SUNGI	-23.87540	32.22625	89	Y30C	Na	09 Jun 2021	Winter

Conditions based on the limited reference data was categorised as moderately impaired, mainly linked to instream habitat availability. Taxa considered sensitive to flow and water quality was present but not abundant. Most taxa were recorded in 2021 were present in the in and out of current marginal vegetation, and aquatic vegetation biotopes sampled.

TABLE 8.68. A SUMMARY OF THE ECOSTATUS DERIVED FROM MIRAI USING HISTORICAL DATA COLLECTED AND DATA FOR THIS SURVEY. DISCHARGE PRESENTED FOR EACH SURVEY WAS MEASURED AT THE SITE.

Quaternary Sub-catchment	River		RQOs	Y3ELEP-MASSI 02/vii/05	Y3ELEP-MASSI 19/v/06	Y3ELEP-SUNGI 09/vi/21	Target Achieved
Y30C	Elephantes	MIRAI	≥62%	63%	66%	**74%**	100%
			C	C	C	**C**	
		SASS		109	101	**125**	
		ASPT		4.7	5.6	**5.2**	
B8H008	Discharge (m^3/s)			22.000	8.500	**30.287**	

9.1.2 SHIN-B90H-POACH

Flow was visually rated as low, with moderate habitat diversity. The water colour was light brown to clear, with sand-gravel substrates dominant. A rapid downstream from the bridge culverts provided some bedrock substrate in moderate to fast flows. The rest of the substrates in the channel was dominated by coarse sand-gravel. The water during the 2021 survey was categorised as cool, alkaline freshwater. Instream habitat diversity was rated as moderate (59% - Table 4 61). Site photographs are included in FIGURE 4.15.

9.1.2.1 Water Quality

Nutrients, pH, and dissolved oxygen were slightly elevated, but more data is required to determine relevance.

TABLE 8.69. IN SITU WATER QUALITY RESULTS FOR THE SHINGWEDZI RIVER UPSTREAM FROM THE DZOMBO CONFLUENCE.

Date	Time	IC -OOC	Temp (°C)	pH	DO (%)	DO (mg/L)	EC (µS/cm)	TDS (mg/L)
01-v-2021	09:00	IC	22.0	8.12	106.7	9.68	931	648
		OOC	20.9	8.60	93.10	8.26	869	595
Average			21.5	8.2	100	9.0	900	622

9.1.2.2 Instream Habitat

Six sampling efforts were carried out, limited in terms of substrates, velocity classes and hydraulic biotopes. Habitat heterogeneity at the site was rated as moderate (59% - Table 8.70).

Table 8.70. Infield habitat categories for each biotope sampled in the Shingwedzi River at the Dzombo confluence.

Effort	Category			Hydraulic Biotope	Dominant Substrates and/or Vegetation
	Turbulence	Depth	Flow		
1	Ex-High	V Shallow	Fast	Chute	Bedrock
2	Ex-Low	Shallow	Stagnant	Pool	Cobble-gravel
3	Ex-Low	Shallow	Stagnant	Pool	Reeds-sand
4	Low	V Shallow	Slow	Run	Gravel-sand
5	Ex-Low	Intermediate	Stagnant	Glide	Sand-silt
6	Ex-Low	Intermediate	Stagnant	Pool	Reeds-sand
Habitat Heterogeneity					59%

Cover for aquatic invertebrates on the bedrock was very limited, but in the stones out of current effort (effort 2), cover was moderate to high (Table 8.71. The bulk of the streambed was dominated with sand-gravel.

Table 8.71.. A summary of the occupied volume of the substrates measured in the volume-area of the sampled biotope.

Effort	% Of Volume Sampled					TOTAL
	Small Boulder	Large Cobble	Cobble	Coarse Gravel	Gravel	
2		26.44%	8.46%	2.47%	0.02%	37%

9.1.2.3 Aquatic Macroinvertebrates

Aquatic macroinvertebrate information was collected from the Freshwater Biodiversity Information System (FBIS). In addition, reference conditions were made up of sampling data collected during this survey and supplemented with taxa listed for the PESEIS Reach (B90H-00145) (Department of Water and Sanitation, 2014).

Table 8.72. Details of sites on the Shingwedzi River in the vicinity of the 2021 sampling site. The monitoring data for this survey is indicated in blue font

Site Code	Latitude (S)	Longitude (E)	Elevation (M a.s.l.)	Quat. Catch.	Aq. Ecoregion Lev II	Date	Season
B9SHIN-ALTEI	-23.13741	30.90036	446	B90F	3.03	24 May 2001	Autumn

B9DZOM-POACH	-23.22188	31.55185	245	B90H	3.05	02 May 2021	Autumn
B9SHIN-KANNI	-23.14410	31.47280	261	B90H	3.05	19 Jun 2012	Winter
B9SHIN-POACH	-23.22194	31.55492	242	B90H	3.05	01 May 2021	Autumn

Conditions in the Shingwedzi River at the sampling site was categorised as largely natural to moderately impaired. The Shingwedzi is annually restricted to subsurface flow regulated by groundwater inputs, while surface water is mostly restricted to isolated pools. Taxa expected based on historical data and available biotopes were mostly present in the 2021 sample.

TABLE 8.73. A SUMMARY OF THE ECOSTATUS DERIVED FROM MIRAI USING HISTORICAL DATA COLLECTED AND DATA FOR THIS SURVEY. DISCHARGE PRESENTED FOR EACH SURVEY WAS MEASURED AT THE SITE.

Quaternary Sub-catchment	River		RQOs	B9SHIN-ALTEI 24/v/01	B9SHIN-KANNI 19/vi/12	B9DZOM-POACH 02/v/21	B9SHIN-POACH 01/v/21	Target Achieved
B90H	Shingwedzi	MIRAI		57%	45%	62%	**79%**	
				D	D	C	**B/C**	
		SASS		71	60	89	**134**	
		ASPT		4.2	4.6	5.0	**5.0**	
Discharge (m^3/s)					0.003*		**0.012***	

9.1.3 LIMP-Y30F-CHOKW

Flow was visually rated as moderate, with moderate to low habitat diversity. The water colour was light brown to clear, with sand-gravel substrates dominant. The water during the 2021 survey was categorised as cool, alkaline freshwater. Instream habitat diversity was rated as moderate to low (54% - Table 8.75). Site photographs are included in FIGURE 4.16.

9.1.3.1 Water Quality

All parameters measured fell within acceptable limits.

TABLE 8.74. IN SITU WATER QUALITY RESULTS FOR THE LIMPOPO RIVER AT CHOKWE IN MOZAMBIQUE.

Date	Time	IC -OOC	Temp (°C)	pH	DO (%)	DO (mg/L)	EC (µS/cm)	TDS (mg/L)

10-vi-2021	16:25	IC	21.3	8.1	120	13.7	494	470

9.1.3.2 Instream Habitat

Six sampling efforts were carried out, limited in terms of substrates, velocity classes and hydraulic biotopes. Habitat heterogeneity at the site was rated as moderate to low (54% - Table 8.75).

TABLE 8.75. INFIELD HABITAT CATEGORIES FOR EACH BIOTOPE SAMPLED IN THE LIMPOPO RIVER AT CHOKWE.

Effort	Category			Hydraulic Biotope	Dominant Substrates and/or Vegetation
	Turbulence	Depth	Flow		
1	V Low	Shallow	Slow	Run-glide	Gravel-sand
2	V Low	Shallow	Slow	Run	Reed-Gravel-Sand
3	Ex-Low	Deep	Stagnant	Glide-eddy	Grass-Mud
4	Ex-Low	Shallow	Stagnant	Glide-pool	Mud-Sand
5	V Low	Intermediate	Moderate	Run	Gravel-Sand
6	V Low	Intermediate	Slow	Run	Branch-Sand
Habitat Heterogeneity					54%

Cover for aquatic macroinvertebrates preferring flowing waters was mainly restricted to branches and vegetation, with gravel biotopes limited and providing only limited cover (Table 8.76).

TABLE 8.76. A SUMMARY OF THE OCCUPIED VOLUME OF THE SUBSTRATES MEASURED IN THE VOLUME-AREA OF THE SAMPLED BIOTOPE.

Effort	% Of Volume Sampled					TOTAL
	Small Boulder	Large Cobble	Cobble	Coarse Gravel	Gravel	
1				0.16%	0.03%	0.2%

9.1.3.3 Aquatic Macroinvertebrates

Aquatic macroinvertebrate information was supplied by Nepid Consultants from a 2005 low flow and 2006 high flow survey conducted in the Elephantes and Limpopo Rivers in Mozambique. Sampling dates for available information is included in Table 8.77.

TABLE 8.77. DETAILS OF SITES ON THE LIMPOPO RIVER IN MOZAMBIQUE IN THE VICINITY OF THE 2021 SAMPLING SITE. THE MONITORING DATA FOR THIS SURVEY IS INDICATED IN BLUE FONT.

Site Code	Latitude (S)	Longitude (E)	Elevation (M a.s.l.)	Quat. Catch.	Aq. Ecoregion Lev II	Date	Season
Y3LIMP-EWR02	-23.30000	32.82130	40	Y30F	Na	01 Aug 2005	Winter
						18 May 2006	Autumn
Y3LIMP-CHOKW	-24.50138	33.00882	30	Y30F	Na	17 Jun 2012	Winter
						10 Jun 2021	Winter

Conditions at the site was rated as moderately impaired. Taxa associated with high flow and acceptable water quality was encountered clinging on to a submerged branch (Effort 6 - Tricorythidae and Simuliidae), and a very small number of Hydropsychidae in the gravel biotope (Effort 1). Taxa associated with slow to stagnant waters dominated, mainly linked to habitat availability.

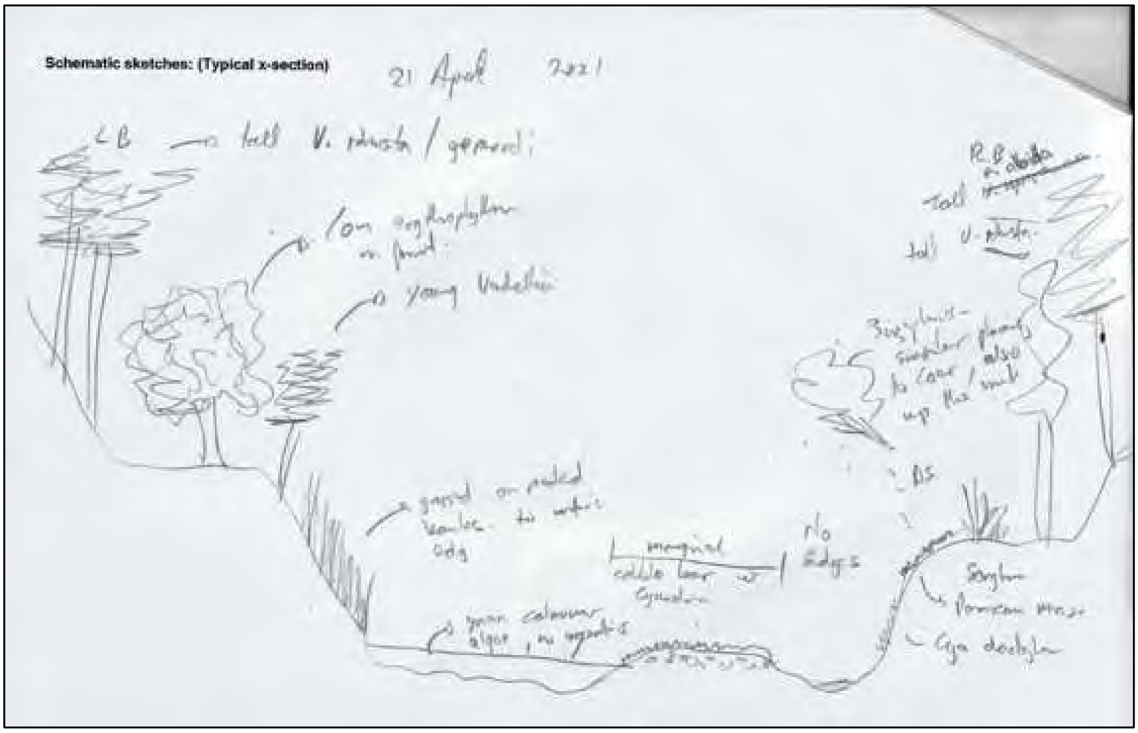
TABLE 8.78. A SUMMARY OF THE ECOSTATUS DERIVED FROM MIRAI USING HISTORICAL DATA COLLECTED AND DATA FOR THIS SURVEY. DISCHARGE PRESENTED FOR EACH SURVEY WAS MEASURED AT THE SITE.

Quaternary Sub-catchment	River		RQOs	Y3LIMP-EWR02 01/viii/05	Y3LIMP-EWR02 18/v/06	Y3LIMP-CHOKW 17/vi/12	Y3LIMP-CHOKW 10/vi/21	Target Achieved
Y30C	Elephantes	MIRAI	≥62%	78%	58%	48%	64%	50%
			C	B/C	D	D	C	
		SASS		165	81	63	114	
		ASPT		5.5	5.8	5.3	5.7	
B8H008	Discharge (m^3/s)			17.000*	60.000*	18.782*	35.058*	

9.2 APPENDIX B: RIPARIAN VEGETATION

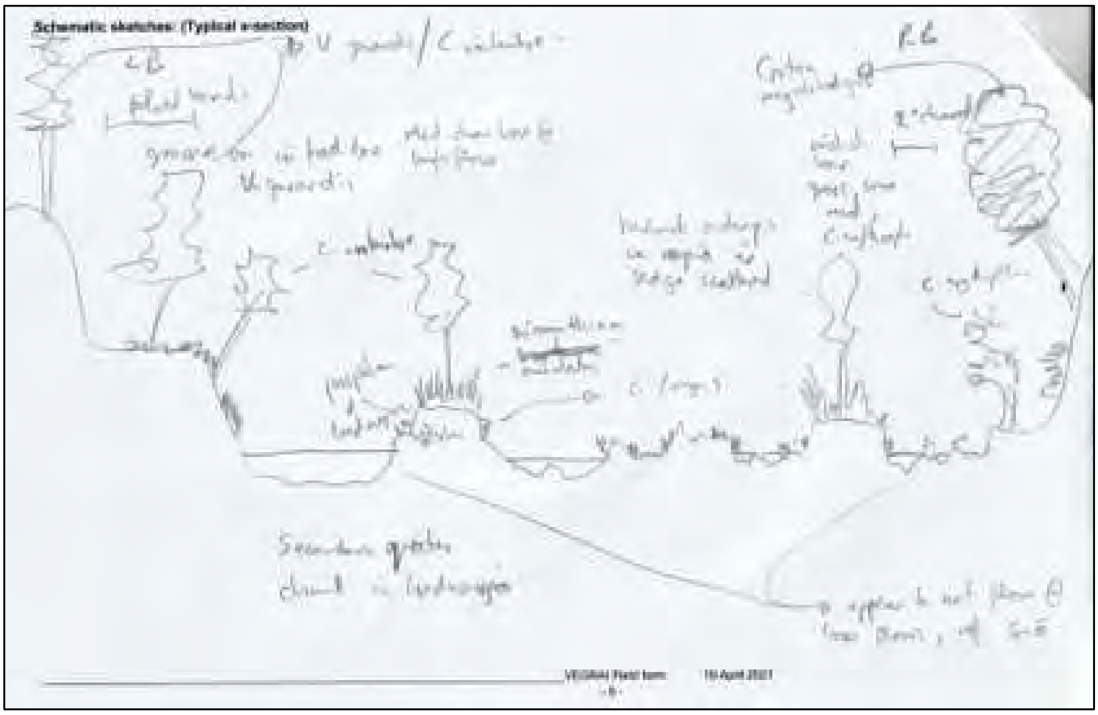
9.2.1 Field Sketches of Typical Cross Sections and associate Vegetation

9.2.2 Crocodile River (CROC-A24J-ROOIB):



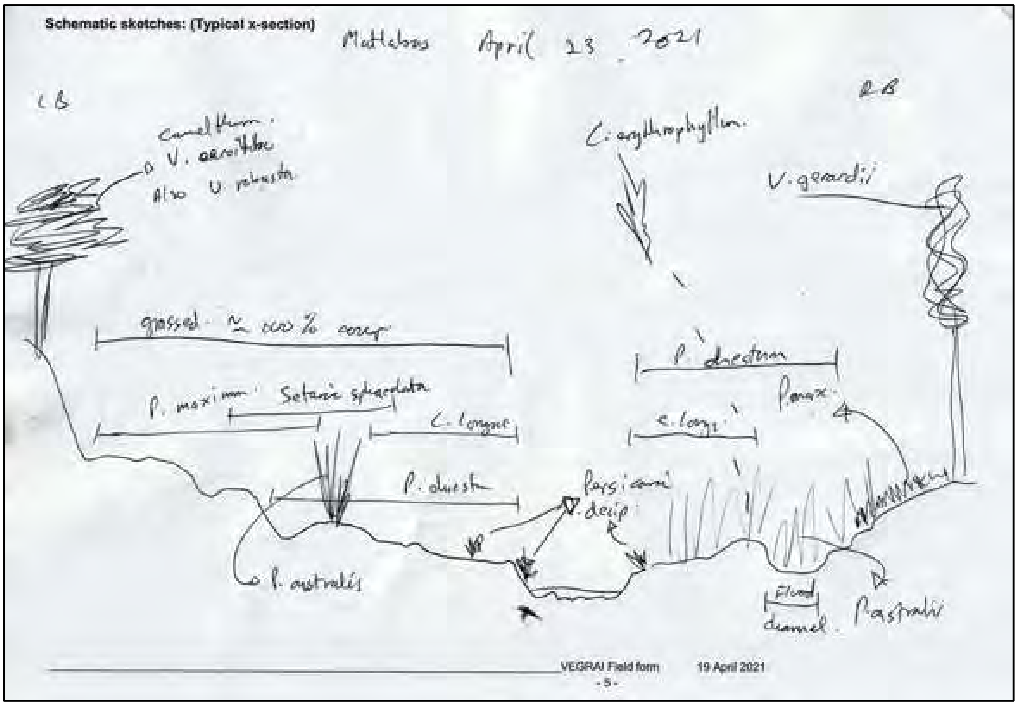
Schematic profile drawn in the field to show where vegetation components occur.

9.2.3 Limpopo River @ Spanwerk (LIMP-A41D-SPANW):



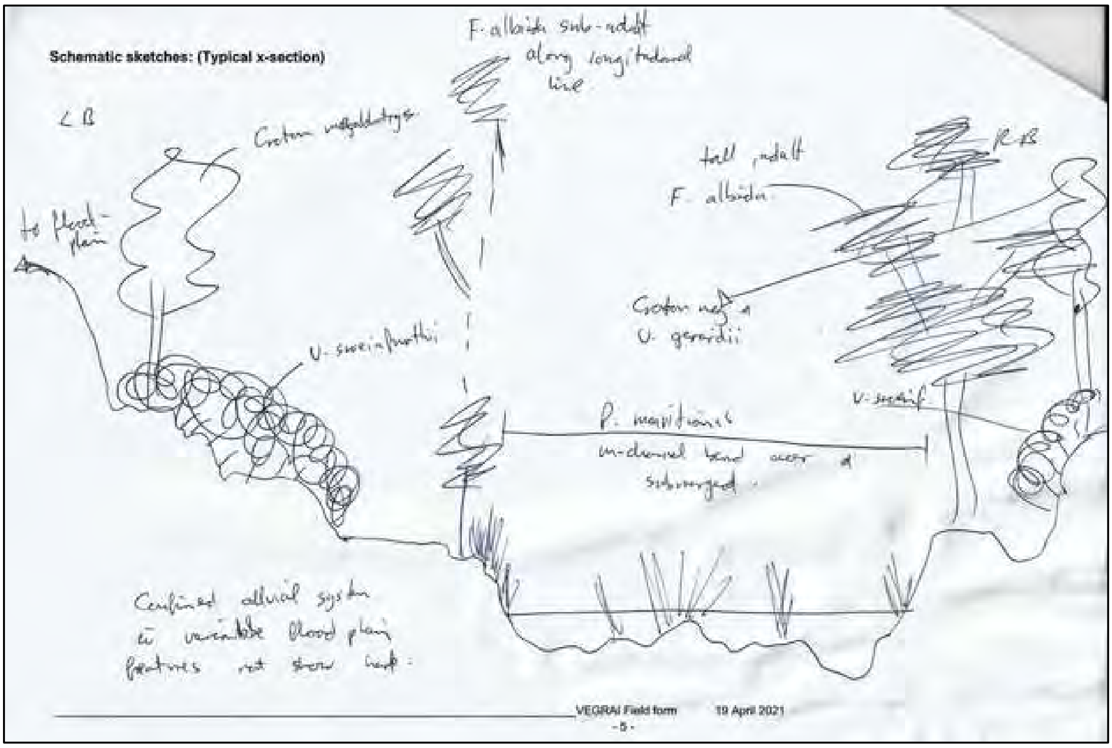
Schematic profile drawn in the field to show where vegetation components occur.

9.2.4 Matlabas River (MATL-A41D-WDRAAI):



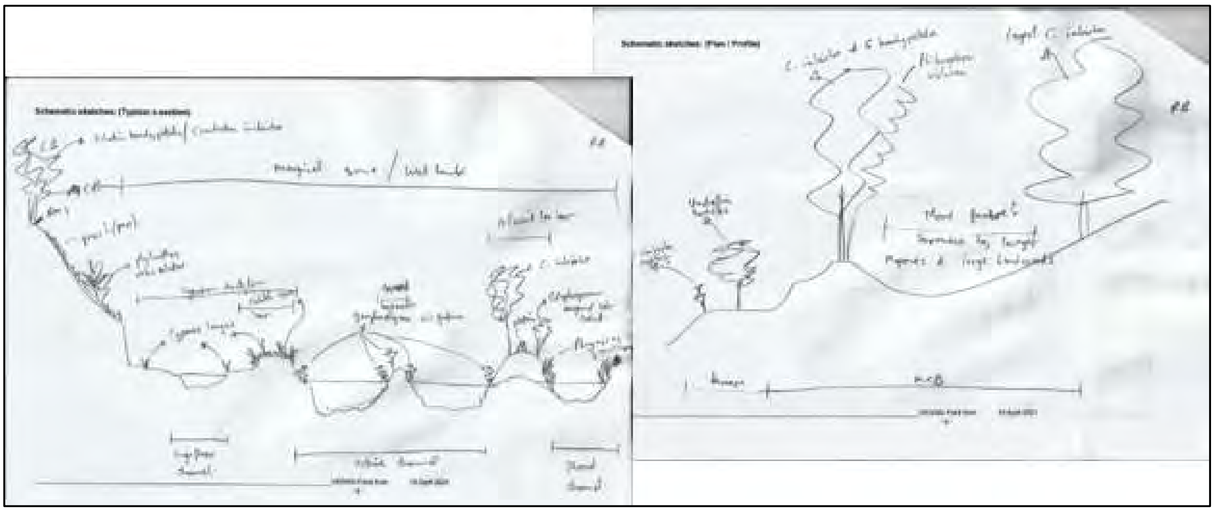
Schematic profile drawn in the field to show where vegetation components occur.

9.2.5 Lephalala River (LEPH-A50H-SEEKO):



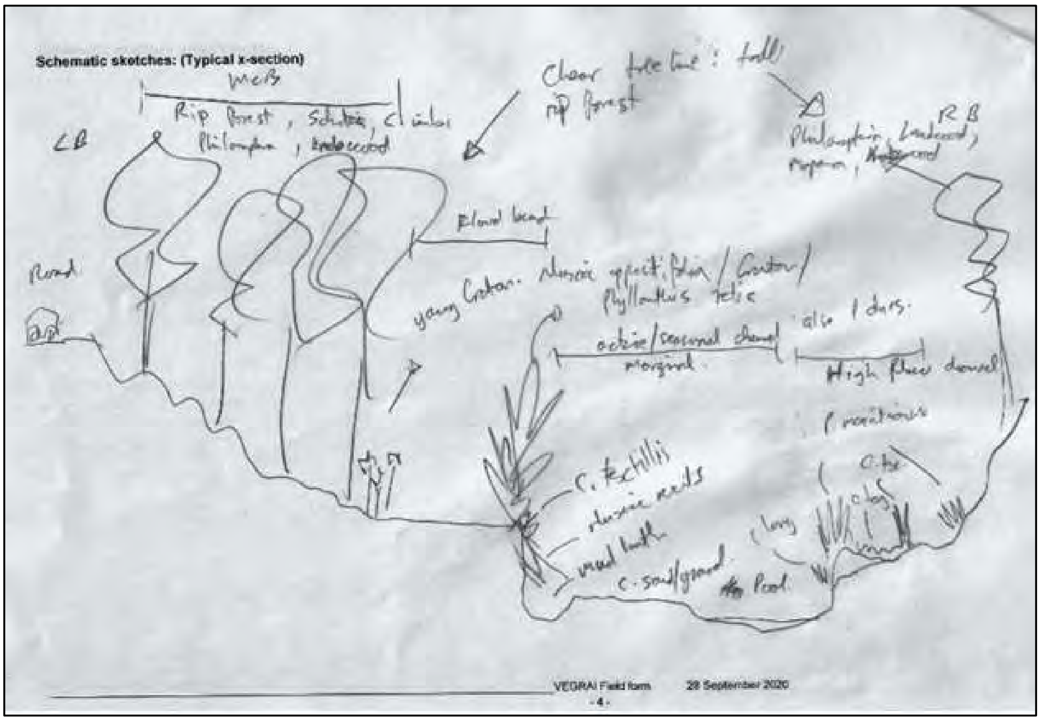
Schematic profile drawn in the field to show where vegetation components occur.

9.2.6 Limpopo River @ Limpokwena (LIMP-A36C-LIMPK):



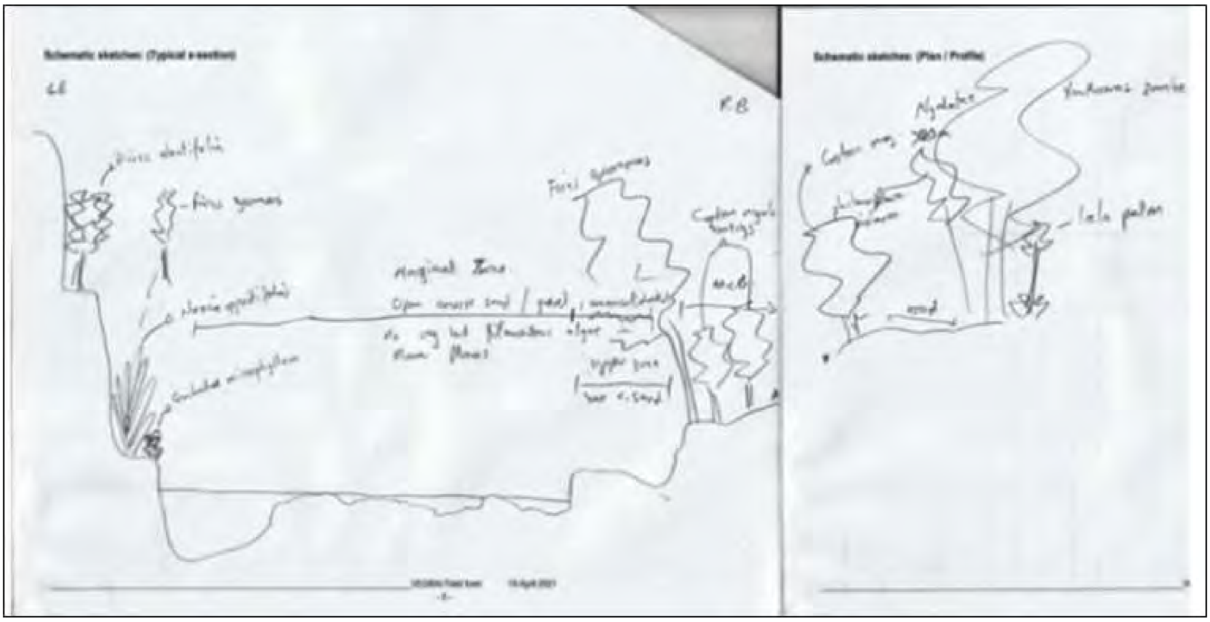
Schematic profile drawn in the field to show where vegetation components occur.

9.2.7 Mogalakwena River (MOGA-A36D-LIMPK):



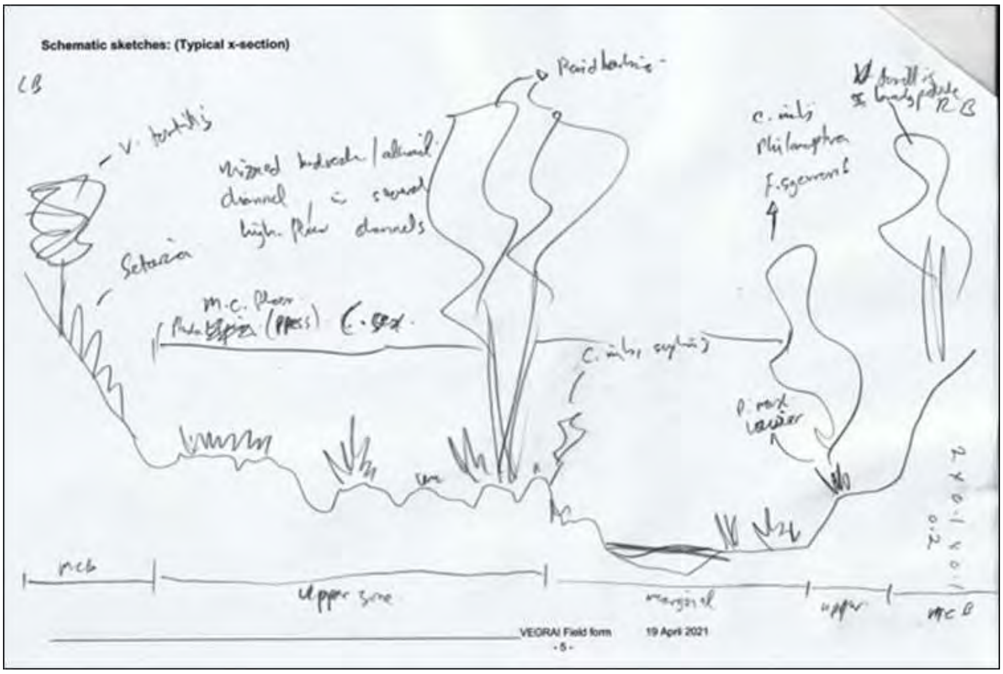
Schematic profile drawn in the field to show where vegetation components occur.

9.2.8 Limpopo River @ Poachers Corner (LIMP-A71L-MAPUN):



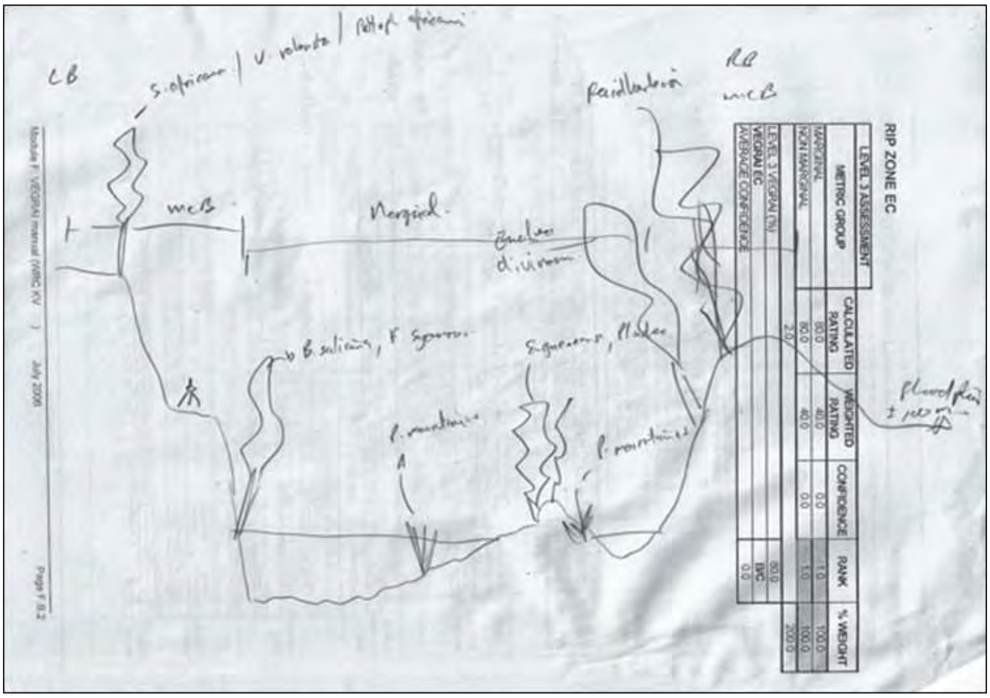
Schematic profile drawn in the field to show where vegetation components occur.

9.2.9 Sand River (SAND-A71K-R508B):



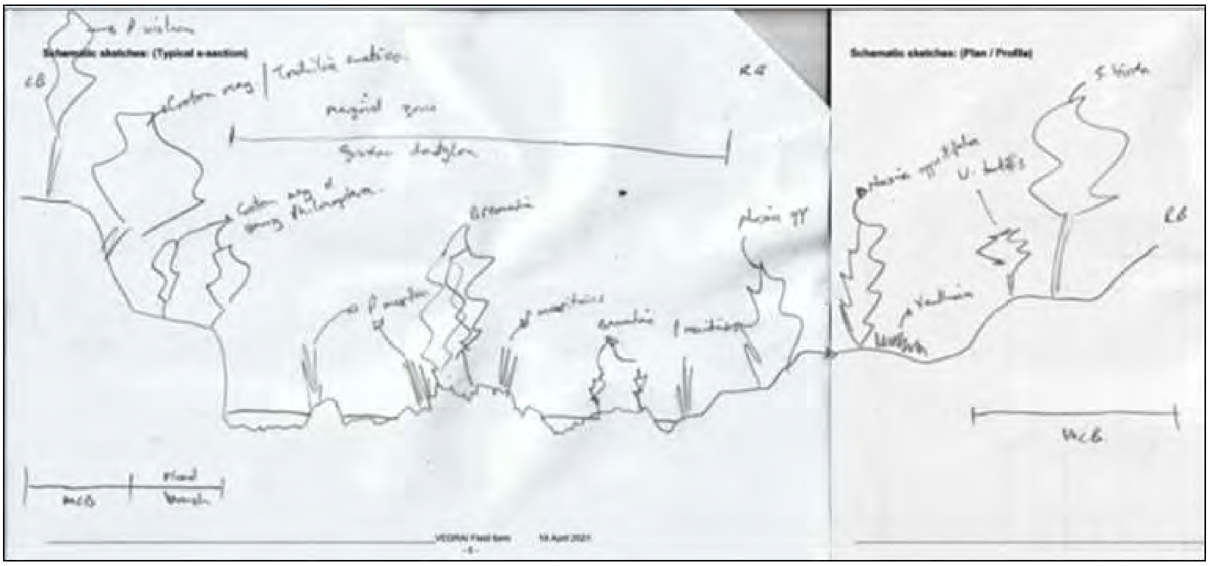
Schematic profile drawn in the field to show where vegetation components occur.

9.2.10 Levuhvu River (LUVU-A91K-OUTPO):



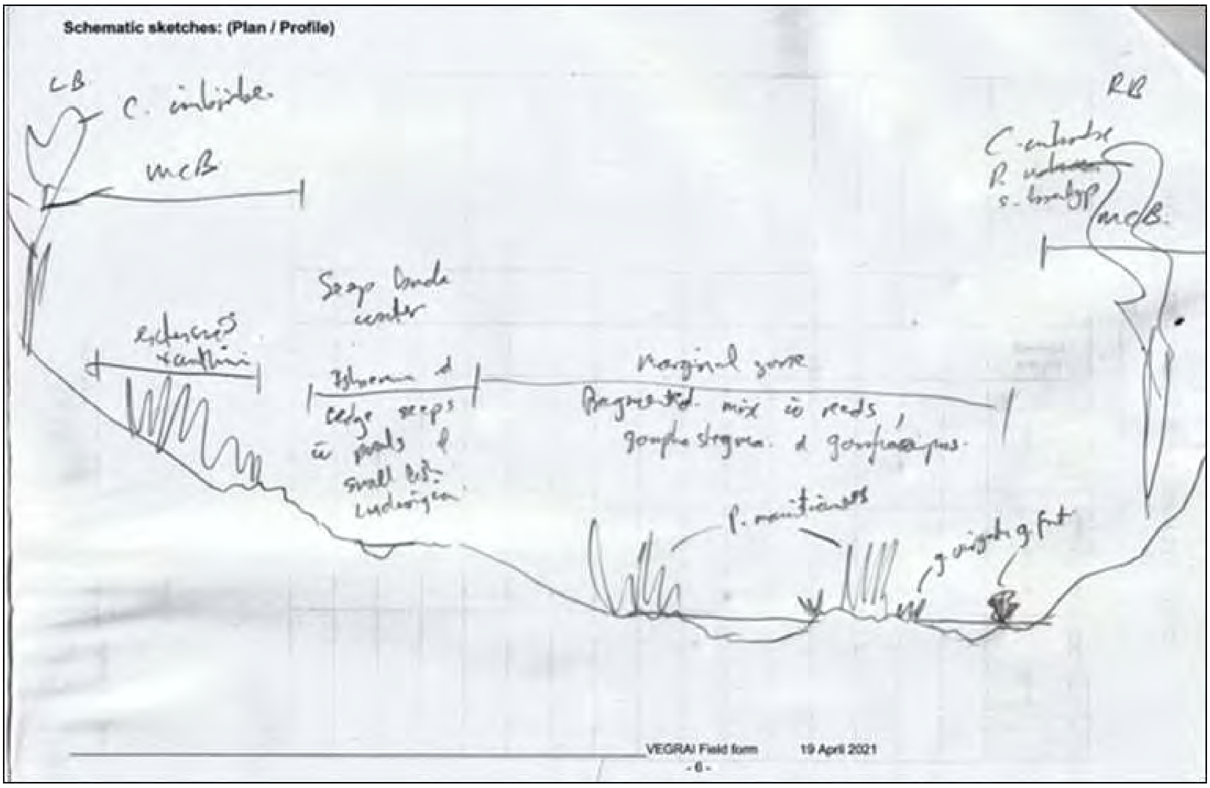
Schematic profile drawn in the field to show where vegetation components occur.

9.2.11 Olifants River @ Mamba (OLIF-B73C-MAMBA):



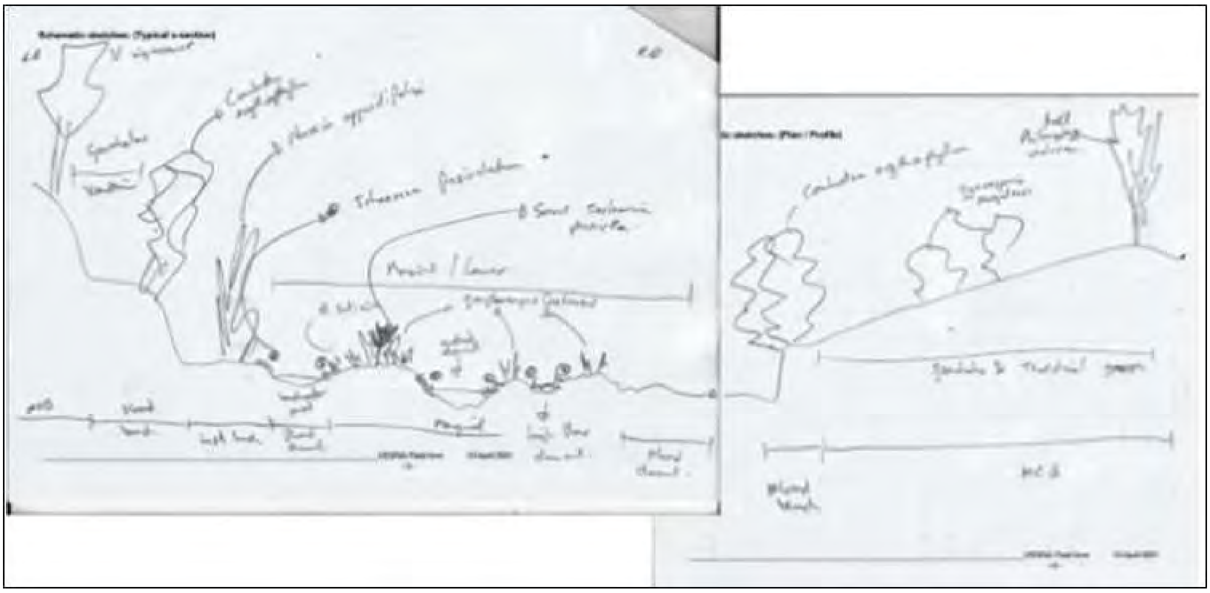
Schematic profile drawn in the field to show where vegetation components occur.

9.2.12 Olifants River @ Balule (OLIF-B73H-BALUL):



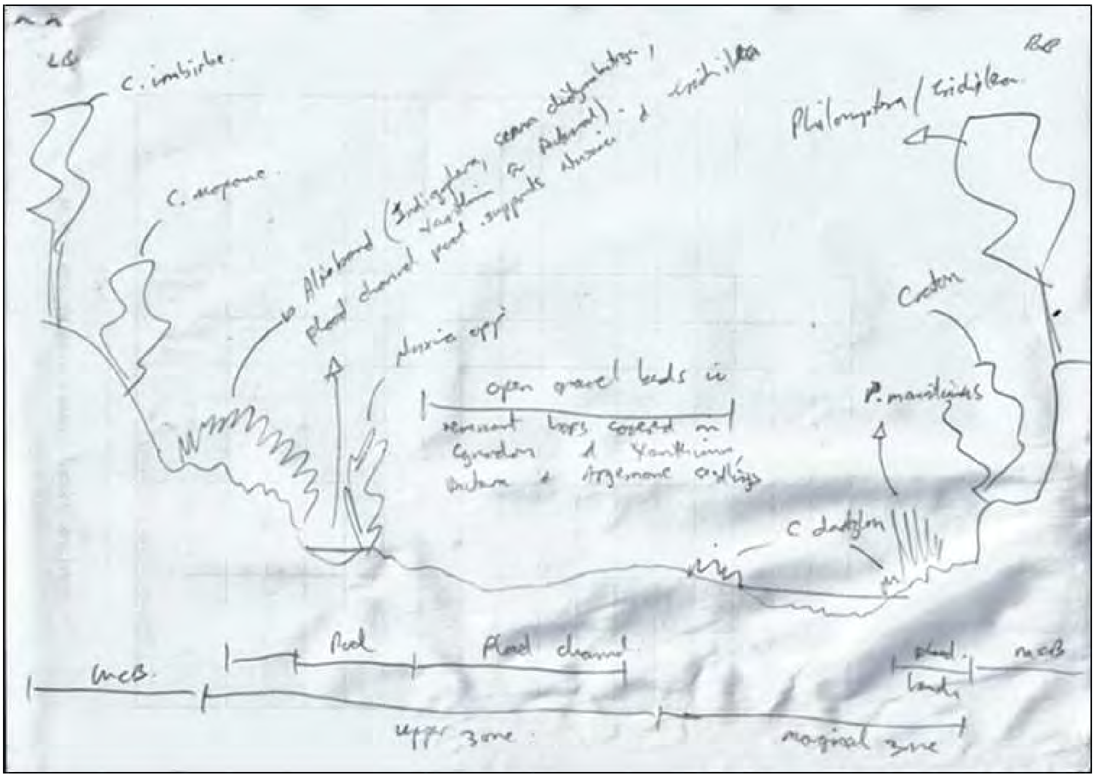
Schematic profile drawn in the field to show where vegetation components occur.

9.2.13 Groot Letaba River (GLET-B81J-LRANC):



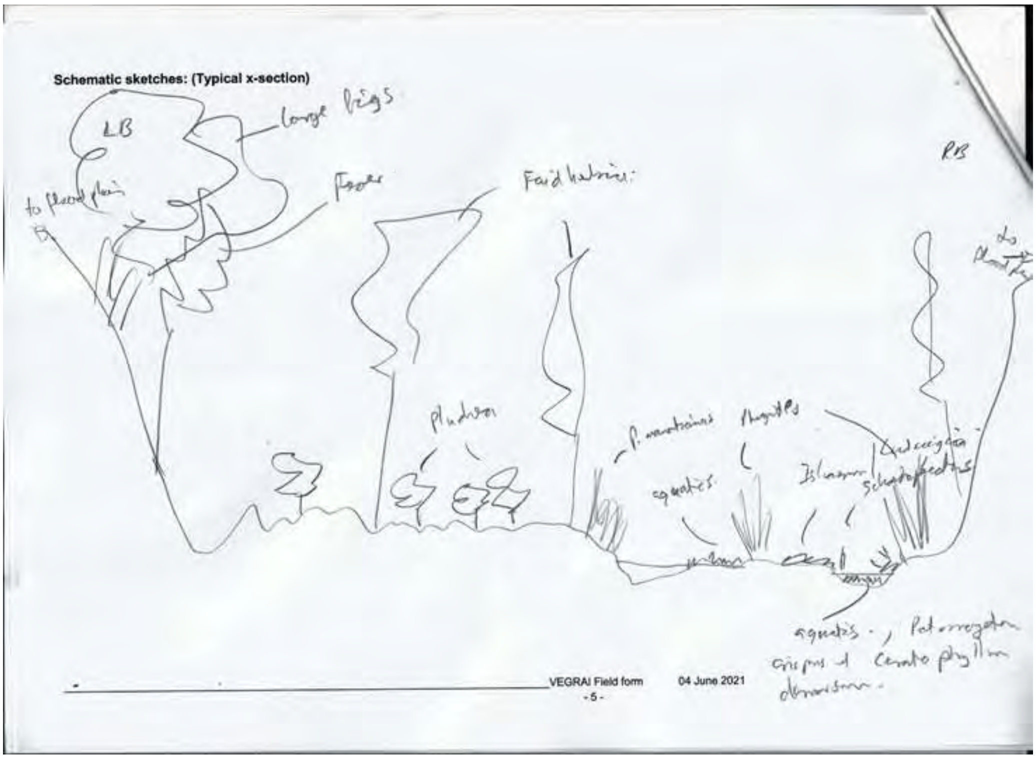
Schematic profile drawn in the field to show where vegetation components occur.

9.2.14 Letaba River @ Lonely Bull (LETA-B83A-LONEB):



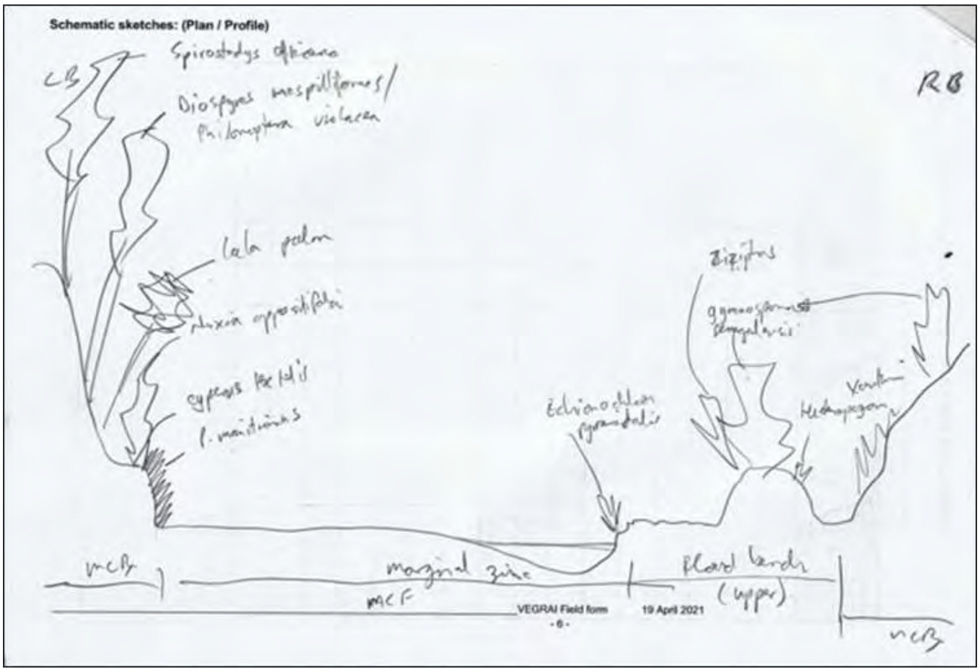
Schematic profile drawn in the field to show where vegetation components occur.

Elefantes River below Massingir (ELEP-Y30C-SINGU):



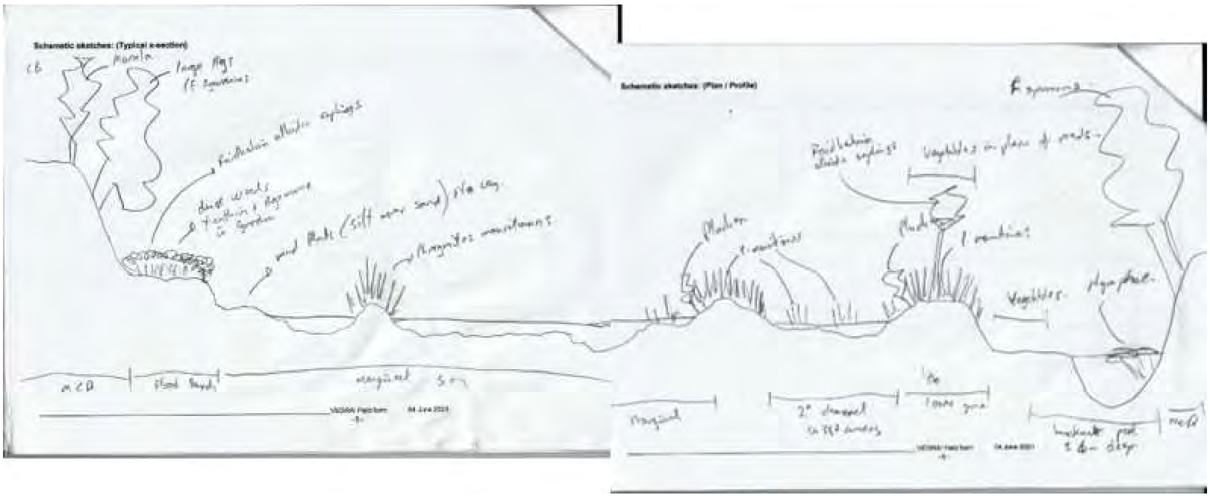
Schematic profile drawn in the field to show where vegetation components occur.

9.2.15 Shingwedzi River (SHIN-B90H-POACH):



Schematic profile drawn in the field to show where vegetation components occur.

9.2.16 Limpopo River @ Chokwe (LIMP-Y30F-CHOKW):



Schematic profile drawn in the field to show where vegetation components occur.

9.2.17 List of Plant Species Observed at Site

9.2.18 Crocodile River (CROC-A24J-ROOIB):

Species	Feature / Zone						
	Aquatic	Marginal	Lower	Upper	MCB	Backwater	Foo
Argemone mexicana forma mexicana				x			x
Commelina africana				x		x	
Cynodon dactylon			x	x			x
Faidherbia albida				x	x		x
Ficus capreifolia			x	x			
Ficus sycomorus				x	x		
Ludwigia adscendens subsp. diffusa						x	
Nymphae sp	x					x	
Phragmites mauritianus		x	x			x	
Pluchea bojeri			x	x			
Ricinus communis				x			x
Sclerocarya birrea subsp. caffra					x		
Xanthium strumarium				x			x

9.2.19 Limpopo River @ Spanwerk (LIMP-A41D-SPANW):

Species	Feature / Zone					
	Aquatic	Marginal	Lower	Upper	MCB	Mid-channel Bar
Agrostis lachnantha var. lachnantha				x		
Cardiospermum grandiflorum						x
Combretum erythrophyllum						x
Combretum imberbe			x	x	x	x
Commelina africana		x	x			
Croton megalobotrys					x	x

Cynodon dactylon		x	x	x		x
Cyperus longus		x	x			x
Cyperus sexangularis				x		x
Datura innoxia						x
Dichanthium annulatum var. papillosum		x	x			x
Digitaria eriantha		x	x			x
Ludwigia adscendens subsp. diffusa		x				x
Melia azedarach						x
Mentha aquatica				x		
Nicotiana glaucea						
Panicum maximum						
Phragmites australis		x	x			x
Plumbago auriculata						
Sesbania punicea						x
Tagetes minuta						
Tithonia diversifolia					x	x
Vachellia gerarrdii				x	x	x
Vachellia tortilis					x	
Xanthium strumarium				x	x	x
Ziziphus mucronata subsp. mucronata				x	x	x

9.2.20 Matlabas River (MATL-A41D-WDRAAI):

Species	Feature / Zone					
	Aquatic	Marginal	Lower	Upper	MCB	Flood Channel
Combretum erythrophyllum				x		
Cyperus longus		x	x	x		x
Digitaria eriantha				x		
Eragrostis plana				x	x	

Panicum deustum		x	x	x		x	
Panicum maximum				x	x		
Persicaria decipiens		x				x	
Phragmites australis		x	x	x			
Setaria sphacelata var. sericea				x		x	
Vachellia erioloba		x		x	x		
Vachellia gerrardii				x			
Vachellia robusta				x			

9.2.21 Lephalala River (LEPH-A50H-SEEKO):

Species	Feature / Zone						
	Aquatic	Marginal	Lower	Upper	MCB	Flood Bench	Lateral Bar
Cardiospermum grandiflorum				x		x	
Combretum erythrophyllum						x	
Croton megalobotrys					x	x	
Datura innoxia				x		x	
Dichrostachys cinerea					x		
Faidherbia albida			x	x		x	
Grewia bicolor							
Grewia favescence							
Gymnosporia senegalensis					x	x	
Panicum deustum						x	
Panicum maximum							
Phragmites mauritianus		x	x				x
Phyllanthus reticulatus				x		x	
Ricinus communis				x		x	
Senegalia schweinfurthii var. schweinfurthii				x		x	
Tithonia diversifolia						x	
Vachellia gerrardii subsp. gerrardii				x		x	

Vachellia tortilis			
Xanthium strumarium		x	x

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