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LIMPOPO WATERCOURSE COMMISSION

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RESILIENT WATERS PROGRAM

E-FLOWS FOR THE LIMPOPO RIVER BASIN:

SPECIALIST LITERATURE AND DATA REVIEW

E-FLOWS FOR THE LIMPOPO RIVER BASIN: SPECIALIST LITERATURE AND DATA REVIEW

(Submitted in fulfilment of Milestone 4: Specialist eflow data and literature review)

Report citation: Dickens, C.; O'Brien, G.; Stassen, R.; van der Waal, B.; MacKenzie, J.; Eriyagama, N.; Villholth, K.; Ebrahim, G.; Magombeyi, M.; Wepener, V.; Gerber, S.; Kaiser, A.; Diedericks, G. 2021. ***E-flows for the Limpopo River Basin: specialist literature and data review.*** Project report prepared by the International Water Management Institute (IWMI) for the United States Agency for International Development (USAID). Colombo, Sri Lanka: International Water Management Institute (IWMI); Washington, DC, USA: USAID. 252p. (E-flows for the Limpopo River Basin: Report 4). doi: https://doi.org/10.5337/2022.219

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About IWMI

The International Water Management Institute (IWMI) is an international, research-for-development organization that works with governments, civil society and the private sector to solve water problems in developing countries and scale up solutions. Through partnership, IWMI combines research on the sustainable use of water and land resources, knowledge services and products with capacity strengthening, dialogue and policy analysis to support implementation of water management solutions for agriculture, ecosystems, climate change and inclusive economic growth. Headquartered in Colombo, Sri Lanka, IWMI is a CGIAR Research Center with offices in 13 countries and a global network of scientists operating in more than 30 countries.

USAID statement and disclaimer: *This report was produced under United States Agency for International Development (USAID) Prime Contract No. 720-674-18-C-00007 and was made possible by the generous support of the American people through USAID. The contents are the responsibility of IWMI and do not necessarily reflect the views of USAID or the United States Government.*

Acknowledgements:
This project was funded by the United States Agency for International Development (USAID). It was implemented by the International Water Management Institute (IWMI) as part of the CGIAR Research Program on Water, Land and Ecosystems (WLE). The CGIAR and WLE combine the resources of 11 CGIAR centers, the Food and Agriculture Organization of the United Nations (FAO), the RUAF Foundation, and numerous national, regional and international partners to provide an integrated approach to natural resource management research. WLE promotes a new approach to sustainable intensification in which a healthy functioning ecosystem is seen as a prerequisite to agricultural development, resilience of food systems and human well-being. Special thanks go to Mayford Manika and Nkobi Moleele from USAID and Simon Johnson from JG Africa who managed the contract and provided project oversight. We would also like to thank representatives from LIMCOM especially Sergio Sitoe, Ebenizario Chonguica, and Zvikomborero Manyangadze, who will be the ultimate beneficiaries, and also Eddie Riddell and Robin Petersen from SANParks who helped so much both inside the Kruger Park and outside. Lastly, we would like to thanks the members of the Steering Committee, largely members of LIMCOM, for their participation and perspectives.

Collaborators:

International Water Management Institute, Colombo, Sri Lanka

Limpopo River Commission, Mozambique

Rivers of Life located in the University of Mpumalanga, South Africa

South African National Parks, Kruger National Park, South Africa

Donor:

Donor agency, Washington DC, USA, Contract No. 720-674-18-C-00007 Subcontract No. FPSC-02-SWER; Grant Agreement No.: RWP-G5-IWMI

Project:
This project was part of a Resilient Waters Project https://chemonics.com/projects/natural-resources-management-and-water-security-in-southern-africa/ entitled *Natural Resource Management and Water Security in Southern Africa*.
This specific project undertaken by IWMI was titled *Environmental flows for the Limpopo River - building more resilient communities and ecosystems through improved management of transboundary natural resources*
The project was funded by USAID Contract No. Contract No. 720-674-18-C-00007
Subcontract No. FPSC-02-SWER, Grant Agreement No.: RWP-G5-IWMI

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: Limpopo River sunset (Picture credit James MacKenzie)

PROJECT TITLE:
Environmental flows for the Limpopo River - building more resilient communities and ecosystems through improved management of transboundary natural resources

REPORT TITLE:
E-flows for the Limpopo Basin: Specialist Literature and Data Review.

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.

TERMS OF REFERENCE:
USAID has funded Chemonics to implement the Resilient Waters Program. In turn this project was a response to a Grant call that had as its overall goal "*to build more resilient communities and ecosystems through improved management of transboundary natural resources*……".

The International Water Management Institute (IWMI) was commissioned by Resilient Waters to undertake a project titled: *Environmental flows (e-flows) for the Limpopo River - building more resilient communities and ecosystems through improved management of transboundary natural resources*. The study incorporated the PROBFLO method to determine e-flows and eveluate the risk of altered flows and non-flow variables to the ecosystems services in the Limpopo Basin. The project has resulted in two final reports including:

- Environmental flow determination in the Limpopo Basin.
- Risk of altered flows to the ecosystems services of the Limpopo Basin.

This report presents a summary of all of the data and literature available to interpret the e-flows for the Limpopo Basin.

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ACRONYMS

BF	Baseflow – the groundwater contribution to streamflow
BN	Bayesian Network
CPT	Conditional Probability Table
DWS	Department of Water and Sanitation South Africa (=DWA)
DRM	Desktop Reserve Model (Hughes, 1999)
E-flow	The quantity, timing, and quality of freshwater flows and levels necessary to sustain aquatic ecosystems which, in turn, support human cultures, economies, livelihoods, and well-being (Arthington et al., 2018).
EF	Environmental flows (=E-flow)
EI	Ecological importance
ES	Ecological sensitivity
EWR	Environmental Water Requirement (=E-flow)
FAII	Fish Assessment Integrity Index
FFHA	Fish Flow Habitat Assessment Index
FRAI	Fish Response Assessment Index
GW	Groundwater
HC	Hazardous concentration for x% of species
IWMI	International Water Management Institute
LIMCOM	Limpopo Watercourse Commission
LoE	Line of Evidence
MAR	Mean Annual Runoff
MCM	Million cubic meters
NAT	Natural (flows)
PES	Present Ecological State
PRS	Present day flows
PROBFLO	E-flow method (O'Brien et al, 2018)
RQO	Resource Quality Objective
RR	Risk Region
RSA	Republic of South Africa
RW	Resilient Waters Program of USAID
SANBI	South African National Biodiversity Institute
SSD	Species sensitivity distribution (water quality)
SW	Surface water
VEGRAI	Riparian Vegetation Response Assessment Index
WWF	World Wide Fund for Nature

EXECUTIVE SUMMARY

CONTEXT

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

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. 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 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., will be applied. These requirements will be determined at project initiation. 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 will consider the requirements of rural stakeholders for flow-related ecosystem services, and will document 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 e-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 link stream flow to the requirements of stakeholders. Greater evidence on the ecological requirements will be gained as this project will focus much of its efforts on the wet-season situation, something that was missed during the Monograph study. It will also carry out more intensive field investigations, and most importantly, will introduce a probabilistic approach to the e-flow investigation, thus enabling the results to be interpreted with greater understanding.

OBJECTIVES OF THIS REPORT:

This report is a collation of all specialist perspectives needed to establish the e-flows for the Limpopo. This data and information are needed to provide evidence and understanding of the flow-ecosystem relationships. It is drawn up from a combination of published literature, existing "grey" reports especially those on the Limpopo River, and existing data.

Included in this report are:

- Hydrology
- Groundwater
- Water quality
- Geomorphology and hydraulics
- Vegetation
- Fish
- Benthic invertebrates

SUMMARY OF SPECIALIST CONTRIBUTIONS

This project has several specialists as part of the team, each of whom contributes their specialisation to the assessment of e-flows for the Limpopo Basin. The chapters that follow provide an understanding of the approach to be followed and a baseline of data that is derived from prior sources and will be added to by new data collected during this project. The summary below provides a succinct explanation of the data and information that is available, and what is needed to add for this project.

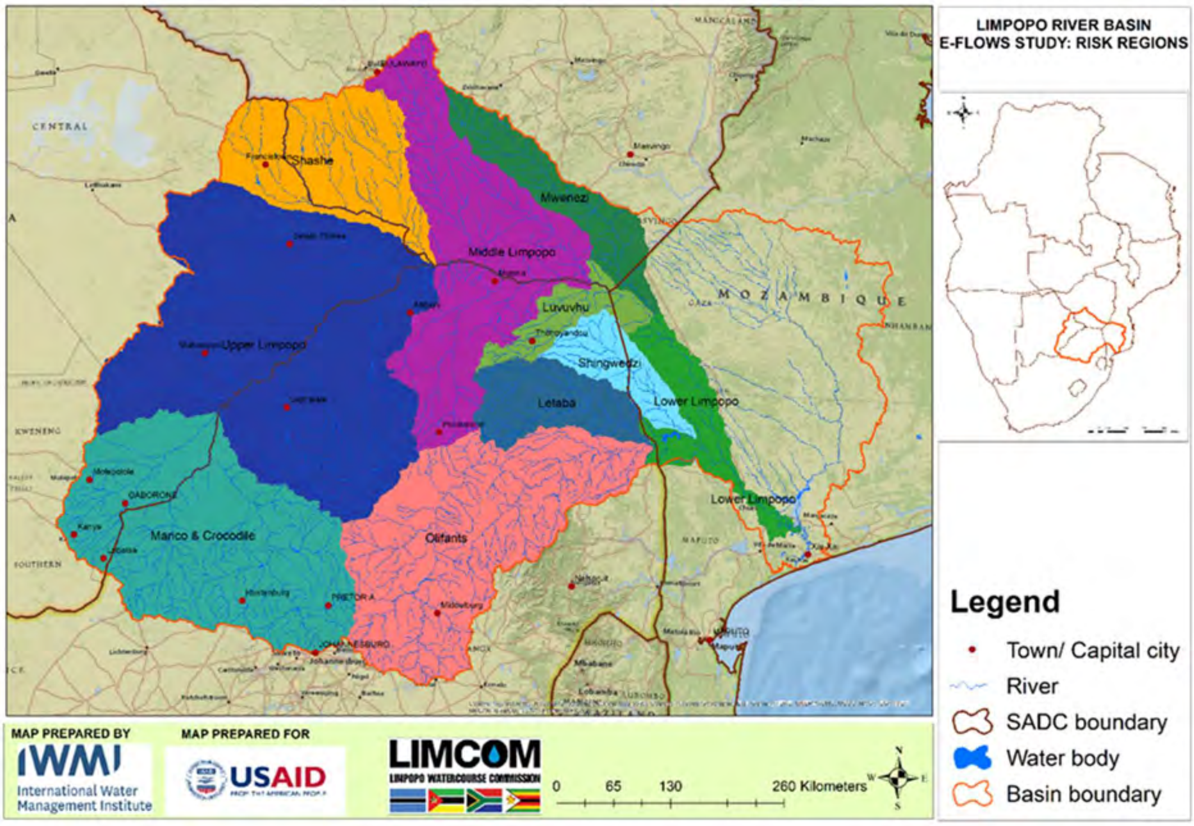


FIGURE: PRELIMINARY RISK REGIONS

The Risk Regions shown in this map and table are preliminary, and analysis of the information and data collected here is already suggesting a change. The final map will be produced in time for the Workshop to be held with stakeholders where the vision and objectives for each RR will be finalised.

TABLE: RISK REGIONS

1. Marico Crocodile	2. Olifants
3. Upper Limpopo	4. Shashe
5. Middle Limpopo	6. Mwenezi
7. Luvuvhu	8. Letaba
9. Shingwedzi	10. Lower Limpopo

Hydrology

Limpopo – Hydrology

Purpose of the data/information

The hydrological data available from previous studies will be used as the baseline for the ecologists for the determination of the E-flows and the evaluation of management options.

Status of data for the Limpopo Basin

Natural condition

Monthly time series before anthropogenic impacts were simulated at various selected points (sites) within the Limpopo mainstem as well as the major tributaries. The natural mean annual runoff (MAR) at these points are listed in the table below and is based on the period 1920 to 2010.

TABLE: PRESENT DAY MAR IN THE LIMPOPO BASIN

MAJOR TRIBUTARIES	FLOWS (MILLION M^3)	
	NAT	PRS
Marico Crocodile (West) Ngotwane Mainstem @ LmEWR01	110 595 92 592	40 399 62 373
Matlabas Mokolo Lephalale Mogalakwena Bonwapitse Mhalatswe Lotsane Motloutse	52 210 124 198 81 38 35 125	46 165 67 127 81 38 22 86
Shashe	688	513
Umzingwani Sand Nzhelele Bubye Mainstem @ LmEWR02	438 74 200 100 1683	260 40 187 70 1200
Luvuvhu Mainstem @ LmEWR04	560 2792	456 1969
Mwanedzi	412	332
Olifants	1910	1104
Letaba	642	379
Shingwedzi	160	159
Elephantes Mainstem @ LmEWR05	2713 3087	1394 2192
Mainstem @ LmEWR07	5572	3325

Present condition

The present-day flows at the selected sites are based on the current water demands/ use in the catchment. These demands are for domestic, irrigation, mining, forestry, and rural use as well as return flows from wastewater treatment works, irrigation, and mining. The present day mean annual runoff (MAR) at the selected sites are listed in the table below and when compared to the natural flows give an indication of how much water is used on average in the Limpopo catchment.

Status of existing e-flow data/information for the Limpopo Basin

Several IFR/ EWR/ Reserve or E-flow studies have been undertaken since 2000. These studies specify the flows that need to be available at the selected sites to maintain or improve the ecological condition of the rivers. Most of the studies were undertaken in South Africa, except the 2013 Monograph study that include sites on the mainstem Limpopo River and some tributaries within Zimbabwe and Mozambique. The table below lists the sites on the mainstem Limpopo River as well the lowest sites selected on the major tributaries.

TABLE: EXISTING E-FLOW SITES FOR THE LIMPOPO BASIN

MAJOR RIVERS	IFR SITES		
	SITE NAME	LATITUDE	LONGITUDE
Marico	MAR_EWR4	-24.706	26.424
Crocodile (West)	CROC_EWR8	-24.645	27.326
Limpopo to Ngotwane confluence (at Spanwerk)	Lm_EWR01	-23.945	26.931
Matlabas	MAT_EWR4	-24.052	27.359
Mokolo	MOK_EWR4	-23.771	27.755
Limpopo to Bubye confluence (at Mapungubwe)	Lm_EWR02	-22.184	29.405
Luvuvhu	Luvuvhu_3	-22.427	31.196
Limpopo to Mwanedzi confluence (at Pafuri)	Lm_EWR04	-22.460	31.503
Mwanedzi (at Malapati)	Lm_EWR03	-22.064	31.423
Olifants to Letaba confluence	Olifants_EWR16	-24.049	31.732
Letaba to Olifants confluence	LET2	-23.827	31.591
Shingwedzi to Elephantes confluence	SHI1	-23.185	31.525
Elephantes	Elephantes_1	-23.880	32.253
Limpopo to Elephantes confluence (at Combumune)	Lm_EWR05	-23.472	32.444
Limpopo mainstem to estuary (at Chokwe)	Lm_EWR07	-24.500	33.010

Requirements for data/information collection

Existing data from previous studies will be used for this study.

General comments

Hydrological time series are available for natural and present-day conditions and will be adjusted to the final selected sites. Graphs and statistics will be generated to show the characteristics of the flows at the sites to be used by the ecologists for interpretation and to calculate the minimum flows that should be available in the river.

Limited flow data will be available for ecological evaluation of future water management options (construction of dams, climate change, etc).

Specialist report below

The hydrology has been presented for selected major tributaries and the Limpopo mainstem at specific sites with an initial indication of the flow patterns (monthly graphs), characteristics (perennial/ seasonality/ ephemeral) and how these have changed from natural to present day.

Groundwater

Purpose of the data/information

The main objective this section is to develop a methodology to integrate groundwater concept in the e-flow assessment. Two sites with relatively good groundwater data representing two river conditions (i.e. Perennial and Ephemeral River) were selected. At this two sites a detail assessment of baseflow separation, isolated pool characterization and streamflow depletion will be carried out. The detailed knowledge obtained at these two experimental sites will be up scaled to risk regions/basin scale. Upscaling can be accomplished based on source identification of isolated pools of water using isotope analysis, baseflow filter parameter calibrated against isotope or tracer method, streamflow depletion assessment as function of distance of pumping well from the river channel and groundwater surface water interactions. All of these information will be integrated into the overall e-flow assessment. This will help to make groundwater allocation with due consideration of ecological needs that maintain sufficient groundwater discharge for various ecosystems and ensure groundwater management to be made in accordance to ecological integrity.

Status of data for the Limpopo Basin

Natural condition

There is no data available that describes the natural conditions of groundwater in the Limpopo River Basin. Nevertheless, it is clear that under natural condition, groundwater flowing to streams would have not been intercepted by groundwater pumping and rivers may have sustained river flows during dry periods.

Present condition

According to the Limpopo River Basin monograph study (2013) there are around 75,480 boreholes in the Limpopo Basin (Figure). Most of these boreholes (92%) are located in the South African side of the basin. These unsustainable abstraction of groundwater results in reduced groundwater, which in turn affect baseflow that support e-flows.

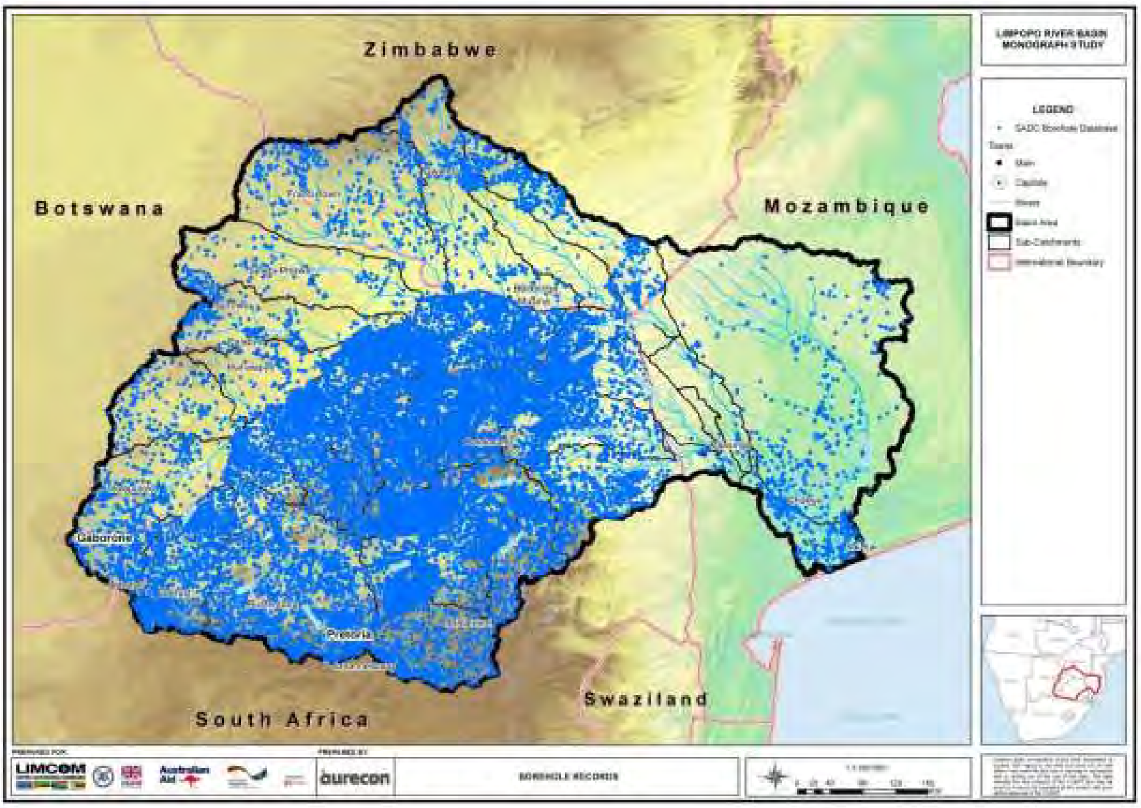


FIGURE: BOREHOLE RECORDS IN THE LIMPOPO RIVER BASIN (SOURCE: LIMPOPO RIVER BASIN MONOGRPAH STUDY (2013))

Status of existing e-flow data/information for the Limpopo Basin

The 2013 Limpopo Monograph study was confined to surface flow and did not directly consider the groundwater beyond the estimation of baseflows (that are one of groundwater contributions to streamflow). Nevertheless, abstraction of groundwater from the riverbank or the riverbed is common in the Limpopo River. Moreover, previous studies did not considered the linkage between groundwater and isolated pools in the ephemeral rivers. In ephemeral rivers one of the critical parameter affecting ecological function is the spatial and temporal dynamics of pool storage. Hence, isolated pool characterization in ephemeral rivers is more important from e-flow perspective.

Requirements for data/information collection

Stable isotope and hydro chemical samples at least at the two selected sites need to be collected to determine source of water for isolated pools in non-perennial/Ephemeral rivers and to quantify groundwater surface water interaction, and to constrain the recursive digital filter parameter value for baseflow separation.

General comments

In the past e-flow assessment is carried out considering only baseflow without considering the effect of groundwater pumping, which significantly reduces the baseflow to river flows. Furthermore, most of the e-flow assessment methods in the past are developed for Perennial River and has little significance for ephemeral rivers characterized by episodic flow and disconnected isolated pools of water. The inclusion of grounswater will strengthen the e-flow assesment approch. There are limiations regarding this approch. This study foucses on two selcted sites, hencce there are uncertianties when extrapolating results to other risk regions. The full impact of groundwater pumping can only be quntified using three dimensional numerical groundwate models by comparing simulation model run with and with out groundwater pumping. Howver, setting up and clibrating these models are time consuming and ofen require a lot of input data, which cannot be possible in the scope of this project.

Specialist report below

This section on groundwater provide an overview of: i) the state of knowledge on groundwater-surface water interactions, effect of groundwater pumping on the streamflow and approaches of e-flow assessment in non-perennial rivers, ii) the two selected case studies and data, iii) proposed approach for inclusion of groundwater in the e-flow assessment, and iv) expected results.

Water Quality

Purpose of the data/information

It is essential to provide an understanding of the natural changes in water quality of the Limpopo Basin due to differences in climate, geomorphology, geology and soils, and biotic composition. The historical and current water quality status of 23 sites in the 11 risk regions will be assessed using fitness for use classifications schemes. These schemes classify individual water quality parameters between "Good" and "Unacceptable". Within the environmental flow assessment process, the fitness for use classification of individual water quality variables at each of the sites will used to evaluate the probable water quality consequences that result from flow reductions or increases. These consequences are reported in terms of chemical, biotic, and toxicological responses to flow changes.

Status of data for the Limpopo Basin

Natural condition

The purpose of a natural condition is to provide a benchmark against which the present condition of each water quality aspect can be evaluated. The natural condition is derived using pre-impact data or data from unimpacted sites from neighbouring basins. The historical water quality data only go back as far as 1980 and in many instances these data do not represent pre-impact / activity conditions. Thus, natural conditions will have to be derived from basins that represent similar ecological regions.

Present condition

The present ecological status / condition (PES) is the measured, current water quality for each risk region and provides the point of departure for the development of any management objectives. Chemical and biotic response data are linked to a class in a generic classification scheme based on 'good - blue', 'tolerable - green', 'poor – amber and 'unacceptable - red' (See Table below). The PES is derived from recent data (i.e. preferably data from 1 to 3 years). However, if the data record is poor, then data from up to, but no longer than, 5 years will be used.

TABLE: AN EXMPLE OF BOUNDARY VALUES FOR WATER QUALITY VARIABLES TO CLASSIFY THE FITNESS FOR USE OF WATERS IN THE LIMPOPO RIVER BASIN.

Variable	Units	Good (Blue)	Tolerable (Green)	Poor (Amber)	Unacceptable (Red)	Sensitive user group
Water quality variable e.g. Electrical conductivity	mS/m	40	150	370	>370	Irrigation & Domestic

Status of existing e-flow data/information for the Limpopo Basin

There are adequate general water quality data available for most of the South African sites in the Limpopo Basin and the major tributaries, to contribute the necessary information for E-flow determination at the selected sites. These data are available from organisations such as the Department of Water Affairs and SANPARKS. Data for some of the smaller systems such as the Luvuvhu, Mogalakwena and Nzhelele Rivers are not recent. There is also a distinct lack of recent data on the sub-basins in the neighbouring countries, i.e. Botswana, Zimbabwe, and Mozambique. Available literature on the basin indicates that the major tributaries, e.g. the Crocodile and Olifants Rivers are contaminated by toxicants such as metals and nutrients. Even though resource quality objectives have been derived for toxicants in the different tributaries, there is a general lack of data on levels of these toxicants in the basin. For this reason, it is essential that concentrations of toxicants such as metal and nutrients are determined.

Requirements for data/information collection

The limited water quality data available for most sites outside of South Africa need to be supplemented with samples collected during field surveys. The concentrations of toxicants such as metals also need to be determined during field surveys.

General comments

The role of water quality considerations in the setting of environmental flow requirements becomes apparent when the consequences to water quality of the recommended flows are evaluated. If a situation arises where the natural water quality was to be impacted by recommended flows, then higher environmental flows would be recommended (for example, if a stream had a naturally high salt content and low flows would result in increased salt concentrations to unacceptable levels). The available data as well as the additional data that will be collected during the field survey should be sufficient to provide the necessary water quality input into deriving environmental flows for the Limpopo River and main tributaries.

In the specialist report that follows the available water quality data for the selected sites that represent the 11 risk regions, are evaluated. The evaluation includes the extent of the data set (i.e. sampling duration and frequency), the parameters that have been measured and the sources of water quality stressors at each site. The approaches that will be used to provide boundary values to classify the water quality based on fitness for use is also outlined in the report.

Geomorphology

Purpose of the data/information

The section on geomorphology focuses on two spatial scales; the first is a high-level overview of the catchment and its rivers within the basin and the second a review of site-specific geomorphic characteristics. This will familiarise the reader with the evolution of the basin's drainage network, its underlying rock types, its topography, associated morphology, and broad geomorphic zones along the river courses. A basin level overview of land degradation, soil erosion and sediment load is presented as this influences river morphology and habitat availability. The location and size of reservoirs indicate which rivers have reduced longitudinal sediment connectivity. The variability and expected changes in channel planform and habitat template as a result of hydrology is presented for work done on bedrock-controlled reaches.
Previous geomorphic descriptions for the EWR sites are presented along with the hydraulic surveys.

Status of data for the Limpopo Basin

Natural condition

There is no data available on the natural characteristics of the Limpopo's geomorphology. It is envisioned that the Limpopo basin under a natural condition had less land degradation and sediment input, and larger more frequent and sustained surface flows. This would allow for frequent habitat reworking and habitat maintenance resulting in a wider range of habitat types with lower levels of embeddedness of larger particles along riffles and sedimentation in pools. This would scour woody vegetation from the channels and result in better-defined geomorphic zones along the channels.

Present condition

Large parts of the Limpopo basin are in a fairly natural state and is used for grazing purposes. Some transformed areas are associated with urban centres and former homelands. Some of the regions show elevated soil erosion, see Figure X1. This increase in soil erosion results in excessive sediment availability in many of the rivers and can smother or embed coarse-grained habitats with finer sediment, resulting in decreased habitat quality and availability. Due to the steep bedrock nature and dams and weirs trapping sediment along most of the Limpopo's tributaries, the effect of the land degradation and increased erosion is not fully visible at the site level due to high flow velocities that effectively entrain the sediment.

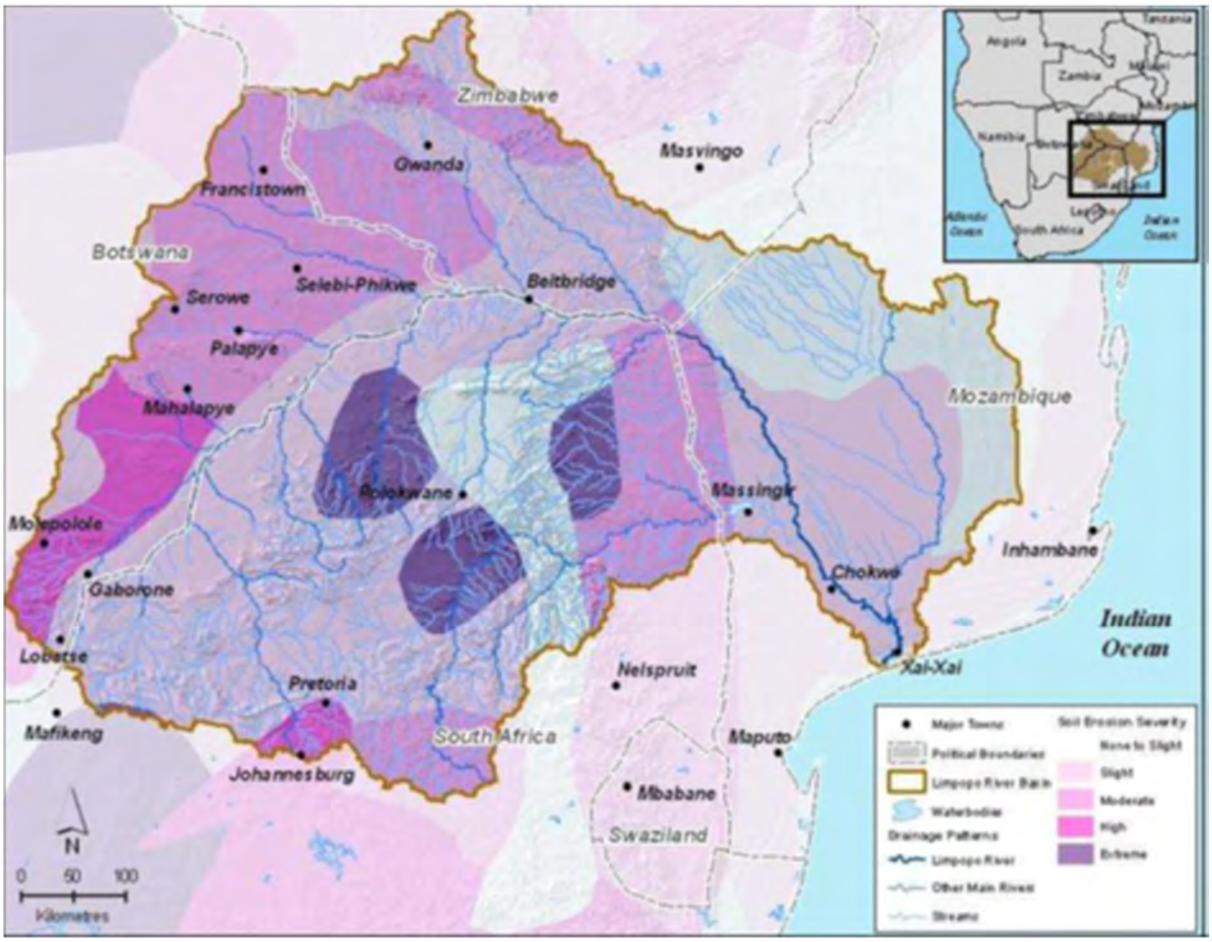


FIGURE: EROSION SEVERITY IN THE LIMPOPO BASIN (TAKEN FROM LIMPOPO RIVER AWARENESS KIT, 2020, MAP DATA BY OLDEMAN ET AL. (1991))

Status of existing e-flow data/information for the Limpopo Basin

Various e-flow studies that include geomorphology were done on the South African tributaries (Olifants, Luvuvhu, Mokolo, Crocodile, and Groot Marico Rivers). No studies that include geomorphology are available for Botswana, Zimbabwe, or Mozambique. The previous basin level assessment (Limpopo Basin Monograph, 2013) did have sites on some of the tributaries in all the countries, but this study did not include geomorphic assessments per se.

Requirements for data/information collection

Given that there are no sites that include geomorphology at a basin-level, this study will attempt to fill that gap by collecting field data for a selection of tributaries and mainstem sites. The site descriptions will include river planform, river cross-section showing morphological features and sediment character. It will also assess changes to drivers upstream of the site and the pressures and habitat modification at the site. These assessments will be combined using the Geomorphic Assessment Index to calculate a present ecological state for geomorphology. The field information will be used to calculate flow requirements to maintain the morphology and associated habitat types at the site.

General comments

The inclusion of geomorphology will strengthen this holistic e-flow assessment by adding an independent flow requirement that focuses on maintaining the physical template that is provided by these rivers. There are limitations regarding this method, especially temporal and spatial scale constraints. The study will focus on a single site on a specific day which might not be a suitable reflection on the system's natural variability and cyclic processes over time and space. Other limitations include the subjective assessment of the sites without a deeper understanding of the drivers and site modifications over time. Despite these limitations, the addition of geomorphology will contribute to the holistic assessment of e-flows for the Limpopo basin.

Specialist report below

The section on geomorphology gives an overview of the morphological history of the drainage development, the underlying rock types, and changes to sediment production and delivery at a basin scale. Descriptions of observed changes to river morphology within the basin as a function of flow were reviewed. Descriptions for the previously visited sites during the Limpopo River Basin study (2013) were described based on the information presented in the monograph.

Hydraulics

Purpose of the data/information

This section presents the hydraulic data that were collected and modelled for the Limpopo River Basin Monograph study (2013). These data will be included in future hydraulic models to improve the confidence in the modelling output through multiple observations instead of a single observation. The modelled hydraulic data can be used to translate the flow rates into water depth and flow velocity at each site. This forms the link between hydrology and the various other indicators that are used to set the e-flows. Status of data for the Limpopo Basin

Natural condition

No hydraulic information is available for the Limpopo basin under natural conditions.

Present condition
Information on the hydraulic conditions for sites in the Limpopo basin do exist, but the information is largely available for the South African tributaries. Some of the data were collected years to decades ago and might not be representative of the sites as the morphology of the channels and associated hydraulic character or boundary conditions are likely to change. The hydraulic data are available in 1D format (a single line observed across the channel, with a model interpolating and extrapolating the data for a range of flow rates) that poorly represents the reach as there is significant spatial variability.

Status of existing e-flow data/information for the Limpopo Basin
Various e-flow studies that include hydraulics were done on the South African tributaries (Olifants, Luvuvhu, Mokolo, Crocodile, and Groot Marico Rivers). These studies typically include a single 1D hydraulic cross-section with possibly more than one flow and hydraulic observation. The tributaries in Zimbabwe (Mwanedzi River) and Mozambique (Changane River) have a single 1D cross-section (a single flow observation) and the Limpopo mainstem has five 1D cross-sections (a single flow observation) spread out along the river profile (Spanwerk along the upper reaches to Chokwe just upstream of the Limpopo Estuary).

Requirements for data/information collection
This study will improve the hydraulic data by adding hydraulic observations to the existing sites. This will increase the confidence in the hydraulic models for the various existing sites. Additional sites on tributaries with no data will be described in terms of hydraulics which will allow the assessment to link hydrology to water depth and velocity requirements.

General comments
Hydraulic models for the various sites are essential to translate flow rate time series or hydrology into depth and velocity variables that can be used by the various disciplines to set flow requirements. For several of the sites, there are no existing hydraulic data, thus the confidence in the hydraulic model will be low compared to the sites that do have existing data. Some of the existing sites might have changed morphologically (due to the recent floods), resulting in the existing hydraulic data being less useful to improve the confidence in the hydraulic model. Another limitation is the use of 1D over 2D hydraulic models. 2D models have a longer footprint along the river channel compared to the single line of a 1D model, thus representing a wider range of habitats and reduced extrapolation of the averaged 1D model outputs.

Specialist report below
The section on hydraulics presents the existing cross-sectional, roughness, slope and graphic model output for the sites covered by the Limpopo River Basin Monograph study (2013).

Vegetation

Purpose of the data/information
While the LIMCOM reports provide extensive and detailed coverage of past e-flow and biological specialist work, riparian and wetland vegetation is largely limited to the Limpopo estuary and surrounding floodplain environments. This report provides some general perspective on broader-scale vegetation within the Limpopo Basin and includes some detail of past and current specific e-flow sites. The purpose of the vegetation component is to summarise what has been done and update and augment previous findings by way of a literature review, field assessments and data analyses. The main outcomes of the new data collected in this project will be the decsription and measurements of present ecological conditions and impacts at chosen river sites and an assessment and quantification of the water requirements for the vegetation component. This water requirement

will be integrated into a modelling approach to generate an overall water requirent for the river's complete diversity and will also feed into management scenarios and strategies.

Status of data for the Limpopo Basin

Natural condition

The Limpopo River Basin essentially comprises 3 vegetation biomes, Savannah, Grassland, and Indian Ocean Coastal Belt. The WWF terrestrial ecoregions (Ohlson *et al.*, 2001), Limpopo Basin Level I ecoregions (Kleynhans reference), and Bioregions from Mucina & Rutherford (2006; 2012; 2018 update) were used for additional detail of terrestrial vegetation distribution within the catchment. These vegetation units, while broad, set the scene for components of the riparian floras, especially those associated with banks and less frequently inundated fluvial features, but do not adequately described the complete characteristics of riparian and wetland flora.

A starting point to describe overall broad-scale vegetation in the Limpopo Basin was the WWF terrestrial ecoregions since this dataset is global and therefore covers the basin in its entirety. Descriptions of the ecoregions are summarized from the WWF in section 5 (Ohlson *et al.*, 2001) and spatial data are shown in Figure 5.1 (and replicated below). In addition, Level I Ecoregions were composed for the Limpopo Basin for this project by Kleynhans (2020, get ref; Figure 5.2), and Bioregions are shown for the South African portion of the Basin (Mucina & Rutherford, 2006; SANBI, 2012; 2018; Figure 5.3).

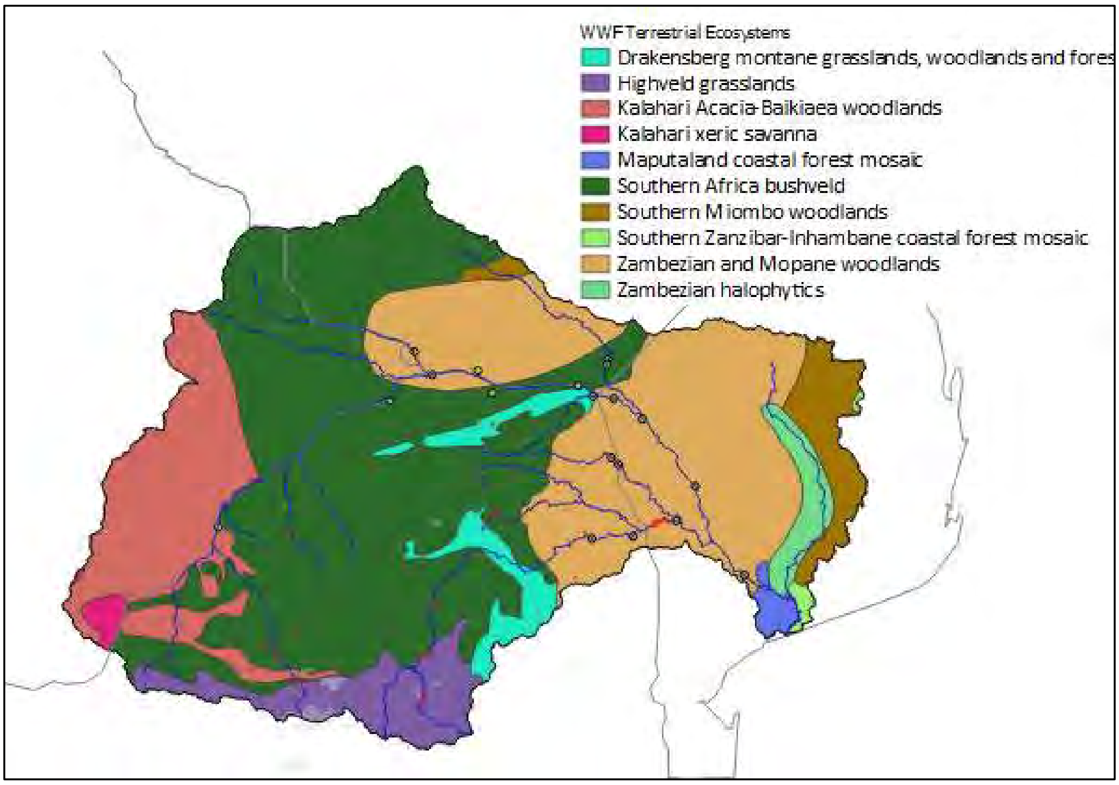


FIGURE: WWF TERRESTRIAL ECOREGIONS (OHLSON *ET AL.*, 2001; WWF)

The natural condition of riparian zones would vary according to river and stage type. Generally, most main tributary riparian vegetation would be characterised by a notable and dense band of woody riparian thicket or forest (tall trees to shrubs) along the macro-channel banks and a mixed to non-woody dominated vegetation matrix along the channel floor. In most cases this would comprise a mixture of grasses, including reeds, and sedges with much of the floor as open sediments or bedrock in some form.

Present condition

The Present Ecological Sate (PES), Ecological Importance (EI), Ecological Sensitivity (ES) project was a landmark project commissioned by DWS to conduct a specialized desktop assessment of the water resources (rivers and wetlands) for South Africa in its entirety (DWS, 2014). The assessments included water quality, instream fauna, hydrology, impacts and riparian and wetland habitats. Figure 5.9 is an example of the Ecological category for the riparian and wetland components of the main Limpopo Catchment (Primary catchment A) and detail of riparian and wetland assessments are shown in Appendix 1: Limpopo (primary catchment A), and appendix 2 : Olifants (primary catchment B). Data that are directly available for this study include PES (riparian and ecostatus), EI (riparian and total), ES (riparian and total), species, especially riverine and wetland specialist, habitats and habitat state, and Impacts affecting each sub-quaternary.

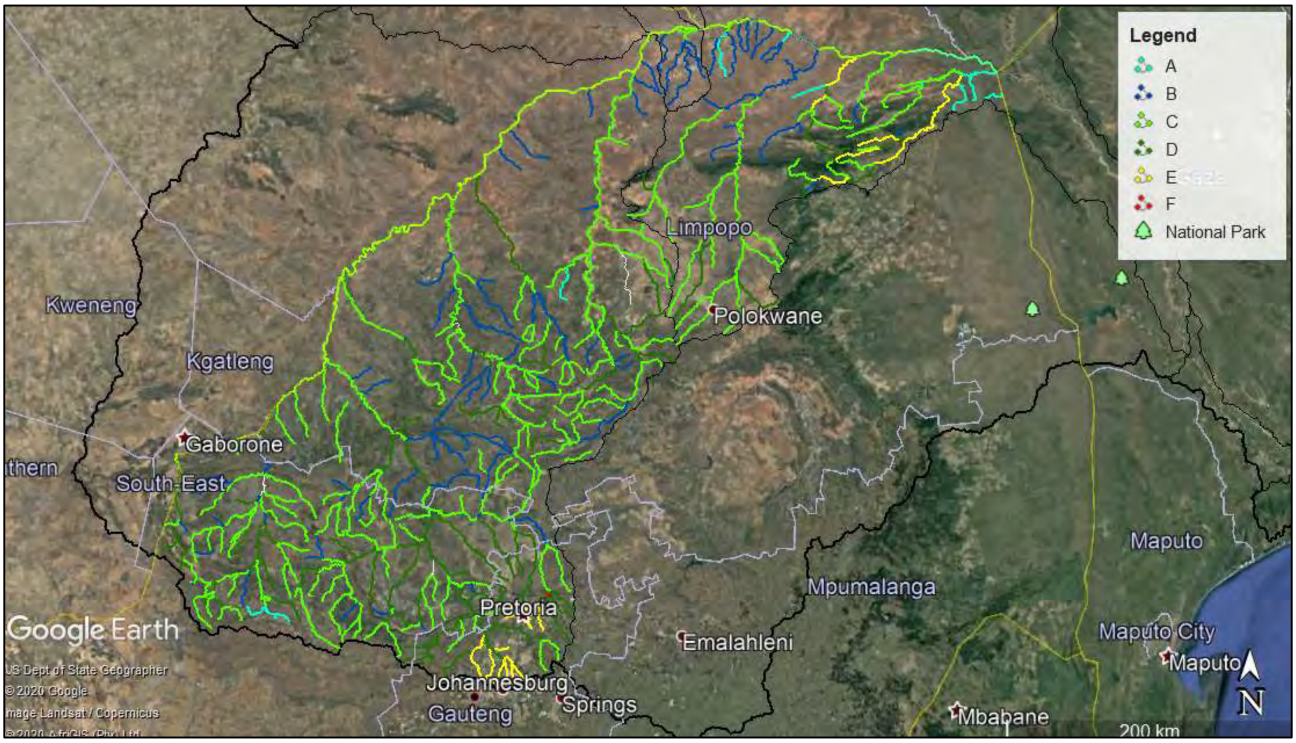


FIGURE: RIPARIAN PES (ECOLOGICAL CATEGORY) FOR THE LIMPOPO BASIN (PRIMARY CATCHMENT A).

Status of existing e-flow data/information for the Limpopo Basin

Previous riparian and environmental work within the Basin includes the Mokolo, Olifants, Elephantes and Wilge rivers. Below are summaries of vegetation descriptions or referrals to appendices of work done.

Olifants & Elephantes River

A single site on the lower Olifants and a single site on the Elephantes was assessed for riparian vegetation and e-flows in 2006 (Mackenzie). The report is included here for reference and interest (Appendix 3).

Wilge River

This was EWR site 4 of an e-flow assessment done in 2010 (Mackenzie, pers data). A description of the site vegetation as part of the VEGRAI level 4 assessment (Kleynhans *et al.,* 2007) is included in Appendix 4 for reference.

Mokolo River

An e-flow assessment was done in 2008 with 4 river sites and the Mokolo / Tabotie floodplain (confluence) as a 5th. The following is a brief description of the riparian / wetland vegetation (Mackenzie, pers data): Each site is described and summarised in the vegetation report below, section 5.

Requirements for data/information collection

This project will endevour to gather and asess the following:

- Assess the current ecological state of the riparian zone and in so doing describe the present state and composition of the vegetation and the impacts thereupon in comparison to natural expected conditions
- Survey indicator species along an hydraulically calibrated profile in order to describe and quantify the hydraulic niche of each. These outcomes will be used to determine the ecological flows for each
- The ecological flows will then be integrated with other components requirements to generate an overall e-flows requirement and also incorportaed into a risk assessment modelling environment.

General comments

The degree of confidence with which the vegetation component contributes to the overall deteremination of the e-flows is high and usually supportive of other components such as aquatic fauna and geomorphology. In this case, given the recent floods that have occurred before the field assessment, riparian indicators may be scant with remnants remaining for assessment. If this is the case the assessment of the e-flows requirement for vegetation will have a lower confidence.

Specialist report below

The vegetation report below introduces the broad scale terrestrial vegetation of the catchment as well as the spatial distribution of wetland types. It also summarises outputs from previous studies both in terms of the present ecological condition of riparian zoes and gives some specific examples where high level e-flows assessments have been conducted before (such as the Mokolo, Elefantes and Limpopo rivers). It aslo summarises the methodology and outcomes of the PES_EI_ES (Present Ecological Sate, Ecological Importance and Ecological Sensitivity) study that was conducted at the catchment scale.

Fish

Purpose of the data/information

Fish have been established as good indicatros of environmental flow assessments and will contribute to the determination of the volume, duration, ferquency and timing of flows in the Limpopo Basin. FIsh are important parts of aquatic ecosystems and provide protien, recreational and other ecosystem services to the people who live in the basin. In this study fish will be used as a line of evidence/measure on various levels of biological orgnisation from population, species and community levels to contribute to the establishment of flow-ecosystem and flow-ecosystem service relationships that the study depends on. To achieve this we need evidence of the historical or potential distributios, populations and community wellbeing of fishes in the catchment, and how people have used or depended on these fishes. We also need to understand how the wellbeing of populations of fishes in the basin have changed and what it is that is driving these communities. This information will result in data we need to contribute to the determination of e-flows for the rivers in the basin and the socio-ecological consequences of altered flows.

Status of data for the Limpopo Basin

Natural condition

The Limpopo River has historically acted as the conduit to distribute fish from the Congo-Zambezi system into South Africa, southern Mozambique and Eswatini. This has resulted in the establishment of the biodiversity hot-spot of fishes that we now find in the region. So while important very little is known about the fish communities and their wellbeing in the Limpopo Basin. This can partially be attributed to the shared nature of the basin and availability of resources to characterise the ecosytem and ecosystem services of this shared system. Apart from a relatively robust understanding of the wellbeing of fishes in major tributaries of the Limpopo River in South Africa, limited work undertaken in Zimbabwe and Mozambique has been historically available to represent the wellbeing of fish communities in the basin. Importantly the fish community data collected for the 2012 e-flow determnation study represents the only catchment scale assessment of fish communities in the basin. The fisheries of the Limpopo Basin are of great ecological importance as they include at least 77 species of which 52% overlap with species that occur in the Zambezi Basin and 11% overlap with species that occur in the Congo Basin. Seven species have conservation status and there are at least four endemic species that only occur within the basin. We have been able to predict what the fish communities may have historically looked like based on available information so that we can determine the present state of communities and determine the consequences of altered flows to fishes and use this information in the study.

Present condition

The Limpopo River Basin is home to more than 18 million people (2012 estimated) making it one of the most populated basins in the Southern Africa Development Community (SADC). Human communities rely on the Limpopo River's ecosystems to provide valuable and often irreplaceable services. Fish especially; anguillids, tilapias, large growing cyprinids, lepidosireniforms and siluriformes are socio-economically important in the basin and are targeted for subsistence fisheries especially in Mozambique and Zimbabwe. Particularly because fish are breeding or migrating in spring/ early summer occurs at the same time when communities begin their planting season and normally there is little or no food left from last year's harvest.

The fish communities of the Limpopo are dynamic and may shift following the perennially changes of areas in the catchment. As such when some areas of the Limpopo Catchment become seasonal and episodic, other areas act as refugia for fishes. Historically, fish communities have been able to shift across the catchment in response to these changes. These communities can be relatively more intolerant to anthropogenic impacts than communities that have stable refuge areas. It appears that due to existing water quality and flow impacts from South Africa predominantly, that appear to affect the upper south and eastern parts of the Limpopo Catchment the importance of the northern, western, and lower parts of the catchment has increased. Degraded water quality conditions continue to pose the greatest threat to fish health in this system, additional impacts such as habitat alteration, flow regime modifications, barriers for migration, disturbance to wildlife and or the impact of non-endemic alien or introduced fishes may be affecting the fish communities in the Limpopo River. The findings of the 2012 assessment included fish communities observed to be in a moderately modified ecological state primarily. In response to the low flows observed in the study area during the survey, it is likely that the fish communities were in a stressed or impacted state. The present seasonal nature of the rivers in the Limpopo Basin suggests that this impacted state may be unnatural. The absence of many species known to be tolerant to low and no flow conditions and corresponding absence of species intolerant to water quality alterations suggests that the rivers in the study area are being impacted on by flow and water quality alteration impacts associated with anthropogenic activities. The statistical assessment of fish community structures using Redundancy Analyses supports these arguments showing that a significant relationship between Present Ecological State (PES) scores and the community structures. These findings show that large shifts in the community structures of fishes in the study area occur. Differences seem to be further driven by flows and depths, which were key features of remaining refuge areas where fish populations were being maintained.

Status of existing e-flow data/information for the Limpopo Basin

During the 2012 Monograph study of the Limpopo Basin, fish were included as an ecological component of the study. This study was the first to consider fish on a regional scale in the Limpopo Basin. Although rapid, the 2012 survey carried out to the eight sites in the Limpopo Catchment allowed for the assessment of the FRAI and fish community structures using multivariate statistical techniques. In addition, with available hydrology and hydraulic data a Fish Flow Habitat Assessment Index (FFHA) assessment was also carried out. During the survey from 4 to 21 June 2012, 46 sampling efforts were carried out which resulted in the collection of 1501 fish from the eight sights selected for the study. Twenty-one species were collected (of the expected 73. Only the two cichlids *O. mossambicus* and *C. Rendalii* were collected at all eight sites. Other cosmopolitan species included the sharptooth catfish (*Clarius gariepinus*) and tank goby (*Glossogobius giuris*) that were obtained at six and five sites respectively. The highest diversity of fishes (12 species) were obtained at the upper site in the Limpopo at Spanwerk. Thereafter between seven and nine species were obtained at the sites including the main stem Limpopo River, Mwanedzi. Although sampling was limited to one day per site fishes observed in relatively good abundances ranging between 122 and 485 individuals at all of the sites. The explanatory data obtained from each site showed that substrate, habitat and cover features as well as depths and velocities varied considerably between sites. This data was used in the FRAI, multivariate community structure assessment and the FFHA assessment considered in the study. Knowledge of the habitat, cover, velocity-depth classes, water quality and migratory requirements of fishes from the Limpopo River Basin is available.

Requirements for data/information collection

In this study, due to the importance of including fish as socio-ecological indicators, we require a better understanding of the present distributions and wellbeing of fish communities and will use attributed of fish populations, species and communities to describe flow-ecological and flow-ecosystem service relationships. To achieve this we will undertake a review of knowledge of the fish in the basin and their biology and ecology, and how communities have already responded to chnges in flows, water quality and habitats in the basin. This information will be used to describe relationships between seasonal flow variabilities and attributed of the fishes for present conditions. For the determination of e-flows historical flow conditions will be used to determine the probable diversity and abundance of fishes in the basin. This data will be used to evaluate the socio-ecological consequences of altered flows in the study.

General comments

This study will make a valuable contribution to our knowledge of fish, their mangment and use in the basin which is of great socio-eclogical importance. We forsee that the fish component of this study will contribute to the robust determination of e-flows for the basin and the requirement to mitigate the consequences of altered flows in the basin. In addition our knowledge of the fishes that occur in the basin from e-flow case studies in central and southern Africa will strengthen our e-flow determination procesures for the region.

Specialist report below

The report below reviews our knowledge of the fish from the basin, and what we know about these fishes. We have included data on drivers of fishes and what we propose to be the present state of communities in the basin. With additional data, for which the methodology is reviewed below, we will establish fish as important indicators for the determination of e-flows in the region.

Aquatic Invertebrates

Purpose of the data/information

The purpose of field data assimilation is in support of a project in the Limpopo basin which focusses on environmental flow requirements for the river system in terms of quantity, quality, and timing. Field data collected are centred on providing insight into flow and habitat preferences of the aquatic macroinvertebrates encountered at the lowest taxonomic level possible.

Status of the data for the Limpopo Basin

Natural Condition

Limited data on aquatic macro-invertebrates are available for sites sampled on the Limpopo River. This lack of detailed historical data makes the categorisation of natural conditions speculative. Most available data for the Limpopo main channel are from the LIMCOM 2012 survey, but there are numerous family level data available for several of the tributaries. More data is available for the Olifants sub-catchment (Category B). The LIMCOM 2013 report documented the Recommended Ecological Category (REC) of the Limpopo main channel from the results of eight sites sampled during June 2012. The rest of the Recommended Ecological Categories (62 RECs) documented in the same report were determined from desktop reviews using the Desktop Reserve Model (SPATSIM, version 2.12) (Dickens et al. 2013). A summary of the recommended EC and present ecological status is illustrated in Figure.

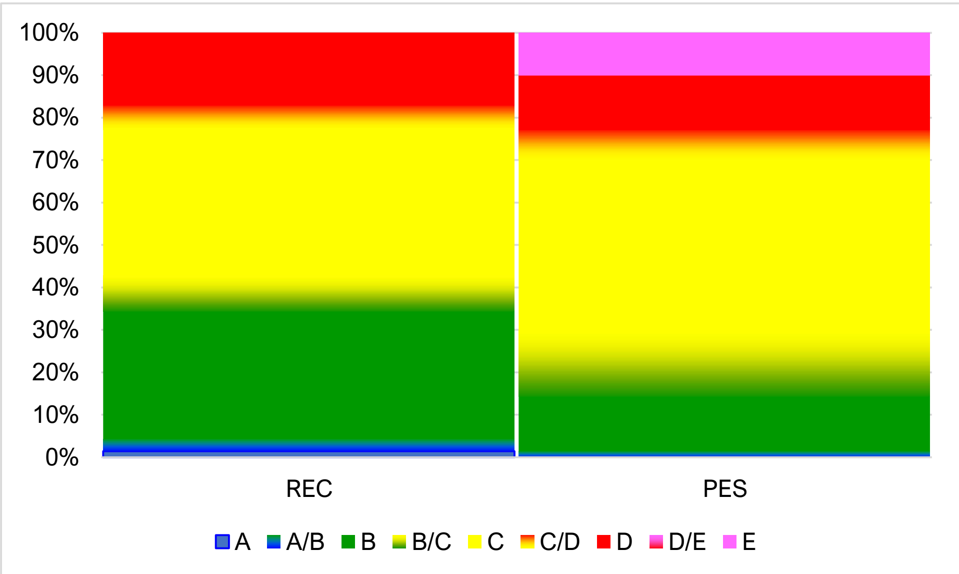


FIGURE: GRAPHICAL IMAGE OF THE RECOMMENDED ECOLOGICAL CATEGORY (REC) AND PRESENT (PES) ECOLOGICAL STATUS OF SITES FROM THE DATA PRESENTED IN THE LIMCOM 2013 REPORT.

Present Condition

Ecological categories of aquatic macroinvertebrates in the LIMCOM 2013 report were determined using the Aquatic Macroinvertebrate Assessment Index (MIRAI). It is clear from Figure that Present Ecological Status (LIMCOM 2013) is worse than the Recommended Ecological Category. The figure that follows presents results of the June 2013 field survey in terms of responses to flow, habitat, and water quality (based on the LIMCOM 2013 report, Dickens et al. 2013).

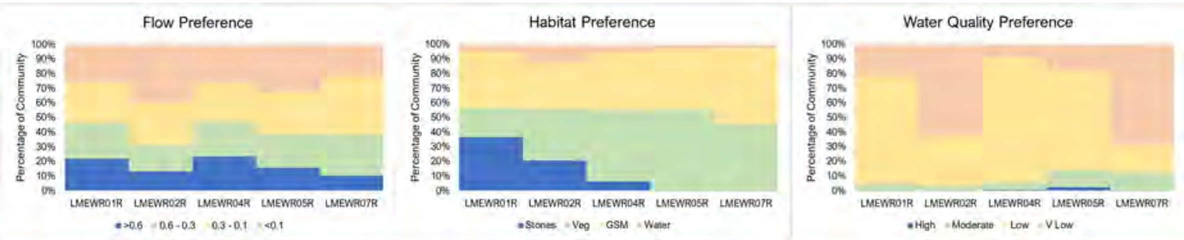


FIGURE: TAXA FLOW, HABITAT AND WATER QUALITY PREFERENCES EXPRESSED LONGITUDINALLY FOR SITES ON THE LIMPOPO RIVER SAMPLED JUNE 2012.

Limpopo River Sites – Main channel

- **Flows**: On family level, taxa with preference stagnant waters and slow flows were dominant at all sites sampled in June 2012. No clear trend in response to flows. Hydraulic biotopes sampled were the most diverse and abundant at the upstream site (Spanwerk - LMEWR01R), rapidly decreasing in a downstream direction (Chokwe - LMEWR07R).
- **Habitat**: The stones biotope is mostly present as bedrock, with sand and filamentous algae dominant. Hydraulic biotope diversity also decreases in a downstream direction.
- **Water quality**: Taxa (on family level) tolerant to' poor' and "very poor' water quality dominate, with some sensitive taxa present and more abundant further downstream.
- **OVERALL:** On a family level, taxa responded mostly to instream habitat conditions and water quality.

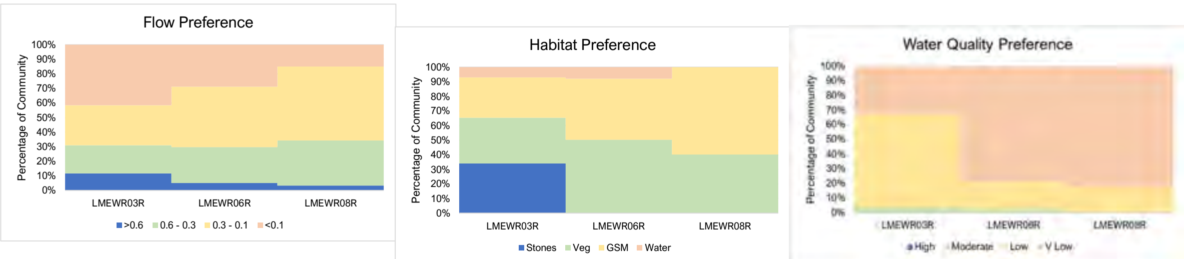


FIGURE: TAXA FLOW, HABITAT AND WATER QUALITY PREFERENCES EXPRESSED LONGITUDINALLY FOR SITES ON TRIBUTARIES OF THE LIMPOPO RIVER SAMPLED JUNE 2012.

Limpopo River Sites - Tributaries

- **Flows**: On family level, taxa with preference moderate and slow flows increased towards the coast, while taxa associated with fast flows decreased.
- **Habitat**: The stones biotope is mostly present as bedrock, with sand and filamentous algae dominant. Hydraulic biotope diversity also decreases in a downstream direction.
- **Water quality**: Taxa (on family level) tolerant to' poor' and "very poor' water quality dominate, with some sensitive taxa present and more abundant further downstream.
- **OVERALL:** On a family level, taxa responded mostly to instream habitat conditions and water quality.

Existing data/information for the Limpopo Basin

The Freshwater Biodiversity Information System (FBIS) is a southern African database recently developed, but which is continuously updated by the Freshwater Biodiversity Institute and practitioners working in freshwater environments with new and historical data. More data on aquatic macroinvertebrates sampled on a family level has been made available since the previous literature review. This information will be analysed and used in the assessment of conditions where relevant.

Requirements for data/information collection

Quantitative data are collected by sampling specific demarcated areas within different hydraulic and biotopes, substrates, vegetation types, and velocities. Flow velocities are measured in each identified biotope, and all the data are assessed to determine the preferences of taxa encountered.

BELOW IS A DETAILED REPORT FOR EACH COMPONENT

SPECIALIST REPORTS

1 HYDROLOGY

1.1 INTRODUCTION

The availability of hydrological data for the undertaking of the E-flows assessment for the Limpopo River Basin, including the major tributaries is summarised in this report. The focus of this report is the flows in the rivers feeding into the mainstem Limpopo River as well as flows at selected sites on the Limpopo River. These are presented in the 11 provisional risk regions that were selected and provides an overview of the hydrological characteristics of the rivers.

The report further includes the initial analysis of the long-term hydrological flow time series for each of the major tributaries and at the selected sites on the mainstem Limpopo River. These include basic hydrographs, flow duration curves and statistics based on monthly-modelled natural and present-day flow data at the outlets of the major tributaries and at the selected sites on the Limpopo mainstem. Detailed analysis will be undertaken when the risk regions have been finalised and the final E-flow sites have been selected. These will include inter alia daily flow data interrogation at gauging weirs close to the selected E-flow sites to provide additional information to the ecologists for the setting of specifically freshets and floods.

The information used in this report is mainly based on the results from the hydrological study (Volume C – hydrological assessment, 2013) as part of the Limpopo Monograph study as well as any other hydrology available for the study area, e.g. information from the Limpopo Reconciliation study. These studies undertook detailed assembly and processing of the hydro-meteorological data, historical water use collation and the generation of long-term natural and present day streamflow time series for the period 1920 to 2010 through calibration of the WRSM2000 model at selected river gauging weirs in the four basin countries. No additional hydrological modelling has been undertaken for this phase of the current study.

The e-flow requirement results presented in this report are from various Reserve and Classification studies undertaken, mainly for the catchments in South Africa as well as the results from the ecological component of the Limpopo Monograph study.

A general description of the catchments of the Limpopo River Basin has been provided in the basin report and thus no detailed discussions on this are provided in this report.

1.2 PROPOSED RISK REGIONS

The Limpopo River catchment has been divided into 11 provisional risk regions (RR) based on several criteria, including hydrological considerations (already there is an additional RR not shown in Figure 0.1). 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, or hydropower) were also taken into consideration to assist the assessment of the habitats and biota by the ecologists. The main tributaries per risk region are listed in the table below.

TABLE 1.1SUMMARY OF THE MAIN TRIBUTARIES PER RISK REGION IN THE LIMPOPO BASIN

No.	MAJOR TRIBUTARIES	PLACE
RR1 Marico-Crocodile	Marico Crocodile (West) Ngotwane Mainstem @ LmEWR01	A32E A24J Confluence with Limpopo Spanwerk
RR2	Matlabas Mokolo Lephalale Mogalakwena Bonwapitse Mhalatswe Lotsane Motloutse	A41D Confluence with Limpopo Confluence with Limpopo A42J A50H Confluence with Limpopo A63D Confluence with Limpopo
RR3	Shashe	Confluence with Limpopo
RR4	Umzingwani Sand Nzhelele Bubye Mainstem @ LmEWR02	Confluence with Limpopo A71K A80G Confluence with Limpopo Mapungubwe
RR5	Luvuvhu Mainstem @ LmEWR04	A91K Pafuri
RR6	Mwanedzi	Confluence with Limpopo
RR7	Olifants	B73H
RR8	Letaba	B83E
RR9	Shingwedzi	Confluence with Elephantes
RR10	Elephantes Mainstem @ LmEWR05	Confluence with Limpopo Combumune
RR11	Mainstem @ LmEWR07	Chokwe

1.3 FLOW STATISTICS FOR MAIN TRIBUTARIES IN THE LIMPOPO BASIN

Flow statistics (mean, percentage zero flows, minimum and maximum flows per month as well as various percentiles) have been calculated for each of the major tributaries. As variability is very high for most of the rivers in the Limpopo Basin, the median was also calculated to give an indication of the characteristics of the rivers.

Baseflow separation has been undertaken using the approach developed by Smakhtin, 2001. This provides an indication as to the groundwater contribution to surface flows without the influence of high flows (freshets and floods) and assist the ecologists with the setting of baseflows (maintenance low) flows for the rivers. The baseflow separation approach used for this report is based on the natural flow time series at the outlet of the proposed Risk Regions and existing EWR sites and haven't been verified with sampled groundwater results. When the information from the detailed groundwater analysis become available, these quantities of groundwater contribution to surface flows during especially the low flow moths, will be revised to provide higher confidence in the baseflows component of the E-flows.

A variability index (CV_Index) was also calculated for each of the major tributaries to get an indication of the seasonal, perennial, or ephemeral character of the river. This index was calculated for both the natural (NAT) and present day (PRS) flows to give an indication if the nature of the rivers has changed from natural to present day due to catchment developments. This index summarises the variability within the wet and dry seasons and is based on the average coefficient of variation for the three main wet and dry months (excluding zero flow months).

The table below presents the natural and present day mean annual runoff (MAR) from the Limpopo Monograph study and the calculated CV_Index for each of the major tributaries.

TABLE 1.2: SUMMARY OF THE MAIN STATISTICES PER TRIBUTARY IN THE LIMPOPO BASIN

No.	MAJOR TRIBUTARIES	FLOWS (MILLION M³)		CV_INDEX	
		NAT	PRS	NAT	PRS
RR1	Marico	110	40	3	6
	Crocodile (West)	595	399	2	5
	Ngotwane	92	62	5	10
	Mainstem @ LmEWR01	592	373	2	3
RR2	Matlabas	52	46	3	5
	Mokolo	210	165	5	9
	Lephalale	124	67	2	10
	Mogalakwena	198	127	3	8
	Bonwapitse	81	81	11	11
	Mhalatswe	38	38	8	8
	Lotsane	35	22	10	10
	Motloutse	125	86	8	8
RR3	Shashe	688	513	9	9
RR4	Umzingwani	438	260	7	7
	Sand	74	40	8	14
	Nzhelele	200	187	11	12
	Bubye	100	70	4	11
	Mainstem @ LmEWR02	1683	1200	2	4
RR5	Luvuvhu	560	456	2	2
	Mainstem @ LmEWR04	2792	1969	3	3
RR6	Mwanedzi	412	332	11	11
RR7	Olifants	1910	1104	2	2
RR8	Letaba	642	379	3	4
RR9	Shingwedzi	160	159	7	8
RR10	Elephantes	2713	1394	2	2
	Mainstem @ LmEWR05	3087	2192	3	4
RR11	Mainstem @ LmEWR07	5572	3325	3	2

A CV_Index between 1 and 4 indicates a perennial system, 5 a seasonal and >6 an ephemeral system. It can be seen from the table that several systems are naturally ephemeral, especially those in Botswana. It should be noted that this index was calculated for the flows at the outlets of the tributaries. Thus, some systems might still be perennial or seasonal in the upper reaches. Several systems have been changed from perennial to seasonal or even ephemeral with water uses in the upper catchments, especially those from South Africa.

The percentage zero flows per month for the natural and present-day flows have been determined to give an indication if the systems have zero flows.

TABLE 1.3 PERCENTAGE ZERO FLOWS PER MONTH PER TRIBUTARY IN THE LIMPOPO BASIN

MAJOR TRIBUTARIES		PERCENTAGE ZERO FLOWS PER MONTH											
		Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep
Marico	NAT	4	3	0	0	1	2	3	3	3	4	4	4
	PRS	76	55	30	25	34	40	51	68	76	77	80	81
Crocodile (West)	NAT	0	0	0	0	0	0	0	0	0	0	0	0
	PRS	0	0	0	0	0	0	0	0	0	0	0	0
Ngotwane	NAT	33	5	0	0	0	0	0	0	1	8	14	33
	PRS	64	29	15	13	29	36	62	90	97	99	100	91
Limpopo @ LmEWR01	NAT	0	0	0	0	0	0	0	0	0	0	0	0
At Spanwerk	PRS	13	7	8	4	2	4	2	5	7	8	12	14
Matlabas	NAT	0	0	0	0	0	0	0	0	0	0	0	0
	PRS	12	2	1	0	0	0	0	2	8	9	9	16
Mokolo	NAT	87	77	56	40	25	23	23	18	18	18	30	65
	PRS	100	95	87	71	58	53	49	49	60	70	98	99
Lephalale	NAT	0	0	0	0	0	0	0	0	0	0	0	0
	PRS	99	89	65	51	55	48	44	69	87	95	99	100
Mogalakwena	NAT	4	1	0	0	0	0	0	0	0	0	0	0
	PRS	93	75	60	42	37	44	46	62	69	77	92	92
Bonwapitse	NAT	66	36	18	16	33	42	69	96	98	99	100	96
	PRS	66	36	18	16	33	42	69	96	98	99	100	96
Mhalatswe	NAT	74	31	10	10	15	27	49	85	98	100	100	100
	PRS	74	31	10	10	15	27	49	85	98	100	100	100
Lotsane	NAT	78	32	16	13	12	27	43	86	97	99	99	99
	PRS	92	47	31	23	34	42	62	91	99	100	100	99
Motloutse	NAT	31	2	0	0	0	1	15	47	80	92	97	88
	PRS	36	3	0	0	0	3	16	56	87	95	99	91
Shashe	NAT	34	2	0	0	0	1	9	45	85	93	100	87
	PRS	76	13	0	1	4	11	27	69	95	98	100	98
Mzingwani	NAT	80	25	15	7	11	24	41	66	86	95	100	97
	PRS	90	42	24	13	27	42	54	81	92	97	100	100
Sand	NAT	52	21	9	12	13	15	16	30	38	51	56	60
	PRS	96	79	64	58	59	71	86	97	97	97	98	99
Bubye	NAT	87	36	18	9	13	23	42	75	92	98	99	97
	PRS	91	44	20	14	16	25	45	77	92	98	99	97
Nzhelele	NAT	24	15	8	3	2	0	0	4	7	9	11	22
	PRS	99	87	71	53	43	40	40	60	80	95	99	100
Limpopo @ LmEWR02	NAT	0	0	0	0	0	0	0	0	0	0	0	0
At Poachers Corner	PRS	18	2	0	0	0	0	1	2	2	3	4	4
Luvuvhu	NAT	0	0	0	0	0	0	0	0	0	0	0	0
	PRS	0	0	0	0	0	0	0	0	0	0	0	0
Limpopo @ LmEWR04	NAT	0	0	0	0	0	0	0	0	0	1	1	2

MAJOR TRIBUTARIES		PERCENTAGE ZERO FLOWS PER MONTH											
At Pafuri	PRS	4	0	0	0	0	0	0	1	0	2	2	4
Mwanedzi	NAT	76	23	14	4	14	16	38	76	91	98	99	97
	PRS	70	21	7	3	11	12	0	69	89	97	97	95
Olifants	NAT	0	0	0	0	0	0	0	0	0	0	0	0
	PRS	7	12	4	1	0	0	0	0	0	0	0	1
Letaba	NAT	0	0	0	0	0	0	0	0	0	0	0	0
	PRS	0	0	0	0	0	0	0	0	0	0	0	0
Shingwedzi	NAT	82	38	20	12	12	29	55	76	86	91	93	92
	PRS	86	41	20	12	13	29	55	77	87	93	95	93
Elephantes	NAT	0	0	0	0	0	0	0	0	0	0	0	0
	PRS	0	0	0	0	0	0	0	0	0	0	0	0
Limpopo @ LmEWR05	NAT	19	3	1	0	0	0	1	2	4	11	16	22
At Combomune	PRS	35	12	4	4	2	1	2	4	11	23	41	48
Limpopo @ LmEWR07	NAT	0	0	0	0	0	0	0	0	0	0	0	0
At Chokwe	PRS	0	0	0	0	0	0	0	0	0	0	0	0

From the above table, the mainstem Limpopo still has only a few zero months, even with present day flows, with the sites at Spanwerk and Combumune a higher percentage of zero flows for present day. This is due to the very high percentage of zero flows for the Marico and Ngotwane Rivers that contribute to the flows at Spanwerk. Combumune is towards the lower reaches of the Limpopo River before the confluence of the Elephantes River with more constant present day flows due to the releases from Massinger Dam.

Most of the tributaries show an increase in zero flows for present day due to upstream developments. The Lephalale, Mogalakwena and Nzhelele Rivers show a large shift from almost no zero flows for natural to almost 100% zero flows for present day. It seems as if the operation of the Mwanedzi River resulted in less zero flows for present day.

The hydrographs for the main tributaries indicating the natural (NAT), present day (PRS) and baseflows (BF) per risk region are shown in the graphs below. Detailed flow duration graphs and total annual flow graphs for natural and present-day flows for the period 1920 to 2010 are available electronically.

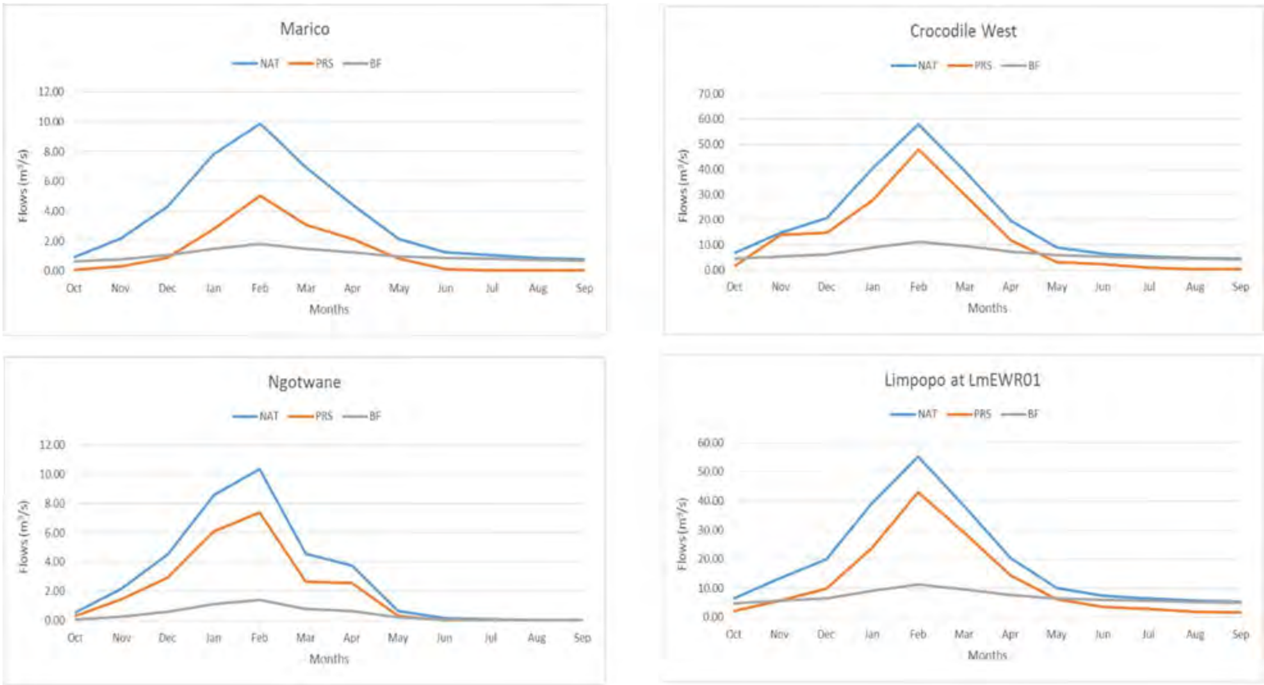


FIGURE 1.1 HYDROGRAPHS FOR TRIBUTARIES AND MAINSTEM IN RISK REGION 1

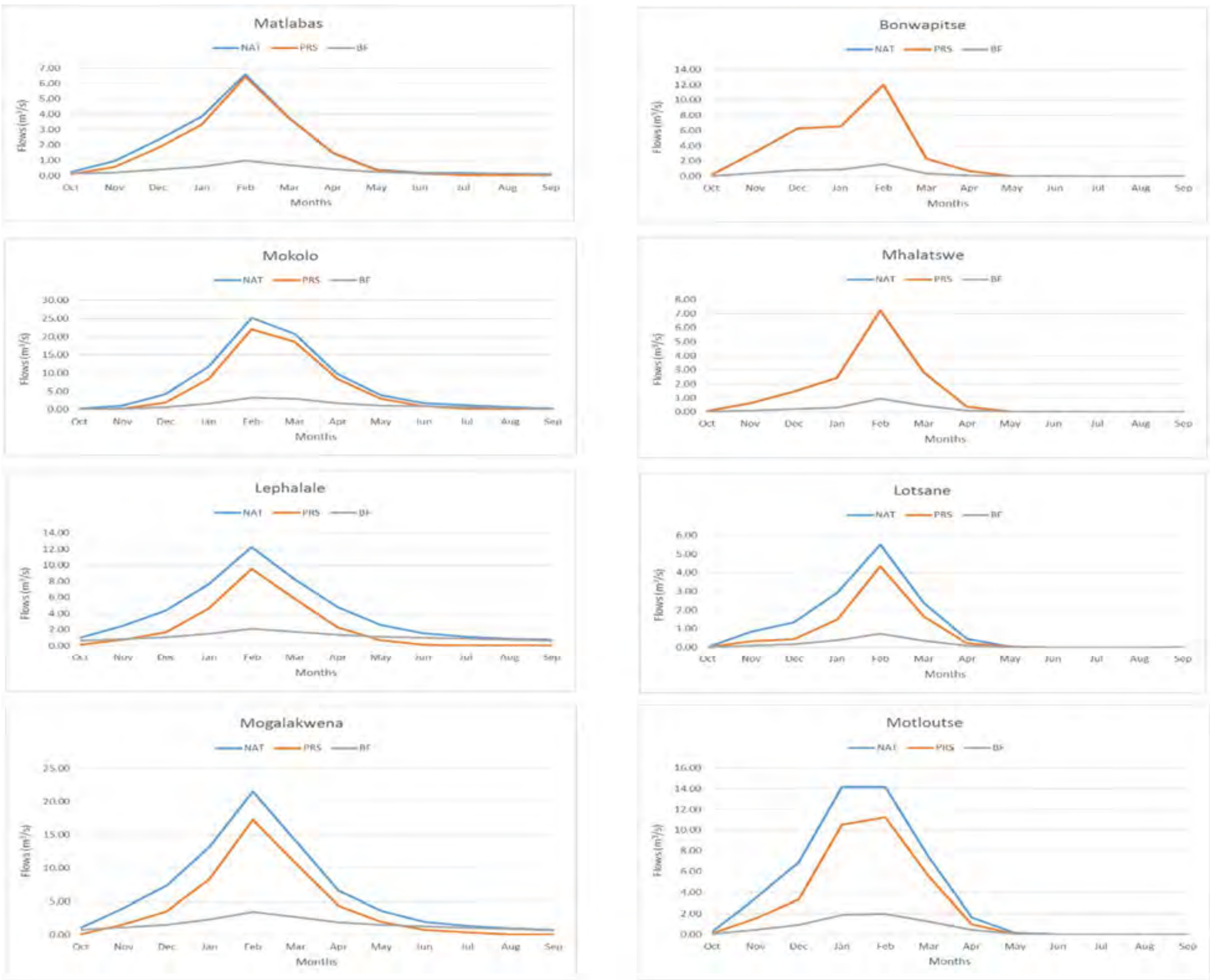


FIGURE 1.2 HYDROGRAPHS FOR TRIBUTARIES IN RISK REGION 2

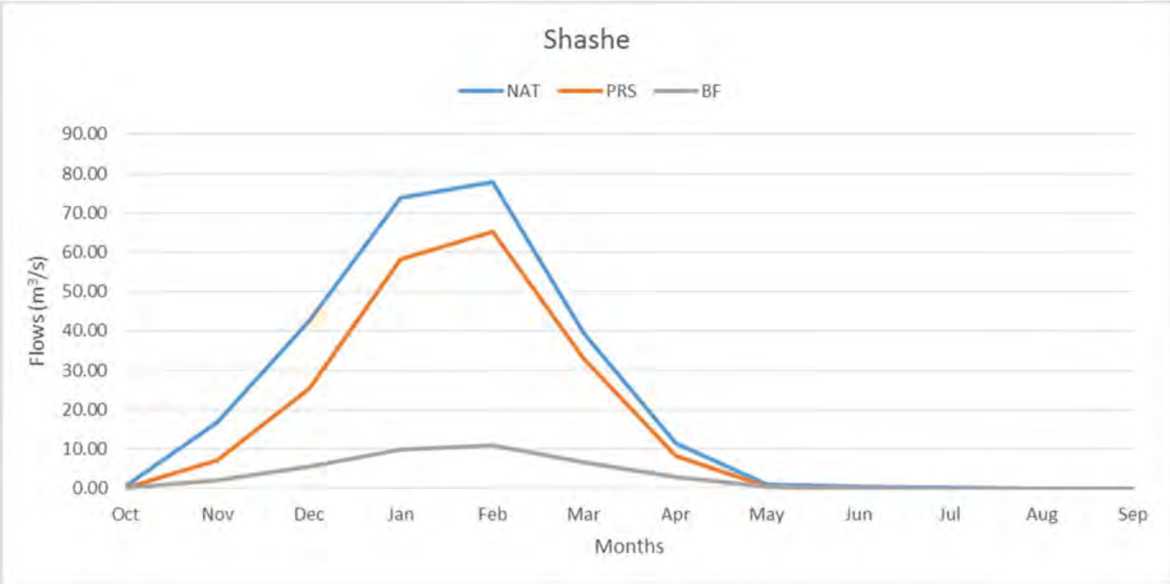


FIGURE 1.3 HYDROGRAPHS FOR TRIBUTARIES IN RISK REGION 3

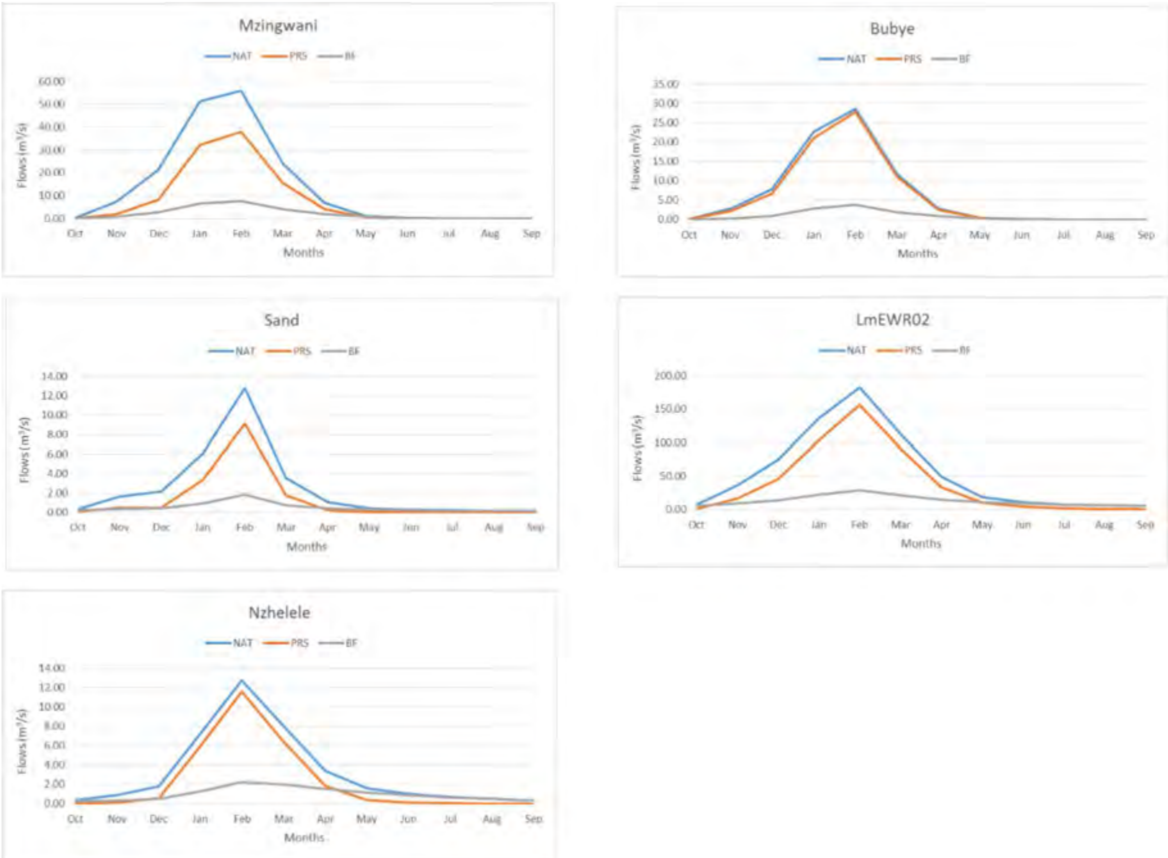
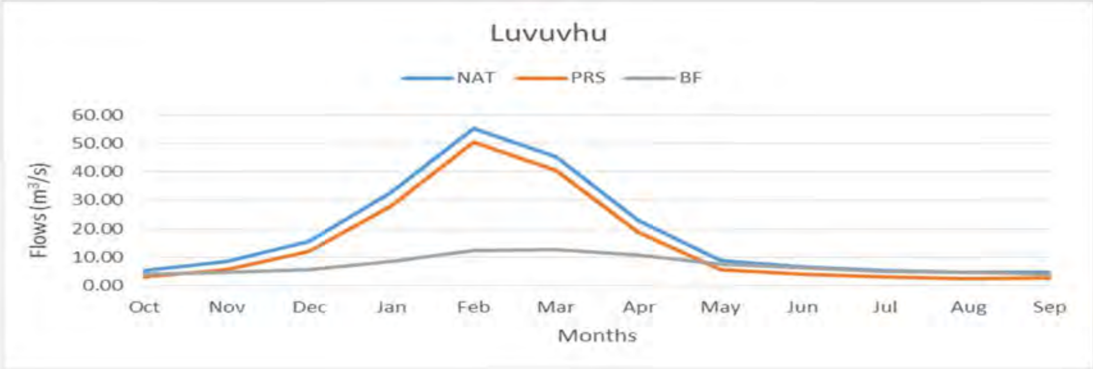


FIGURE 1.4: HYDROGRAPHS FOR TRIBUTARIES AND MAINSTEM IN RISK REGION 4



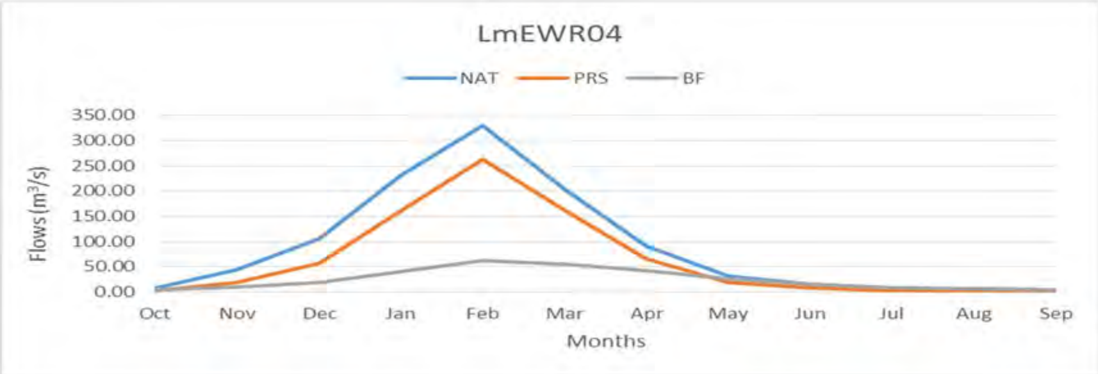


FIGURE 1.5: HYDROGRAPHS FOR TRIBUTARIES AND MAINSTEM IN RISK REGION 5

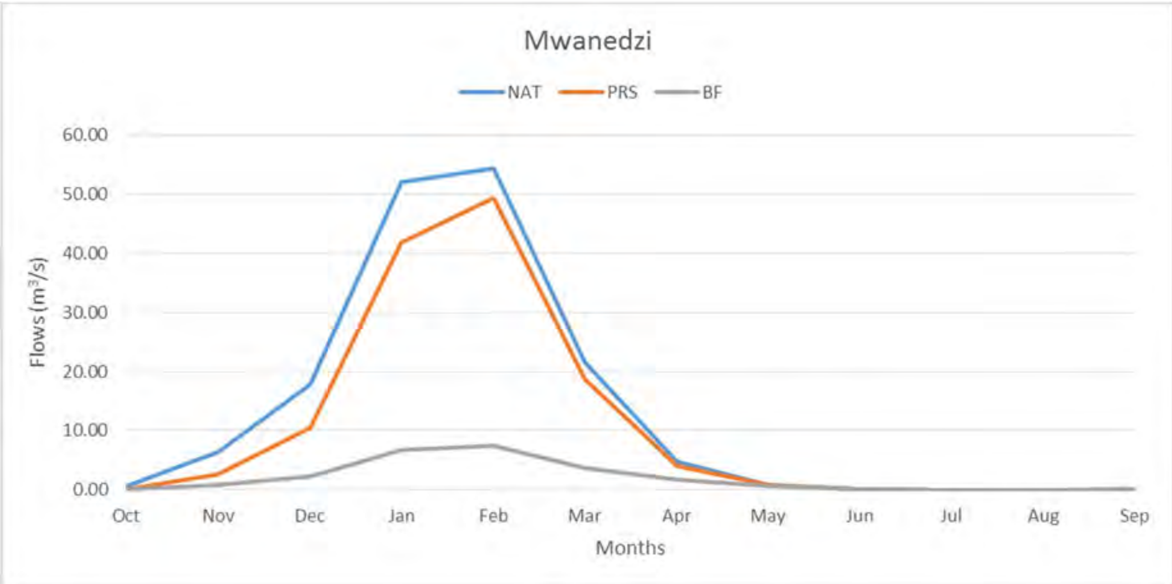


FIGURE 1.6: HYDROGRAPHS FOR TRIBUTARIES IN RISK REGION 6

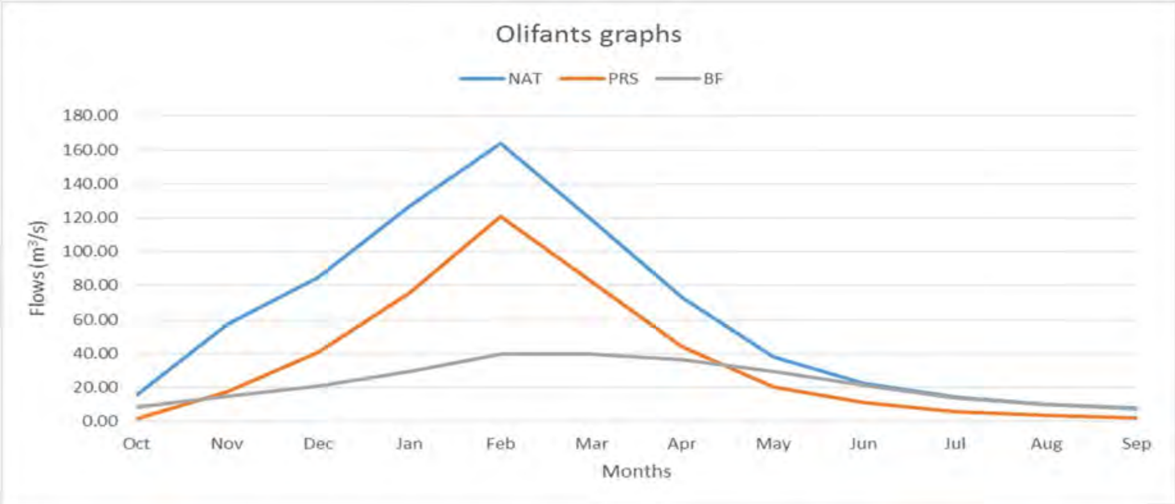


FIGURE 1.7: HYDROGRAPHS FOR TRIBUTARIES IN RISK REGION 7

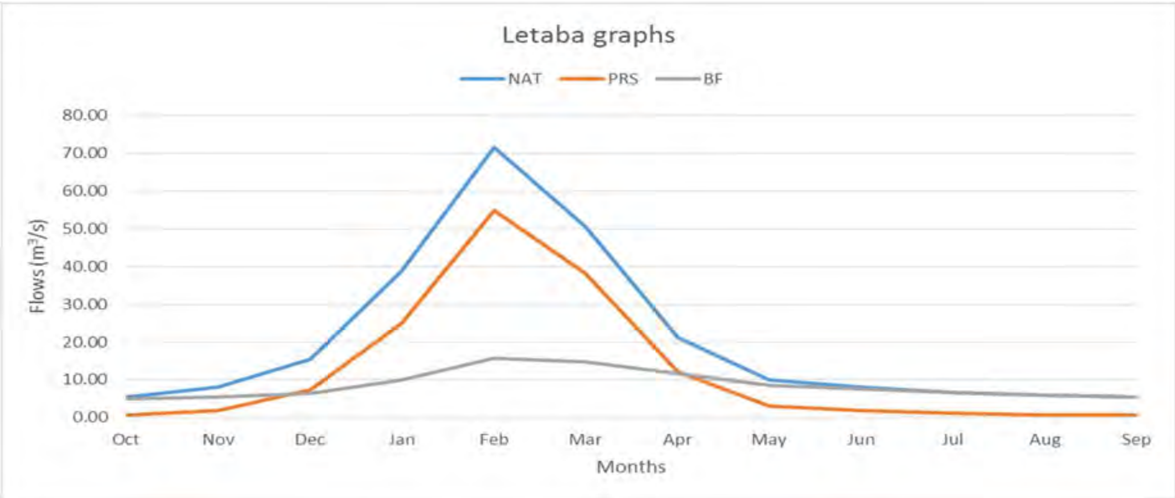


FIGURE 1.8: HYDROGRAPHS FOR TRIBUTARIES IN RISK REGION 8

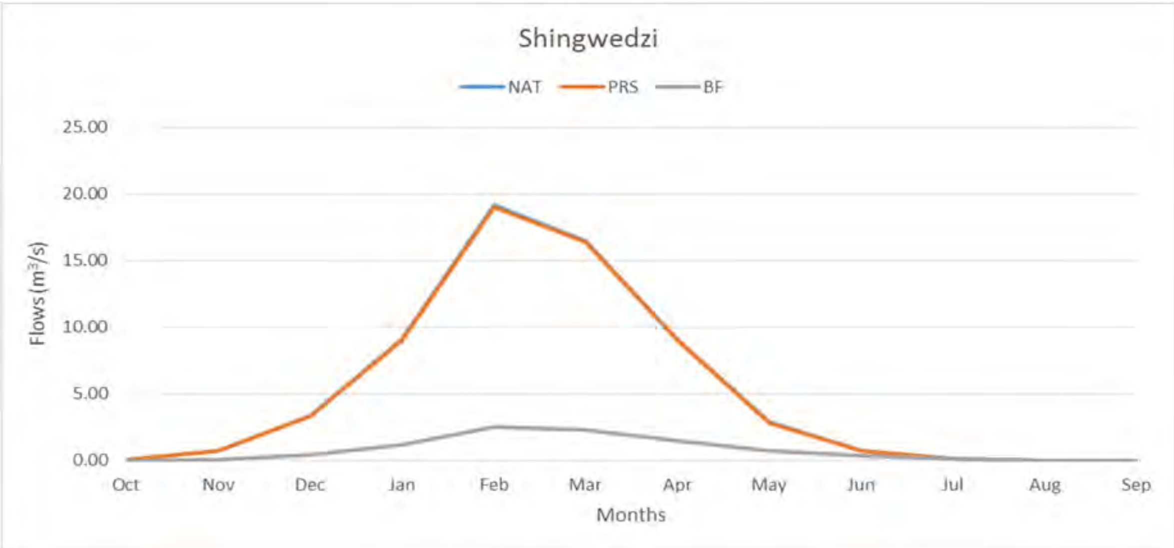


FIGURE 1.9: HYDROGRAPHS FOR TRIBUTARIES IN RISK REGION 9

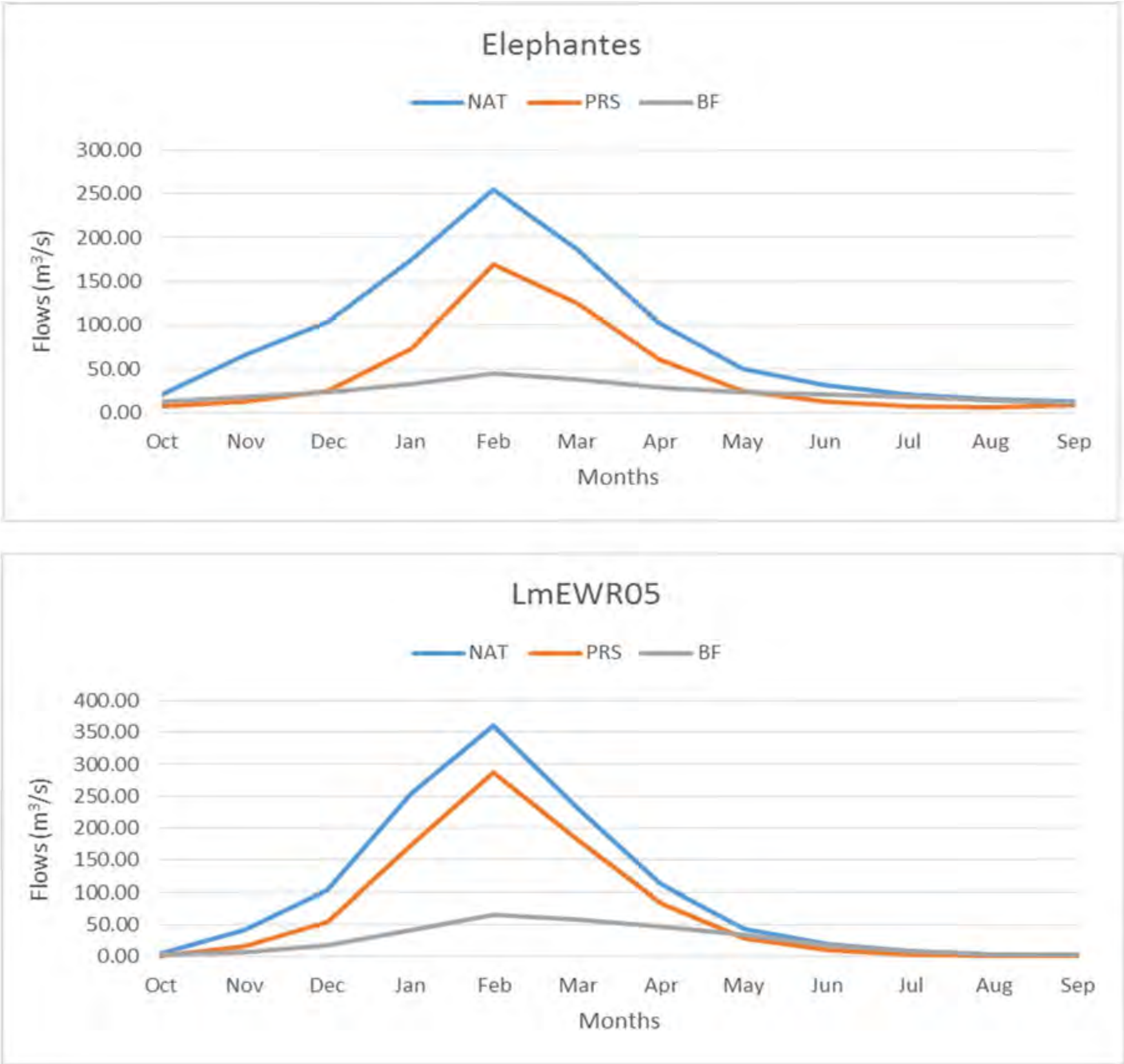


FIGURE 1.10: HYDROGRAPHS FOR TRIBUTARIES AND MAINSTEM IN RISK REGION 10

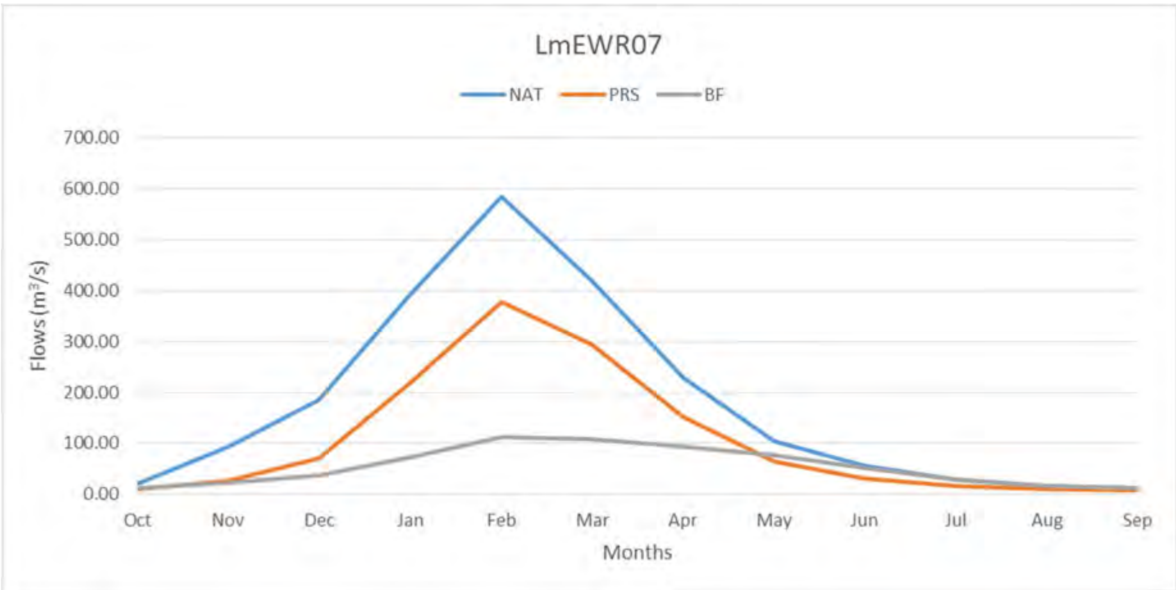


FIGURE 1.11: HYDROGRAPHS FOR TRIBUTARIES AND MAINSTEM IN RISK REGION 11

1.4 EXISTING E-FLOW/ EWR SITES

TABLE 1.4: SUMMARY OF E-FLOW/EWR SITES PER TRIBUTARY IN THE LIMPOPO BASIN

No.	MAJOR TRIBUTARIES	SITES			
		NAME	LAT	LONG	COMMENTS
RR1	Marico	MAR_EWR4	-24.706	26.424	Existing intermediate site – Reserve and RQOs
	Crocodile (West)	CROC_EWR8	-24.645	27.326	Site to be inundated with transfer to Mokolo catchment. Site lower down selected at A2H128 for RQOs (desktop only)
	Ngotwane				No E-flow site, currently ephemeral system
	Limpopo	LmEWR01	-23.945	26.931	Existing rapid at Spanwerk
RR2	Matlabas	MAT_EWR4	-24.052	27.359	Desktop only, limited options for E-flows site due to sandy nature
	Mokolo	MOK_EWR4	-23.771	27.755	Existing intermediate site
	Lephalale				No E-flows site, currently ephemeral system
	Mogalakwena				No E-flows site, currently ephemeral system
	Bonwapitse				No site, ephemeral system
	Mhalatswe				No site, ephemeral system
	Lotsane				No site, ephemeral system
	Motloutse				No site, ephemeral system
RR3	Shashe				No E-flows site, ephemeral system. Floods very important for Limpopo River
RR4	Umzingwani				No E-flow site, ephemeral system
	Sand				No E-flow site, currently almost episodic due to water use
	Nzhelele				No E-flow site, currently ephemeral due to water use upstream
	Bubye				No E-flow site, ephemeral system
	Limpopo	Lm_EWR02	-22.184	29.405	Existing rapid site at Mapungubwe/ Poachers Corner
RR5	Luvuvhu	LUV_EWR3	-22.427	31.196	Very outdated data
	Limpopo	Lm_EWR04	-22.460	31.503	Existing rapid site at Pafuri
RR6	Mwanedzi	Lm_EWR03	-22.064	31.423	Existing rapid site at Malapati
RR7	Olifants	OLI_EWR16	-24.049	31.732	Existing site, comprehensive of 2003 updated with recent surveys
RR8	Letaba	LET_EWR2	-23.827	31.591	Existing site, comprehensive of 2003 updated with recent surveys
RR9	Shingwedzi	SHI_EWR2	-23.185	31.525	Site downstream of rapid site LmEWR06r of 2012
RR10	Elephantes	ELE_EWR1	-23.880	32.253	Existing site downstream Massingr Dam
	Limpopo	LmEWR05	-23.472	32.444	Existing rapid site at Combumune
RR11	Limpopo	LmEWR07	-24.500	33.010	Existing rapid site at Chokwe

A number of classification, resource quality objectives and Reserve determination studies have been undertaken for some of the major tributaries and on the mainstem Limpopo River over the past 20 years. The above table provides an indication of the sites that were selected for these studies that are situated on the lower reaches of the rivers.

1.5 CONCLUSIONS AND RECOMMENDATIONS

Adequate hydrological data is available for the Limpopo Basin and the major tributaries from the 2013 Limpopo Monograph study. This data will be used, together with observed flows from gauging weirs to provide the necessary information for the E-flow determination at the final selected sites.

Several the major tributaries are naturally ephemeral in the lower reaches. Marico, Lephalale, Mogalakwena and Nzhelele Rivers have changed from perennial to ephemeral systems. However, the mainstem Limpopo River is still a perennial system with some increased zero flows at Spanwerk and Combumune due to water resource developments.

Information from existing E-flows/ EWR sites can be used for this study for some of the major tributaries and the mainstem Limpopo River. However, some data, e.g. on the Luvuvhu River is outdated and not readily available.

The following recommendations regarding the risk regions and E-flow sites are made to be considered during the finalization of the provisional risk regions and selection of E-flow sites:

i. Split RR2 in two regions with the rivers from Botswana (Bonwapitse, Mhalatswe, Lotsane and Motloutse Rivers) in a separate RR. This is due to the ephemeral nature of these rivers, whereas the Matlabas, Mokolo, Lephalale and Mogalakwena Rivers were naturally perennial to seasonal systems.
ii. Move the Nzhelele River in RR4 to RR5 with the Luvuvhu River, as the Mzingwani, Sand and Bubye Rivers are naturally more ephemeral.
iii. Select a new site on the lower Crocodile West River as the existing CROC_EWR8 will be inundated with the proposed transfer to the Mokolo catchment. The existing site was selected at A2H128 for RQOs, but no surveys were undertaken.
iv. Although the contribution of the Lephalale and Mogalakwena Rivers to the Limpopo River is very low (2% - 3%), these two systems have been changed from perennial to ephemeral systems. It will be important to have some indication of the ecological requirements of these systems and thus the selection of a new site on one of these rivers is recommended.
v. As the Shashe River is an important to provide floods for the middle reaches of the Limpopo River, it is proposed that an E-flow site is selected in the lower reaches of this river.
vi. The existing E-flows site LmEWR02 at Mapungubwe is downstream of the Shashe River confluence. As the Shashe River changes the characteristics of the Limpopo River, it is proposed that a new site is selected on the Limpopo River upstream of the Shashe River confluence.
vii. The existing information from the previous ecological flow requirements study on the Luvuvhu River is outdated and not readily available. As the Luvuvhu River contributes significant flows to the middle reaches of the Limpopo River, it is recommended that this site be re-surveyed to provide updated ecological requirements.

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2 GROUNDWATER

2.1 SUMMARY

Increasing demand for water in the face of climate variability and change has increased the need to mitigate the environmental impacts of groundwater development. Streamflow depletion due to groundwater pumping can have adverse consequences for riverine ecosystem health. To quantify groundwater pumping from the aquifer while still maintaining low level of ecological impact requires information on the relationship between environmental flow requirement and groundwater pumping. Traditionally e-flow assessment is carried out considering baseflow only and but, ignored the effect of groundwater pumping, which significantly reduces the baseflow to river flows. Furthermore, most of the e-flow assessment methods are developed for Perennial River and has little significance for ephemeral rivers which are characterized by episodic flow and disconnected isolated pools of water.

The main objective of this study is to include groundwater in the concept of e-flow assessment considering both Perennial and Ephemeral rivers. The study aims to provide insights that can help inform the assessment of environmental impacts associated with groundwater development. This will help to make groundwater allocation with due consideration of ecological needs that maintain sufficient groundwater discharge for various ecosystems and ensure groundwater management to be made in accordance to ecological integrity.

Two sites where abundant groundwater data and information are available representing Perennial and Ephemeral River were selected. At these two sites, a more accurate estimation of baseflow, assessment of streamflow depletion due to groundwater pumping, and assessment of groundwater surface water interactions will be made. Some fieldwork will be carried out to support the existing data. The detailed knowledge obtained at the experimental sites will be up scaled to gain better understanding of the role of groundwater to support ecosystems at a basin scale. Upscaling can be accomplished based on source identification of pools of water using isotope analysis, baseflow filter parameter calibrated against isotope or tracer method, streamflow depletion assessment as function of distance of pumping well from the river channel and groundwater surface water interactions. All this information will be integrated into the overall e-flow assessment.

Anticipated results include: 1) resolving uncertainties related to the baseflow separation, 2) source identification of isolated pools in ephemeral rivers, 3) determining rate of stream flow depletion due to groundwater pumping specifically during dry period, 4) determining the response time of streamflow depletion and 5) determining groundwater surface water interaction at local scale.

2.2 BACKROUND, RATIONAL AND OBJECTIVES

Establishment of e-flows is an essential element in preserving riverine ecosystems and the services they provide, and should be included as a constraint in water resource assessment and in national legislative frameworks (WMO, 2019). The term e-flow can also be referred to as instream flow needs, ecological reserve, ecological demand of water, environmental water allocation (or requirement), compensation flow or minimum flow (WMO, 2019). Traditionally, groundwater resource allocation in many areas has ignored the requirements of groundwater dependent ecosystems and made no provision for a water regime that might sustain them (Merz et al., 2001). Allocation of sufficient amount of water to ensure the sustainable ecological functioning and adequate management of ecosystem services supports ecosystem resilience and the resilience of those who depend upon them to cope with stresses such as drought, extreme weather events and climate change (WMO, 2019). Therefore, in the context of increasing water demand a comprehensive e-flow assessment is essential to guarantee freshwater ecosystem services and continued access to water for people.

The 2013 Limpopo Monograph study was confined to surface flow and did not directly consider the groundwater interaction beyond the estimation of baseflows (that are one of groundwater contributions to streamflow). Nevertheless, abstraction of groundwater from the riverbank or the riverbed is common in the Limpopo River Basin, thus affecting the flow and complicating the estimation and management of e-flows. Abstraction wells are often placed close to the streams where the valley depth and aquifer transmissivity are greatest. Because of the close proximity of the wells to the streams and the relatively high transmissivity of the aquifer near the wells, results in fast response time to streamflow depletion due to groundwater pumping (Barlow and Leake, 2012). One of the important concerns associated with streamflow depletion by wells is the effect of reduced groundwater discharge, affecting streamflow, chemistry and temperature of surface water, which is a critical water-quality property in determining the overall health of an aquatic ecosystem (Barlow and Leake, 2012). Depending on the distance of the well from the river and hydraulic properties of the geological material of the groundwater system and adjoining streambeds, some river reaches may be more affected than others. Steep hydraulic gradients at the stream-aquifer interface created by the pumping may cause some stream reaches to become losing, while other reaches remain gaining. Basin wide groundwater development typically occurs over a period of several decades, and the resulting cumulative effects on streamflow depletion may not be fully realized for many years, hence, it is often necessary to take a basin wide perspective to assess the effects of groundwater withdrawals on streamflow depletion (Barlow and Leake, 2012).

Besides, most of the e-flow estimation methods approaches were developed mainly for perennial streams. For the Limpopo River Basin, this is a particularly important aspect given that so much of the Basin has an alluvial bed and, importantly, today has only intermittent river flows where, during the dry season, the flow itself may become sub-surface. This sub-surface flow is still vital for the maintenance of the river ecosystem (and thus for protection of many of the services provided by the river to people) through keeping isolated pools charged with water, supporting riparian vegetation and even supporting the lives of many species that go into a state of hibernation during the dry season.

The objective of this study is therefore, to include groundwater in the overall e-flow assessment approach. Inclusion of groundwater in the e-flow assessment not only allow more meaningful assessment of e-flow, but also provide an understanding that is important for the management of the river and associated groundwater abstractions. Two case studies were selected for detail assessment. Fieldwork and modelling assessment will be carried out in these two sites. The knowledge from these two cases will be used to develop a basin-wide understanding of the role of groundwater in the e-flow assessment. All this information will be integrated into the overall e-flow assessment where its contribution to the risks to social and ecosystem endpoints will be estimated.

2.3 IMPORTANCE OF GROUNDWATER IN ENVIRONMENTAL FLOW

Groundwater contributes significantly to the baseflows of rivers, which are critical to river flows especially in the dry season. In some perennial river's groundwater can account for more than 90% of river flow during dry periods. Groundwater may also provide a different water quality input to the river, which could influence habitats, and e-flow requirements from groundwater. Groundwater help maintaining water level, temperature, oxygen content and chemistry required by riverine ecology (Gleeson and Richter, 2018). Groundwater development without adequate provisions to e-flow requirements will typically lead to degraded aquatic ecosystems (Richter, 2010). This is because, having the right amount flow in rivers is essential to support a healthy ecology. In many non-perennial river's groundwater plays a vital role in sustaining water levels in pools. In addition to precipitation, many different watershed characteristics and human activities influence base flow hydrology, including land use, soil characteristics, geomorphology, climate and groundwater pumping (Miller et al., 2016).

Increasing demand in the face of climate variability and change has increased groundwater use mostly in arid and semi-raid regions. Groundwater abstraction especially near river channels adversely affect river flows particularly summer baseflow. During the summer, there is greatest competition for water between instream flow needs and out of channel users (e.g. irrigation and domestic water supply needs, which are peak during dry periods) (Bradford and Heinonen, 2008). Hence, understanding the relationship of groundwater to e-flows is critical.

2.4 EXISTING KNOWLEDGE BASE

Groundwater Surface Water Interactions

Groundwater and surface water are in a continuous hydraulic interaction (Winter et al., 1998, Sophocleous, 2002). This interaction has practical consequences in the quantity and quality (temperature, oxygen, minerals, sediment, etc.) of water in either system (Gleeson and Richter, 2018). Depletion and/or contamination of one of the systems will eventually affect the other. Groundwater pumping reduces/intercepts the flow of groundwater to many aquatic and riparian ecosystems, including streamflow (Gleeson and Richter, 2018). Nowadays, understanding the connection between surface water and groundwater has received renewed attention due to conjunctive use of groundwater and surface water and instream flow requirements.

Mechanisms of groundwater surface water interactions

According to Winter et al. (1998), streams connected with groundwater interact in three basic ways: (1) water may flow from groundwater to streams through the streambed (gaining streams) (Figure 2.1a), (2) streams may lose water to the groundwater system (losing streams) (Figure 2.1b), (3) streams may be gaining in some reaches and losing in other reaches. Streams can also be separated from the groundwater system by unsaturated zone that are known as disconnected streams (Figure 2.1c). Rapid rise in stream stage due to storm precipitation, rapid snowmelt, or release of water from the reservoir may causes water to move from the stream into the streambanks. This process is known as bank storage and shown in Figure 2.1d.

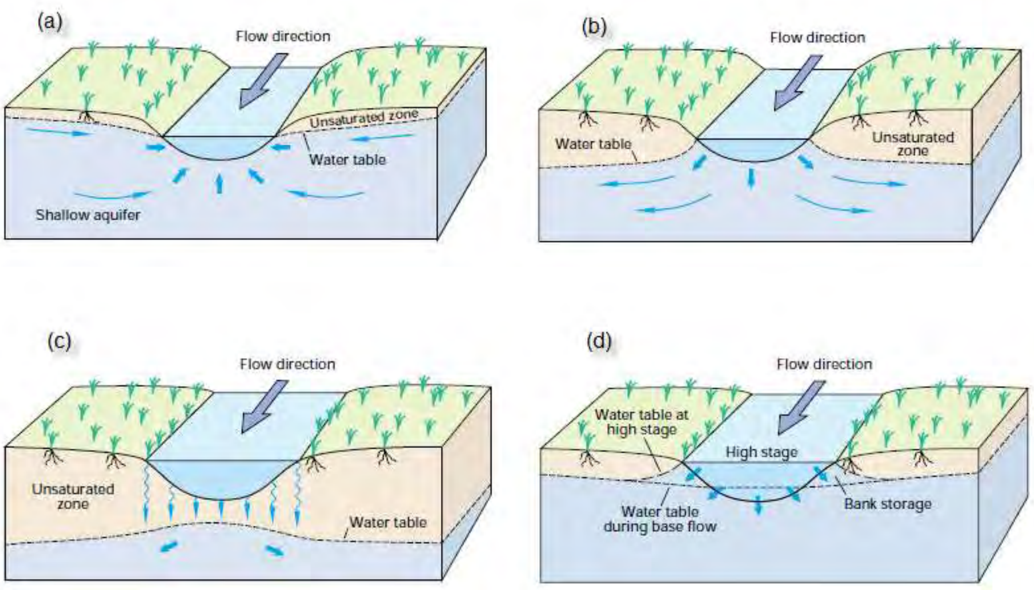

FIGURE 2.1: SCHEMATIC REPRESENTATION OF A GAINING RIVER (A), A LOSING RIVER (B), DISCONNECTED RIVER (C), AND BANK STORAGE (D) (WINTER ET AL., 1998).

2.5 SPATIAL AND TEMPORAL VARIABILITY IN GW SURFACE WATER INTERACTIONS

Groundwater-surface water interaction is highly variable in space and time (mainly controlled by geology, climate, and topography). Owing to the variations in hydraulic gradient and in hydraulic conductivity (caused by heterogeneity), quantifying flow exchange between groundwater and surface water is quite complex (Fleckenstein et al., 2010). At the watershed scale, groundwater flow patterns and their interaction with surface water are influenced by topography, geology and climate (Tóth, 1970). On the other hand, local scale groundwater-surface water interaction is mainly controlled by hydraulic gradient, and hydraulic conductivity of the aquifer and streambed (Woessner, 2000).

In addition to spatial variability, temporal variability of streambed sediments such as erosion and depositions, pools, riffles, streambed topography also affect groundwater surface water interaction at a local scale (Harvey and Bencala, 1993, Rehg et al., 2005). Temporal variability of fluxes may occur as a result of change in hydraulic gradient due to groundwater head variations, hydrologic events or change in river stage (Green, 2006). Hence, investigation of spatial variation of flux exchange between groundwater and surface water require measurements that allow for high spatial resolution (Kalbus et al., 2006). Interest towards investigating the local scale groundwater surface water interaction is growing due to many reasons (Schmidt, 2009) including: (i) for identifying the dominant groundwater discharge zones along the river reach that control flow and contaminant transport; (ii) to understand the biogeochemical conditions in the streambed, and (iii) to characterize the groundwater dependent benthic and aquatic life in the hyporheic zone.

Methods for quantifying groundwater surface water interactions

Kalbus et al. (2006) provided an extensive review of available method for assessing groundwater and surface water interactions. According to the authors, the available methods for quantifying groundwater surface water interaction can be categorized into four groups namely: 1) direct estimation method, 2) mass balance approach, 3) Darcy's Law, and 4) tracer method. Direct estimation method entails direct measurement of water flux across the groundwater and surface water interface (e.g. by using seepage meters). The mass balance approach comprises of incremental flow method, hydrograph separation and environmental tracer methods. The incremental streamflow method is based on the concept of the difference in streamflow measured at two successive cross-sections. Hydrograph separation method involves separating the hydrograph measured at a gauging station into different hydrograph components such as base flow and quick flow. Environmental tracers such as stable isotope and geochemical tracers are in wide use for stream flow origin determination, groundwater dating and separating hydrograph components (Kendall and MacDonnell, 1998). Groundwater-surface water fluxes exchange estimation using Darcy's Law involves determination of hydraulic gradient and hydraulic conductivity. Darcy Law is the standard way of formulating groundwater surface water fluxes exchange mechanisms in most standard groundwater models.

Baseflows and perenniality of rivers

Baseflow Separation

Baseflow is the rate of flow that a given catchment provide in the absence of precipitation, melting snow or any upstream water inputs (Brutsaert and Nieber, 1977). The baseflow at any given point is assumed to be the cumulative outflow from all upstream phreatic aquifers along the river banks (Brutsaert and Nieber, 1977, Brutsaert and Hiyama, 2012). Base flow is then assumed to represent the groundwater discharge. Information on baseflow is required for many purposes including water use allocation, determining the assimilative capacity of streams, preservation of aquatic life, understanding groundwater surface water interactions, and hydrological model calibration (Winter, 1999, Smakhtin, 2001b, Gebert et al., 2007, Santhi et al., 2008).

Baseflow separation has a long history in hydrology (Hall, 1968, Tallaksen, 1995). Historically, baseflow separation (baseflow from surface runoff component of the streamflow hydrograph) is carried out through graphical analysis. These types of methods are limited to hydrograph separation of individual storm events. Graphical approaches are not useful for baseflow separation from a continuous record of streamflow data. To solve this problem, digital filtering techniques were developed (Nathan and McMahon, 1990). Digital filtering techniques are very helpful in removing the subjective aspect of manual baseflow separation. They are fast, consistent and reproducible (Eckhardt, 2005). Various kinds of digital filters have been developed in the past. The recursive digital filter by Nathan and McMahon (1990) is the most widely used.

Nathan and McMahon (1990) recursive digital filter algorithm has the form of Equation 1. The premise behind the algorithm is that the high frequency signals are related to surface runoff while the low signals represent the delayed groundwater flow or baseflow. The technique is indeed arbitrary and there is no physically sound justification for its use (Nathan and McMahon, 1990). However, it does provide an objective and automated solution for baseflow separation. Arnold et al. (1995) compared the performance of the recursive digital filter with manual separation techniques and baseflow separation with the PART model over 11 watershed in USA. Their results showed that the annual baseflow estimated with the recursive digital filter method was in good agreement with the baseflow obtained using the other two methods.

$$q_t = \beta q_{t-1} + \alpha(1 + \beta) * (Q_t - Q_{t-1}) \qquad (1)$$

Where qt is the filtered surface runoff at time step t, Qt is the original streamflow and α, and β are the filter parameters (the recommended α for the daily baseflow separation is 0.5).

Baseflow bt is calculated using Equation 2.

$$b_t = Q_t - q_t \qquad (2)$$

After visual analysis of the different data sets Nathan and McMahon (1990) reported that a filter parameter (β) in the range of 0.9 – 0.95 provides acceptable baseflow separation while the value of filter constant close to 0.925 is optimum. In contrast, for rivers in South Africa Smakhtin and Watkins (1997) cited in Smakhtin (2004), reported higher values of β that range from 0.985 to 0.995 and recommended 0.995 as being suitable for daily baseflow separation. More recently, Ebrahim and Villholth (2016) applied the same value to assess baseflow and groundwater availability excess of e-flow requirements for 21 selected quaternary catchments in South Africa. The authors first determined the baseflow component of the streamflow; second, they determined the ecological reserve required to maintain all rivers in desired or pre-determined ecological conditions; third, they determined the amount of excess baseflow available for groundwater allocation by subtracting the maintenance low instream flow requirement from the annual baseflow for each quaternary catchments. Fourth, baseflow volume in excess of environmental requirement was converted to equivalent storage by multiplying the excess baseflow by drainage time scale.

The recursive digital filter is used to separate baseflow from daily streamflow records, because monthly flow data will smooth out the short-term variations. However, as outlined by Hughes (2001) the hydrological procedure for the determination of e-flow requirements for South African rivers is based on monthly naturalized flows simulated using rainfall-runoff model (e.g. Pitman model) This is because monthly models are commonly much quicker and easier to apply than daily models.

Smakhtin (2001a) determined monthly baseflow filter parameter by calibrating against results of daily baseflow separation performed on the daily data. The author separated daily baseflow using the previously established filter parameter value (β= 0.995 and α=0.5). The β value is calibrated while fixing α=0.5 and found that β value of 0.925 for the monthly baseflow separation in the regions where mean annual precipitations are in the range of approximately 600 to 1 100 mm and recommended to increase the filter parameter by about 2% for regions with mean annual precipitations less than 600 mm and decreased by 2% for the regions where mean annual precipitations is over 1100 mm. Building on the work reported by Smakhtin (2001a), Hughes et al. (2003), calibrated monthly filter parameter by varying both β and α. With this approach Hughes et al. (2003) have documented monthly regional values of filter parameters for South African Rivers. The reported monthly β: α values range from 0.955:0.43 to 0.995:0.47.

The Baseflow Index

Baseflow Index (BFI) is the ratio of baseflow to total flow calculated from a hydrograph separation procedure (either on an annual basis or for an entire observation period, determined as the ratio of total baseflow volume to total streamflow volume (Smakhtin, 2001)). BFI provides a systematic way of assessing the proportion of baseflow in the total runoff of the catchment (Abebe and Foerch, 2006). Its value can be zero, if there is no baseflow, like in ephemeral streams (Smakhtin et al., 1995, Smakhtin and Watkins, 1997) or range from 0.15 to 0.2 for an impermeable catchment with a flashy flow regime to more than 0.95 for catchments with high upstream storage capacity and a stable flow regime (WMO, 2008).

The BFI is used for ecological reserve estimation following the South African procedure of ecological reserve estimation. The Desktop Reserve Model (DRM) developed by the Institute of Water Research, South Africa, to provide a rapid, low confidence, initial tool for ecological reserve estimation (Hughes and Hannart, 2003) uses two measures of hydrological variability, namely the coefficient of variation (CV index) of the long-term dry and wet season flows and the long-term BFI to calculate the overall index of hydrological variability (CVB) required as input for DRM to simulate the instream e-flow requirements. The justification of using these hydrological indices is that while CV can be used to infer long-term climatic variability, BFI is used to capture the short-term variability associated with the runoff generation process.

Constraining Baseflow Filter Parameter

Hydrography separation based on tracers (isotopes, chemical parameters) consists of chemical mass-balance models that assume river flow is composed of distinct flow components having a characteristic concentration of one or more conservative chemical constituents (Wang et al., 2015). Isotopic and chemical hydrograph separation methods are mostly applicable for short-term river flow applications due to high laboratory analyses costs. Therefore, short-term isotopic and chemical measurements of baseflow can be used to calibrate other empirical baseflow separation methods that can then be applied to existing river flow records over longer periods as reported in the Letsitele study (Magombeyi et al., 2019). The two-component isotope and chemical hydrograph separation method (Wang et al., 2015) using 2H, 18O and silica (SiO2) as tracers was applied to separate the total river flow hydrograph into surface runoff and baseflow components. The underlying principle of this separation method is that groundwater with a relatively long residence time (old water) has a much higher mineral content (e.g., silica, chloride, other major ions) than rainfall or surface flow (new or event water), which may on the other hand have higher content of constituents such as organic carbon, than groundwater (Wang et al., 2015).

Figure 2.2 shows the sensitivity of baseflow for different β values (i.e. baseflow decreases as the filter parameter increases). As already indicated this type of baseflow separation is not based on any real knowledge of the hydrological processes. Furthermore, the actual measurements of baseflow is difficult and is not available. Hence, a separate evaluation of the filtering technique against hydro chemical and isotopic methods as was done in Gonzales et al. (2009) would strongly increases the validity of the results as well as efficient e-flow assessment.

More recently for Letsitele River Catchment, located in B81D quaternary catchment of Letaba Water Management Area, Limpopo River Basin, South Africa, Magombeyi et al. (2019) compared the baseflow filter parameter (β) value used by Ebrahim and Villholth (2016) with filter parameter obtained using stable isotope and silica method. The authors compared the baseflow separated by the recursive digital filter method during one period (May 2017- May 2018), where data from stable isotope and silica was available. They also compared long-term (past 60 years) BFI. The authors found that β=0.994 which is close to filter parameter used by Ebrahim and Villholth (2016) β=0.995. From the Letsitele study, the silica was identified to be suitable as the normally used chloride was not conservative due to the disinfectant chlorine added to wastewater effluent discharged in the rivers (Magombeyi et al., 2019). The separation method is applied by collecting and analysing separate or periodic river flow samples for selected, conservative constituents over a range of hydrologic conditions (i.e., high, and low flows, and wet and dry seasons). Since, the baseflow generating process is primarily controlled by catchment geology similar comparison and regionalization is important for different geological setting. This method has potential to be applied in the e-flow project to improve the estimation of BFI, which is used as a proxy of groundwater contribution to river flow that is important for sustaining the e-flow requirements.

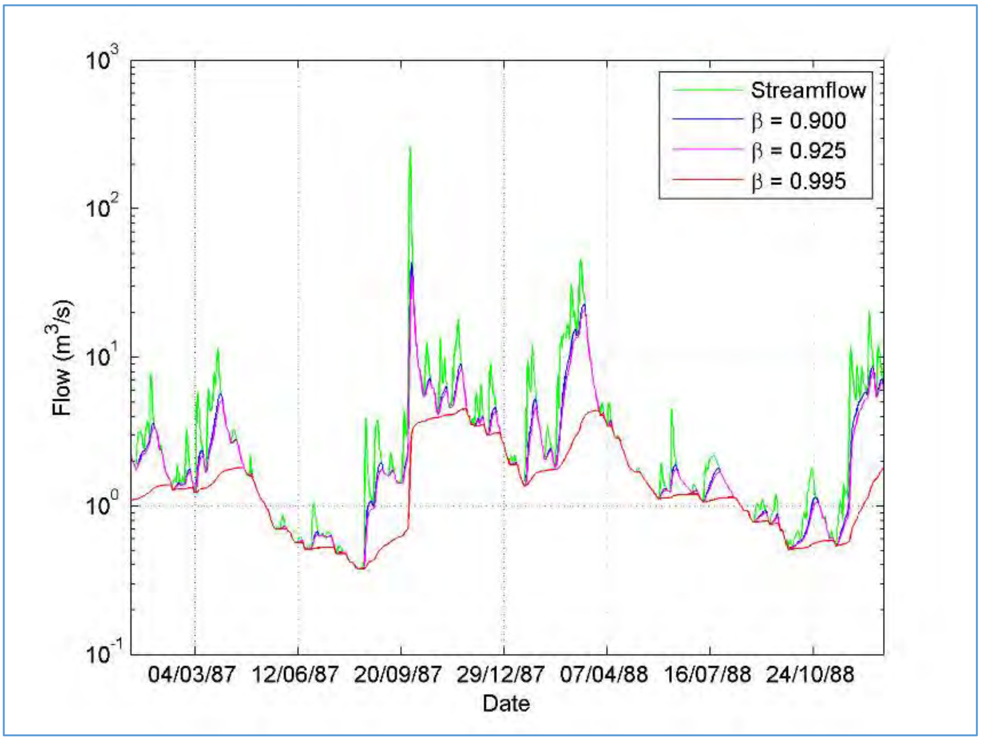

FIGURE 2.2: SENSITIVITY OF BASEFLOW TO FILTER PARAMETER (EXAMPLE FOR QUATERNARY CATCHMENT (U20A), SOURCE: EBRAHIM AND VILLHOLTH (2016))

Perenniality Of Rivers

Classifying rivers in terms of perenniality is important to determine the approach used for the e-flow requirement. River type classification can also be used to extrapolate understanding of ecohydrologic conditions at sites that have been studied to similar sites that have not (Kendy et al., 2012). If the river is gauged, a Flow Duration Curve (FDC) can be created from the flow data for each gauging point, and this will provide the degree of non-perenniality of the system (Seaman et al., 2010). A FDC is a graph that shows the percentage of time a specified discharge is equalled or exceeded during a given period (Searcy, 1959). The shape of the FDC in the high flow regime indicate the type of flood regime the basin likely to experience and the shape in the low flow region shows the ability of the basin to sustain low flows during the dry seasons. The flow exceeded for 95% of the time is often used as the characteristic value for minimum river flow (Where abstraction is prohibited to guarantee the e-flow requirement). FDC is a key tool for the design of irrigation, hydropower and to determine minimum flow requirements in the river for dilution of domestic and industrial discharges (Organization, 2008). If the river is not gauged or has inadequate data standard modelling approaches can be used to generate FDC or understanding of hydrological process (Hughes, 2008).

Rossouw et al. (2005) classified rivers based on their degree of flow persistence. According to the authors' classification, perennial rivers are rivers with perennial flow but may cease flowing for short periods of time during extreme droughts. However, non-perennial rivers are classified into three categories namely: semi-permanent (flow 1-25% of the time), ephemeral (flow 26-75% of time) and episodic (flow at least 76% of time; flows briefly only after rain).

Ephemeral rivers are characterized by much higher flow variability, extended periods of zero surface flow and absence of low flows except immediately after moderate to large high flow events (Hughes, 2005). Streamflow observation networks on ephemeral rivers are sparse and it is widely recognized that the hydrological modelling of ephemeral systems is generally more difficult than perennial systems (Hughes, 2005). This is because representing spatially variable sparse rainfall input and the dominance of in-channel processes that are either difficult to quantify or are simply not understood sufficiently to incorporate into models.

According to Allen et al. (2020) perennial rivers can be conceptualized using longitudinal continuum models however intermittent rivers and ephemeral streams(IRES) are longitudinally discontinuous when they are dry. During dry periods IRES form isolated pools or ponds of standing water, or surface-disconnected reaches that still flow. These disconnected pools and reaches are longitudinally isolated by dry reaches upstream and/or downstream, preventing the downstream transport of materials in surface water. In perennial rivers, hyporheic exchange is considered to occur consistently through time, however hyporheic exchange in IRES is not always continuous and may be unidirectional during drying (surface-to-subsurface only) and rewetting (subsurface-to-surface only) phases (Allen et al., 2020).

Seasonal Pools

In non-perennial rivers one of the most critical factor impacting ecological functioning is the dynamics of pool storage (Seaman et al., 2010). Isolated pools appear at various points along a river system as surface flow ceases. These pools are one of the most distinguishing characteristics of non-perennial rivers and are important refugia for many of the riverine plants and animals. Isolated pools may be a source of water for a wide variety of wildlife and local rural people and their livestock (Seaman et al., 2010). However, predicting the location of surface water pools during period of no surface water flow is difficult.

The location, nature and means of persistence of pools are poorly understood. Not only the location, timing and persistence of pools, but also their chemistry can be highly unpredictable (Seaman et al., 2010). Connectivity between pools is one of the most important attributes of non-perennial rivers. Pools are formed due to topographic depressions or flow obstruction (Buffington et al., 2002). Detail about the occurrence of pools and factors controlling their size for coarse-grained forest river can be found in Buffington et al. (2002).

Effect of groundwater pumping on streamflow

Streamflow depletion due to groundwater pumping has adverse effect that reduce flow for aquatic ecosystems, the availability of surface water and the quality of streams and rivers (Barlow and Leake, 2012). Strong interactions between groundwater and surface water are usually associated with shallow aquifers (often unconfined) (Evans and Merz, 2007). This is mainly due to their proximity to land surface and associated surface water. The rate at which flows between stream and aquifer is governed by the hydraulic gradient between the stream and aquifer, and the hydraulic conductivity of geologic material that exists between groundwater and surface water interface.

When a well begins to pump water from an aquifer, all the water pumped by the well comes from water stored in the aquifer (Figure 2.3). With time, the cone of depression generally deepens and expands laterally and reaches to stream or surface water. The hydraulic gradient that is established within the cone of depression forces water to move from the aquifer into the well. With increasing time the fraction of pumpage derived from storage depletion tends to decrease and the fraction derived from capture increases (Barlow and Leake, 2012, Konikow and Leake, 2014). Capture includes increased recharge through induced infiltration from streams (and other surface water bodies), as well as decreases in groundwater discharge to springs, streams, and other surface water bodies (i.e., decreases in base flow) (Konikow and Leake, 2014). Capture also include reduction in evapotranspiration from groundwater because of declining water level due to pumping.

The primary sources of captured discharge are groundwater that would otherwise have flowed to streams, drains, lakes, or oceans, as well as reductions in groundwater evapotranspiration in low-lying areas such as riparian zones and wetlands (Barlow and Leake, 2012). The main factors affecting the response time of streamflow depletion due to pumping include: geologic structure such as dykes and faults, aquifer hydraulic properties, streambed hydraulic conductivity and the horizontal and vertical distances of wells from the streams (Barlow and Leake, 2012). Figure 2.4 demonstrates the capture of groundwater that would otherwise have discharged to a gaining stream. Groundwater discharge to the stream is reduced due to pumping but there is no reversal in flow gradient and the stream remains gaining.

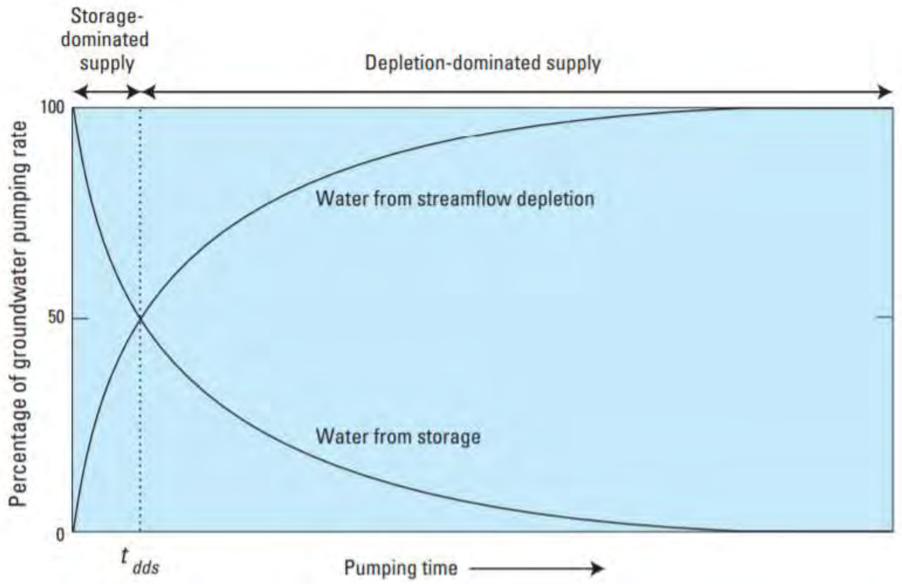

FIGURE 2.3: RELATION OF STORAGE CHANGE AND STREAMFLOW DEPLETION AS SOURCES OF PUMPED GROUNDWATER THROUGH TIME FOR A HYPOTHETICAL WELL SOURCE BARLOW AND LEAK (2012))

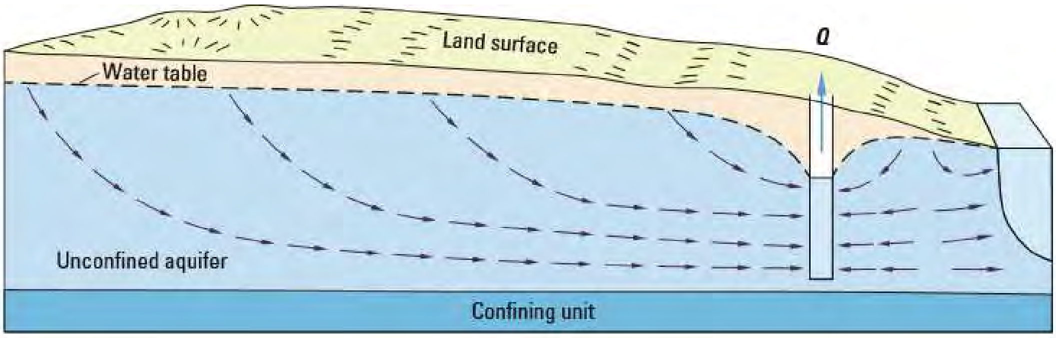

FIGURE 2.4: EFFECTS OF PUMPING ON DISCHARGES TO A STREAM. AS THE CONE OF DEPRESSION EXPANDS OUTWARD FROM THE WELL, THE WELL BEGINS TO CAPTURE GROUNDWATER THAT WOULD OTHERWISE HAVE DISCHARGED TO THE STREAM (SOURCE: BARLOW AND LEAK (2012))

Approaches for quantifying groundwater surface water interactions under groundwater pumping

According to Barlow and Leake (2012) the approaches for determining the effect of pumping on streamflow depletion can be broadly categorized into three; collection and analysis of field data, analytical, and numerical modelling.

Field Techniques

The field techniques for quantifying streamflow depletion can be grouped into three: 1) direct measurement of streamflow, 2) point measurement of flow across the streambed, and 3) measurement of other types of data that indicate the direction or quantity of flow between a stream and adjoining aquifer (Barlow and Leake, 2012). Point measurement of flow across the streambed can be accomplished by using seepage meters placed at specific points in the stream channel. The third approach entail specific point measurements in a stream channel but also include methods that monitor larger areas of a stream reach. These approaches employ water levels measured at observation wells or streambed piezometers, measurements of temperature in the stream and streambed, analysis of geochemical constituents or tracers, and geophysical studies of the stream-aquifer system (Barlow and Leake, 2012).

Groundwater recharge is also a form of groundwater-surface water interaction. Groundwater recharge is simply defined as water that moves from land surface to the groundwater table either as focused or diffuse flow (Tyner et al., 1999). Groundwater recharge is dependent on meteorological conditions, soil, vegetation, physiographic characteristics, groundwater pumping or use, and properties of the geologic material. However, the rate of recharge to an aquifer is difficult to estimate in the evaluation of groundwater resources. In the Letsitele study (Magombeyi et al., 2019), applied both chemical and physically based methods to reduce the uncertainty associated with recharge quantification. These include chloride mass balance (CMB) method, water table fluctuation (WTF) method and baseflow separation. These methods can be applied in the E-flows project to understand groundwater renewal.

Field methods that detect changes in flow between an aquifer and a stream over a long reach are more likely to be more helpful in detecting depletion from pumping than methods that focus on specific locations along a stream channel (Barlow and Leake, 2012). Streamflow measurements at river gauging station can be useful for detecting change in flow over time including streamflow depletion due to groundwater pumping. The estimation of streamflow depletion from streamflow measurements is complicated by several factors. First, the rate of depletion must be large enough to be detected by the stream gauging station, and should be significantly greater than the accuracy of the streamflow measurement, and second, the response time of stream flow depletion may be very long (Barlow and Leake, 2012). The tendency of the aquifer to delay and damp a particular pumping stress can make it extremely challenging, to differentiate streamflow depletion caused by pumping at a particular location from depletion caused by other short-term or long-term stresses to the aquifer (Barlow and Leake, 2012).. Such analyses require the use of analytical or numerical models (Barlow and Leake, 2012).

Analytical Modelling

Analytical modelling approach is one of the most widely applied method for estimating the effects of groundwater pumping on streamflow (Barlow and Leake, 2012). Analytical models offer an inexpensive way to estimate streamflow depletion due to groundwater pumping. However, they are limited to the analysis of idealized conditions in which many of the complexities of the real groundwater system are either ignored or approximated by use of simplifying assumptions. These simplifications typically include representation of the three-dimensional flow system by a one- or two-dimensional system, idealized boundary conditions such as perfectly straight streams, and homogeneous aquifer materials. Although these solutions are highly simplified, they can provide insight into the several factors that affect streamflow depletion and can be used as an initial estimate of the effects of a particular well on a nearby stream.

Several analytical solutions to the groundwater-flow equation have been developed to determine time-varying rates of streamflow depletion caused by pumping. Examples include STRMDEPL (Barlow, 2000) and its extension STRMDEPL08 (Reeves, 2008). The original program STRMDEPL incorporated solutions for a stream that fully penetrates the aquifer with and without streambed resistance to ground-water flow. In contrast, STRMDEPL08 includes solutions for a partially penetrating stream with streambed resistance and for a stream in an aquitard subjected to pumping from an underlying leaky aquifer.

Numerical Modelling

Numerical models provide the most robust approach for determining the rates, locations, and timing of streamflow depletion by wells (Barlow and Leake, 2012). Numerical methods replace the continuous problem represented by the partial differential equations into a finite set of points or volumes via mesh or grid. They transform the partial differential equations to algebraic equations. The groundwater-flow equation mathematically describes the distribution of hydraulic head throughout a groundwater system over time. The governing equations are formulated for each grid, element or volume and the distribution of heads and fluxes (water-balance components, including inflow to the aquifer, change in storage within the aquifer, and outflow from the aquifer). Numerical solutions are more powerful than analytical solutions in the sense that aquifers of any geometry can be analysed, and aquifer heterogeneities can be accommodated and allow complicated boundary and initial conditions to be included. In contrast, numerical models are capable of simulating fully three-dimensional flow in groundwater systems that are horizontally and vertically heterogeneous and have complex boundary conditions (Barlow and Leake, 2012). However, they are time-consuming and often require greater input data. The complexity of the site and data availability determines the time required for model development.

Ahlfeld et al. (2016) reported a very good example of using numerical groundwater simulation model for assessing the impact of groundwater pumping on streamflow depletion. The authors used numerical groundwater simulation model to understand the impact of groundwater pumping by the states of Kansas and Nebraska on streamflow in Beaver Creek in the Republican River Basin.

Groundwater allocations were made using MODFLOW model, and impacts are computed by comparing simulation model runs with and without groundwater pumping from individual states. It is presumed that the sum of streamflow depletions caused by each state is equal to depletion caused by both states pumping, simultaneously.

De Graaf et al. (2019) assessed e-flow limits to global groundwater pumping using physically based GSGM model consisting of the global hydrology and water-resources model PCR-GLOBWB and a two-layer global groundwater flow model based on MODFLOW. The authors estimated where and when environmentally critical streamflow will be reached because of groundwater pumping. They ran the GSGM model with past and future climate forcing (over 1960–2010 and 2011–2100, respectively); once with groundwater and surface water withdrawal and once without (a natural run). Environmentally critical streamflow is defined as the 90th percentile over five years (10% exceedance) of groundwater discharge.

2.6 APPROCHES FOR E-FLOW ASSESSMENT IN NON-PERENNIAL RIVERS

The hydrology of non-perennial rivers is significantly different from perennial rivers. Hence, the approaches developed for determining the e-flow requirements and applied for perennial systems may not be sufficient for non-perennial/ephemeral rivers (Hughes, 2005). The relationships between channel morphology and flow frequency in ephemeral rivers are far more complex than perennial rivers (Hughes, 2005). Perennial rivers are longitudinally continuous and explicitly represented by longitudinal continuum models, however, ephemeral rivers are longitudinally discontinuous at the surface when they are dry and characterized by isolated pools or ponds of standing water (Allen et al., 2020). According to Hughes (2005) the main challenge in e-flow estimation in ephemeral rivers is associated with the potentially discontinuous occurrence of flow in both time and space and the fact that static pools, as well as flowing water, may be of ecological importance. The location of surface water in pools during periods of no surface flow is difficult to predict (Seaman et al., 2010). The other challenge related to lack of clarity on the information required by ecological specialists to be able to determine e-flow in ephemeral rivers specifically related to isolated pools.

According to Seaman et al. (2010) there are six major challenges for determining e-flow in non-perennial rivers. These include: issues related to hydrological modelling, understanding pools, connectivity, groundwater surface water interactions, extrapolation of data and establishing reference conditions (Seaman et al., 2010). Non-perennial systems pose several challenges to hydrological modelling compared to perennial rivers (Seaman et al., 2010). This is because due to lack of rainfall and streamflow gauge sites within a catchment, uncertainty in model calibration due to poor quality and quantity of measured rainfall and runoff data, and poorly understood links between surface and ground water hydrology. The location, timing, and persistence of pool and their chemistry can be highly unpredictable (Seaman et al., 2010). Because of the poor coverage of flow gauging stations and uncertain nature of hydrological data for such systems, connectivity is not well recorded and cannot be simulated with great accuracy (Seaman et al., 2010).

Groundwater surface water interactions affect the occurrence of flow, the existence and persistence of the pools, and the amount of water stored in the alluvial material beneath and adjacent to the channel, but it is challenging and as well as uncertain to quantify groundwater surface water interaction in non-perennial rivers, and under such circumstances extrapolation of ecosystem attributes over long stretches of river is of uncertain (Seaman et al., 2010). Hence, generalization could not be possible, and our understanding remains at the level of individual sites where detailed investigation takes place. Establishing reference condition is difficult due to lack of recent and historical data confounded by an inability to gain a comprehensive understanding of the system through extrapolation from studied sites (Seaman et al., 2010).

Seaman et al. (2010) developed a prototype methodology for estimating e-flow requirements for non-perennial rivers. The methodology was tested in Seekoei River, tributary of the Orange River, South Africa. The method consists of 11 phases and 28 activities. Seventeen key indicators were used: three driving indicators: connectivity of surface water, floods for channel maintenance and sediment delivery and 14 responding indicators: pools, channel aquifer, riparian aquifer, water quality variable, riparian vegetation cover, aquatic/marginal vegetation, number of important invertebrate taxa, abundance of invertebrate pest taxa, status of indigenous fish community, abundance of exotic fish, terrestrial wildlife, contribution to parent river and a quantitative and a qualitative socioeconomic indicator. By selecting these indicators, it is possible to identify and represent the most important characteristics of non-perennial rivers and predict how each would respond to change in the catchment (Seaman et al., 2010).

For perennial rivers the normal procedure is to make use of a yield model that incorporates natural flows, reservoir storage, abstractions and return flows in a systems-type model operating on a monthly time step (Hughes, 2005). However, such models are not very useful for determining e-flow in ephemeral rivers largely due to the coarse temporal resolution or lack hydrological process representation specific to ephemeral rivers. Ephemeral rivers are characterized by short-duration events, and hence, monthly time step models have little value, in addition in many cases the resources required for daily models may be outside the scope of some e-flow determination studies (Hughes, 2005). In larger ephemeral or seasonal river systems, with alluvial aquifer may have substantial storage and this storage has to be satisfied before channel flow, generated upstream, can progress downstream, furthermore extensive abstractions from groundwater also reduce the inflow to pools or sub-surface channel material (Hughes, 2005).

Hughes (2005) used daily time step semi-distributed, Variable Time Interval (VTI) model (Hughes and Sami, 1994, Hughes, 1995) to simulate channel pool dynamics in a gauged basin (D1H004) located in the northern part of the Eastern Cape Province of South Africa. See the model structure in the annex section. The model contains routines that allow the effects of distributed small dams, as well as main channel dams, to be simulated. A small dummy 'dam' was used to simulate channel pools. Losses from this dummy 'dam' only occur through evaporation. In ephemeral rivers, the knowledge gap in groundwater surface water interaction complicates an understanding of the quantity and quality dynamics of static pools, as well as the duration of low flows after large flow events (Hughes, 2005).

Theodoropoulos et al. (2019) used hydrodynamic model named TELEMAC-2D v6.2 to predict the baseflow required to maintain disconnected pools of water during dry period. According to the authors the flow sequence in intermittent rivers can be classified into six: 1) flood (overbank) flows—with unusually high flow; 2) abundant riffles—in which the riverbed is fully covered with water (pools and riffles are fully connected); 3) connected pools— a pool-dominated state, in which pools are connected with flowing water; 4) disconnected pools—when pools are present but isolated; 5) subsurface flow (interflow)—in which the riverbed is dry but the hyporheic zone remains saturated, and 6) dry, with no flow either at the surface or in the hyporheic zone. The authors used four steps in their methodology: first, they estimated baseflow required to ensure adequate habitat suitability for multiple aquatic ecosystem components during the abundant-riffles state (step comparable to e-flow assessment in perennial rivers), second they estimated baseflow required to maintain disconnected pools of water during dry periods., third, they estimated the timing and duration of each aquatic state either using continuous on-site measurements or the application of hydrodynamic model in combination with historical hydrological information, and fourth they developed an intermittent river adapted annual e-flow regime based on the integration of steps described above.

Theodoropoulos et al. (2019) used discharge (Q) at the upstream boundary and water surface elevation (Z) at the downstream boundary based on a stage discharge curve developed using hydrological information from a permanent gauging station. The 2D hydrodynamic model was used to simulate water depths (D) and depth-averaged flow velocities (V) for various Q scenarios. Prior to use for scenario the 2D hydrodynamic model need to be properly calibrated by adjusting the manning's roughness coefficient (n) at different sections of the study reach. The approach proved to be useful in identifying isolated pool at different reach of the river section, but the authors acknowledged that their model lack representation of surface water groundwater interaction which is a major determinate of e-flows in intermittent rivers.

Aproaches to e-flow assessment in perennial and non-perennial systems considering groundwater

As the hydrology of the non-perennial rivers is significantly different from perennial rivers, the approaches developed for perennial rivers may have little significance. Groundwater is an important aspect needed to be included for e-flow estimation in non-perennial rivers (Avenant et al., 2014). As described before perennial rivers are longitudinally continuous, however, non-perennial/ ephemeral rivers are longitudinally discontinuous and characterized by isolated pools or ponds of standing water. Hence, the two system should be treated differently when it comes to e-flow assessment.

For perennial rivers there are standard procedure already developed for estimation of e-flow requirements. However, this approach focused mainly on baseflow and do not explicitly account the impact of groundwater pumping close to the riverbanks. Furthermore, the baseflow estimation is often carried out based on the digital filtering techniques and these techniques are not based on any real knowledge of the hydrological processes. Hence, it is important that the filter parameters constrained based on chemical and isotope tracing studies. The ideal approach for quantifying the regional impact of groundwater pumping on streamflow depletion is to use an integrated modelling approach and run the model with and without pumping effect. This enable assessment of streamflow depletion due to pumping. However, setting up integrated model is time consuming and require a lot of input data, which often difficult to find. On the other hand, analytical models offer an inexpensive way of streamflow depletion assessment due to groundwater pumping. The distance of the well from the stream, aquifer hydraulic properties and pumping time are the main factors affecting streamflow depletion. Due to their less data need, we planned to use analytical models to estimate streamflow depletion.

The following steps are proposed for inclusion of groundwater in e-flow assessment

- Conduct stable isotope analysis to determine the source of water for isolated pools in non-perennial /ephemeral rivers (applicable for non-perennial /ephemeral rivers). Groundwater displays marked temporal and spatial trends in isotopic and chemical signatures. Sources and flow pathways of groundwater-fed streams thus can be identified by comparing variations in the isotopic composition of source waters, with variability in groundwater-fed streams.
- Collect long –term hydro chemical or stable isotope sample covering both the wet and dry periods and determine baseflow separation experimentally by the use hydro chemical or stable isotope tracers. Then, determine baseflow filter parameter value that produce equivalent baseflow values determined experimentally (applicable for both perennial and non-perennial /ephemeral rivers).
- Apply analytical modelling approach at different river section preferably in different geological setting and assess the impact of groundwater pumping on streamflow depletion, reduction of baseflow discharge to the river and response time of streamflow depletion. Response of streamflow depletion is a function of pumping well distance from the riverbank (applicable for perennial rivers).
- If possible, apply integrated hydrological model to assess groundwater surface water interaction as well as to evaluate the regional impact of groundwater pumping on streamflow depletion. Calibrate the model using streamflow and groundwater level data and run the model with and without pumping scenarios (this approach is limited by data availability and is also time consuming and hence, may not be in the scope of the current project period).

2.7 DESCRIPTION OF FIELD SITES FOR DETAILED ASSESSMENTS

Two sites with relatively good groundwater data and information have been selected for detail assessment of the impact of groundwater depletion in stream flow, describing the groundwater surface water interactions and characterizing isolated pools of water. This may lead to the development of more comprehensive e-flow estimation approach. Figure 2.5 shows the location of these two sites (Shashe-Limpopo confluence on the main stem of Limpopo River and Groot Letaba River). Figure 2.6 shows the zoomed section of these two sites.

Each study site represents a different type of stream-aquifer system. The surface water specialist report (see the hydrology section) classified rivers at instream flow sites into three classes using CV-index (i.e. perennial, seasonal, and ephemeral). The CV index is computed as the sum of average of CVs of three months wet and three months dry seasons for both naturalized and present day flow based on Hughes and Hannart (2003). Rivers are classified as perennial when CV index is between 1 and 4, seasonal when CV index is 5 and ephemeral when CV index is between 6 and 9. Accordingly, the CV index for the Shashe-Limpopo confluence is found to be 9 for both naturalized and presented day flow, signifying ephemeral nature. For Letaba CV index is 3 and 4 for naturalized and present-day flow respectively, showing the perennial nature of the river.

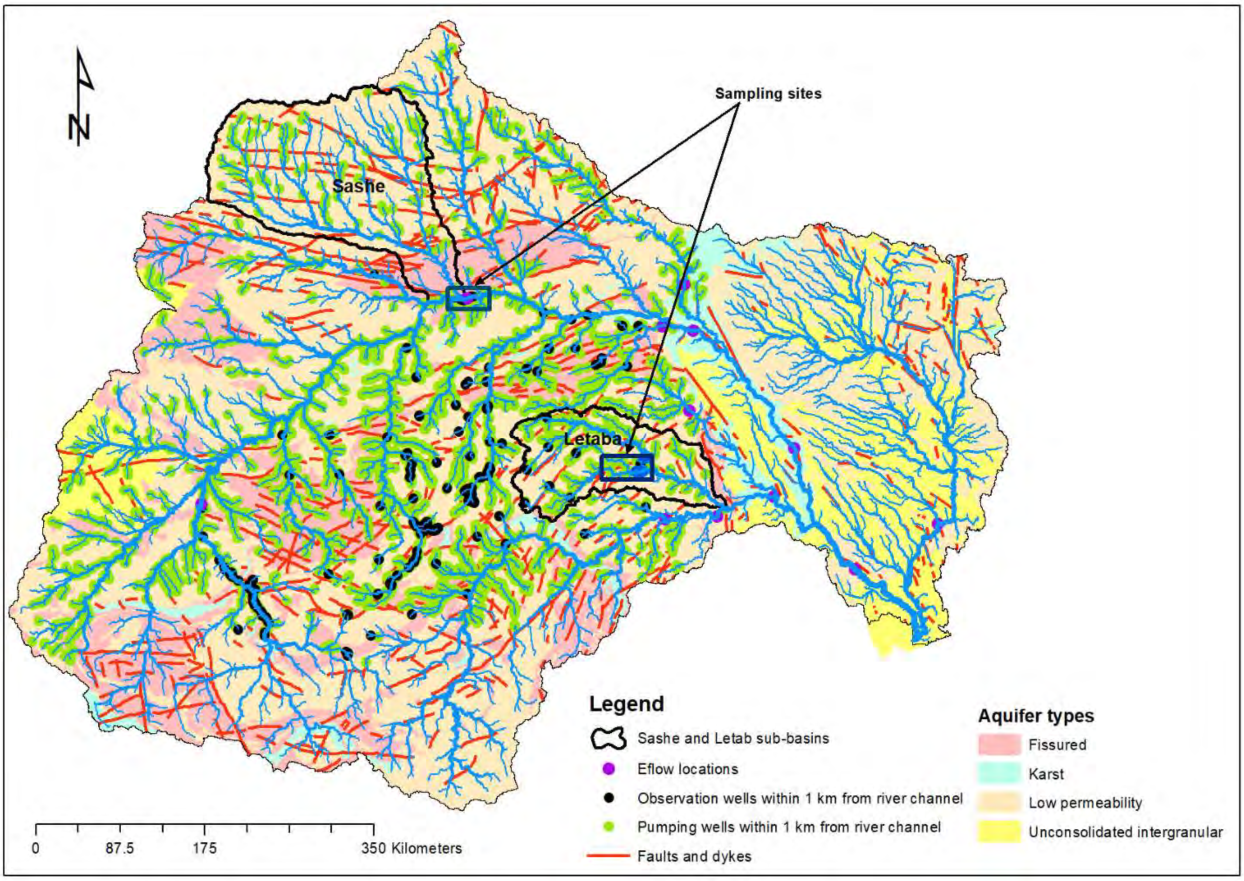

FIGURE 2.5: LOCATION OF STUDY SITES, AQUIFER TYPES, AND PUMPING AND OBSERVATION WELLS WITH IN 1KM OF THE RIVERS

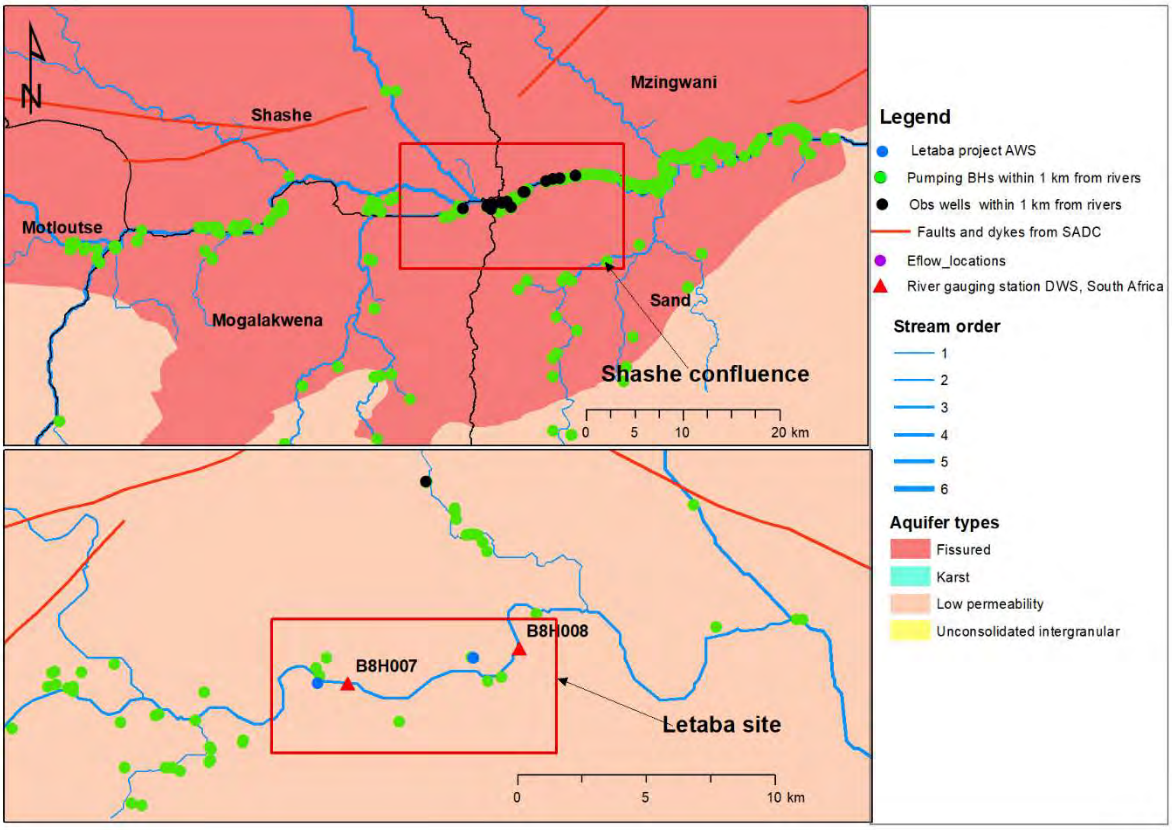

FIGURE 2.6: ZOOMED SECTIONS OF THE TWO STUDY SITES

Perennial site: Groot Letaba

The Letaba catchment covers an area of 13 700 km2. The selected reach is shown in Figure 2.7. We selected this reach because: (1) it has been studied previously during another groundwater surface water interaction-targeting project, 2) the river section is continuously monitored since 2015. Aquifer type at the site is characterized as low permeability aquifer. There are two river gauging station in the Great-Letaba River close to the selected site, namely BH8007 @ Mahale and BH8H008@ Letaba River. BH8007 has data for the period from 1956-05-01 to 1968-07-24 and BH8008 for the period 1959-09-14 to 2020-05-19. The BFI computed using Ebrahim and Villholth (2016) approach at BH8008 gauging station is found to be 0.29.

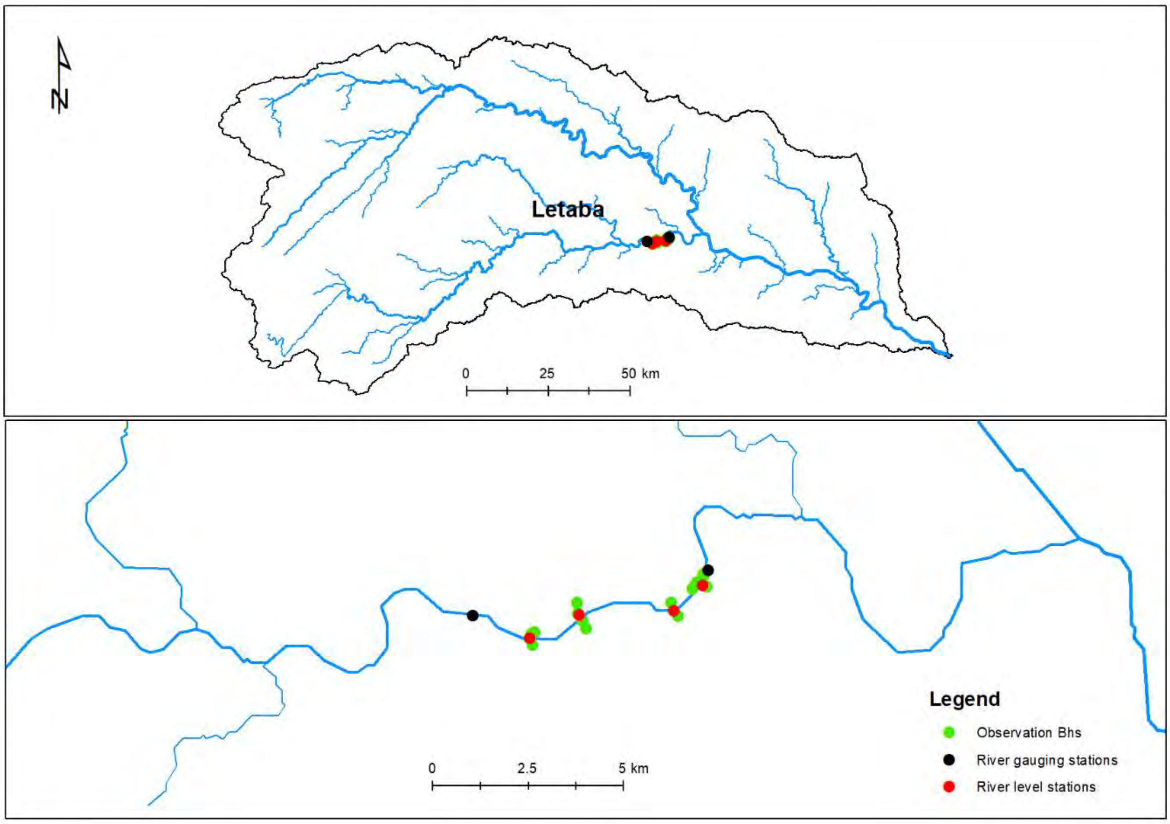

FIGURE 2.7: SITES ESTABLISHED BY SAEON (SOUTH AFRICAN ENVIRONMENTAL OBSERVATION NETWORK) AND USED IN WRC PROJECT

Non-perennial site: Shashe-Limpopo Confluence

As shown in Figure 2.7 the Limpopo River at the Shashe-Limpopo confluence is non-perennial/ephemeral. Alluvial aquifer along the river are extensively developed, having many boreholes along the shallow water strikes. Alluvial aquifers are the sources of most of the water pumped from wells in many region (Aller, 1991). Permeable sands and gravels can yield moderate to large water supplies to wells. Pumping from the alluvial aquifer adjacent to the stream may have fast and large impact on streamflow, whereas significant time lag may exist between pumping and streamflow impact in fractured rock aquifer (Gleeson and Richter, 2018). The depth to water table in the 11 observation wells located in the Southern African side of the river ranges from 2-10 m and the depth of these observation boreholes ranges from 16-42 m. See the annex section for the monthly groundwater level time series data available at the site. Typical photo of the Shashe-Limpopo confluence is shown in Figure 2.8.

For determination of groundwater storage in the alluvial aquifer estimate of aquifer thickness (i.e. saturated sand depth) is one of the critical parameters required. Methods of sand depth assessment include: trial pits, probing and geophysical surveys (Walker et al., 2018). Aquifer hydraulic conductivity estimation is another important parameter. Walker et al. (2018) used four different methods for estimation of hydraulic conductivity at Molototsi sand river, Limpopo, South Africa. These methods include test-pumping of the riverbed well, falling head permeameter tests, grain size analysis (also for porosity), and salt dilution tests. May be similar approach can be used to determine aquifer thickness and hydraulic conductivity for the Shashe-Limpopo confluence.

FIGURE 2.8: LIMPOPO RIVER CLOSE TO SHASHE-RIVER CONFLUENCE (PHOTO CREDITED TO RESGO MOKOMELA, AT MAPUNGUBWE NATIONAL PARK)

A FDC was constructed at Limpopo gauging station at Beit Bridge A7H004 and A7H008 (approximately 74 km from the Shashe-Limpopo confluence) using daily discharge data measured for the period 1955-1992 and 1992-2014, respectively (Figure 2.9). It is important to note that the available data regardless of years with missing data was used for FDC construction. Based on A7H004 flow data, 50% of the time, the flow in the river is equal or exceed 2.13 m^3/s and 95% of the time, flow in the river is equal to or exceeds 0 m^3/s. Similarly, A7H008 streamflow data results shows that 50% of the time the flow in the river is equal or exceed 1.26 m^3/s and 95% of the time, flow in the river is equal to or exceeds 0 m^3/s. Compared to the earlier period 50% exceedance shows significant reduction (about 40.85%, reduction). The BFI computed using Ebrahim and Villholth (2016) approach at the Biet Bridge (A7H008) is about 0.24.

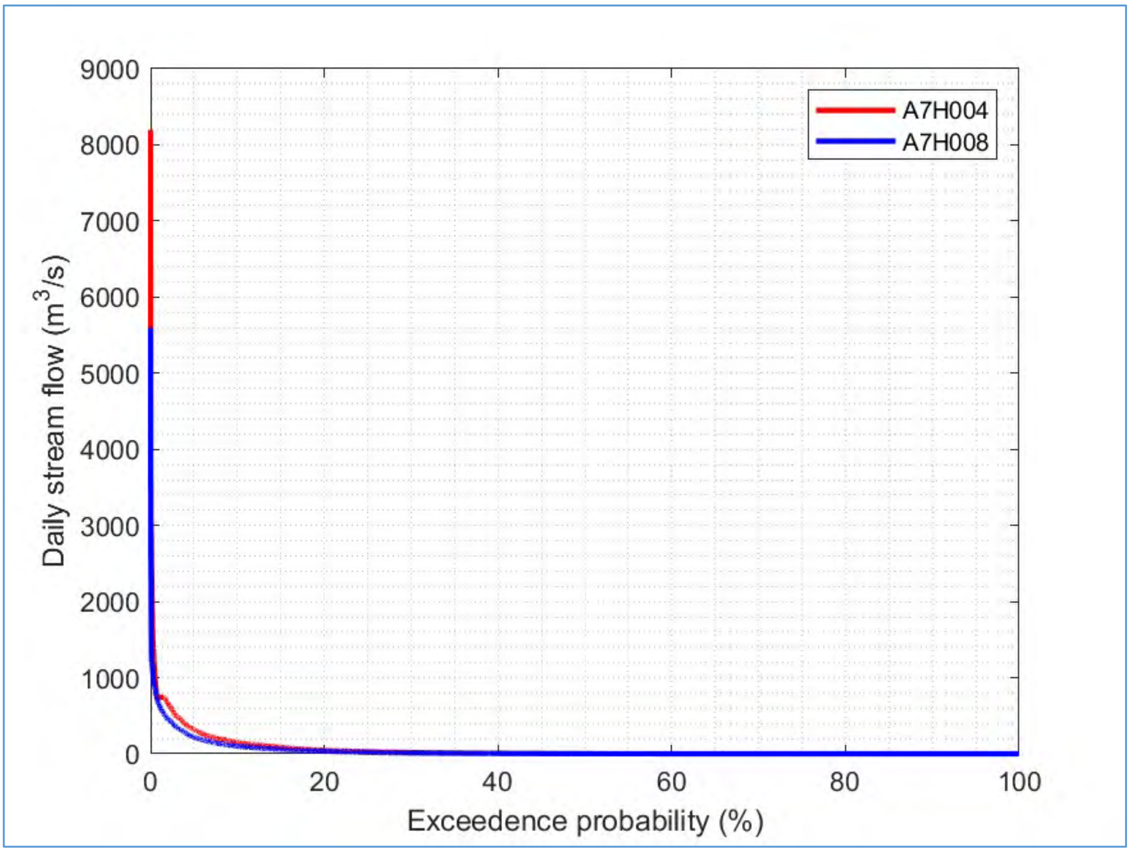

FIGURE 2.9: FLOW DURATION CURVE AT A7H004 AND A7H008 LIMPOPO GAUGING STATION @BEIT BRIDGE

2.8 UPSCALNG ASSESSMENT OF INTERACTIONS TO THE WHOLE BASIN

This section describes how we intend to upscale/extrapolate the knowledge gained in the experimental sites across the Limpopo River Basin. We also summarized the information need and required filed work to complement existing information.

Upscaling strategies

First, the knowledge in the source of water for isolated pools at the experimental sites based on stable isotope analysis can be used to generalize the source of water for isolated pools in the ephemeral rivers in the basin. Second, the baseflow filter parameters calibrated against chemical and isotope tracer can be transferred to other similar catchment and geological setting. Third, the information obtained from analytical modelling (i.e. streamflow depletion as a function of distance of pumping well from the riverbank) in selected river reach can be regionalized based on geology of the basin.

Missing information and planned field work

Some of the missing information and planned fieldwork activities are listed below:

- Estimate of existing individual well groundwater pumping
- Estimate of groundwater recharge (focused & diffuse) or renewal in perennial and non-perennial rivers and catchments
- Riverbed sediment thickness and vertical hydraulic conductivity

- Location, size of isolated pools in the selected sites (field survey is needed to locate these pools and map them)
- Chemical and isotope sample both in groundwater and river water including isolated pools. This may also include isotope sampling of rainwater
- Cross-section of the river channel at selected river reaches (using a differential GPS)
- Thickness of alluvial aquifer specifically at Sashe-Limpopo confluence. As demonstrated by Walker et al. (2018) trial pits can be dug in the river channel during dry period or geophysical surveys can be used.
- Seepage meter can be used to measure seepage across the streambed, by placing the seepage meter inside streambed. This can be used to validate groundwater-surface water interaction estimate

2.9 MODELLING

An improved understanding of streamflow depletion due to groundwater pumping in the Limpopo River Basin is needed to better estimate the effect of groundwater pumping on the natural river discharge, baseflow and riverine ecology. Streamflow depletion estimates often quantified using analytical and numerical modelling approach. Although the numerical modelling approach is more robust in terms of considering aquifer heterogeneity and complex boundary conditions, but they require significant amount of data and time. Hence, we will use the analytical modelling approach to evaluate streamflow depletion to various groundwater-pumping scenario. We choose the STRMDEPL08 (Reeves, 2008) analytical model, because it includes solutions for a partially penetrating stream with streambed resistance. We will use this modelling approach in perennial Letaba River. We will assess the response of streamflow depletion by varying the pumping well distance from the riverbank. Additionally, at the Letaba site we will assess groundwater surface water interaction based on groundwater level and stream stage data obtained from past studies at three river sections for the period of April 2015- June 2016. Results of the simulation of these scenarios, along with those of any future scenarios, will help water-resource planners develop management strategies to satisfy water supply needs while simultaneously maintaining flows to protect the river ecosystem.

At the Sashe-Limpopo confluence, since the river is ephemeral, streamflow depletion assessment may not be necessary as the river is dry most of the time. At this site isolated pools characterization may be more important from e-flow perspective. We still assessing the approach how to characterize isolated pools. What information is needed by the ecological specialist in relation to pool dynamics in the ephemeral rivers? Does the location of the pools is important or the size or its temporal dynamics (shrinking or expansion of the pools)? The ecological specialist needs to be consulted in this regard.

Data Requirements

Streamflow depletion models have three general data requirements: surface water data, groundwater abstraction data, and hydrogeological data (Huggins et al., 2018). Surface water data include the streamflow, stream widths, streambed properties, and streambed thickness. Well withdrawal data consist of well location, depth, pumping rates, and operation dates or schedules. Hydrogeological data consist of aquifer and subsurface properties such as hydraulic conductivity, aquifer thickness, transmissivity, storativity, and aquifer diffusivity. Aquifer properties can also be quantified with the parameter aquifer diffusivity, which is the ratio of transmissivity and storage.

2.10 ANTICIPATED RESULTS

Resolving uncertainties related to baseflow separation analysis provides an indication of the extent to which stream flows are dependent on groundwater. The recursive digital filter algorithm by Nathan and McMahon (1990) is the widely used filtering technique for separation of baseflow from the total stream flow. Since filtering techniques are generally not physically based, in their application, the selection of an appropriate filter parameter value is subject to a high degree of uncertainty. Therefore, to reduce this uncertainty an indirect evaluation of the filtering technique needs to be carried out against in-situ hydro-chemical and isotopic methods. The results of this analysis can be used to calibrate the baseflow filter parameter that can be applied in similar catchment characteristics.

Source identification of isolated pools in ephemeral rivers the source of water that form isolated pools in ephemeral rivers is largely unknown. This could be surface runoff or groundwater discharge or both. The use of tracers, based on stable isotopes of hydrogen and oxygen, is emerging as an effective means of identifying the sources of water. The technique is based on the premise that water from different sources (groundwater, stream water, rainwater) have different isotopic signatures. Each potential source of water is sampled, and its isotopic signature determined.

Rate of stream flow depletion due to groundwater pumping near riverbank reduces baseflow, which in turn may impact in-stream aquatic communities especially during dry seasons. Different approaches can be used to quantitatively express the effects of groundwater pumping on streamflow. The most common way to describe streamflow depletion is to report the change in the instantaneous flow rate of the stream, which is expressed in units of volume of streamflow per unit of time. A related approach is to report the rate of streamflow depletion as a fraction of the pumping rate of the well, which is a dimensionless quantity. Another approach is to describe cumulative (or total) volume of streamflow depletion that occurs over a specified period.

Response time of streamflow depletion there can be a significant delay between when a well begins to pump and when the impacts of that pumping are realized in nearby streams. These delays can range from days to decades, and hence, it is important to assess the response time of the impact of groundwater for meaningful e-flow assessment.

Determining local/reach scale groundwater surface water interaction while baseflow at given gauging station provide an estimate of groundwater contribution or cumulative groundwater discharge from all upstream phreatic aquifers along the river banks, groundwater surface water interaction assessment provides magnitude and direction of flux exchange at local or river reach scale. As indicated before understanding groundwater surface water interaction at local or reach scale helps to identify dominant groundwater discharge zones along the river reach, to evaluate the role of Hyporheic zone in reducing contaminant transport, and to characterize groundwater dependent aquatic habitats.

Other anticipated results may include:

- Spatial and temporal understanding of groundwater contribution to e-flow requirements. This include understanding of recharge/renewal from Chloride Mass Balance and Water Table fluctuations methods.
- Better understanding of impacts of pumping on e-flow requirements contributed by groundwater. This will include the position of a well away from the riverbanks to avoid huge impacts on subsurface flow in the river.
- Location of areas where there is groundwater contribution along the Limpopo basin – these can be areas with water pools during the dry season
- An understanding of how groundwater contributes to e-flow requirements in perennial and non-perennial rivers in the basin.

- Recommendation on groundwater-surface conjunctive use to ensure provision of e-flow requirements in the perennial and non-perennial rivers in the basin.

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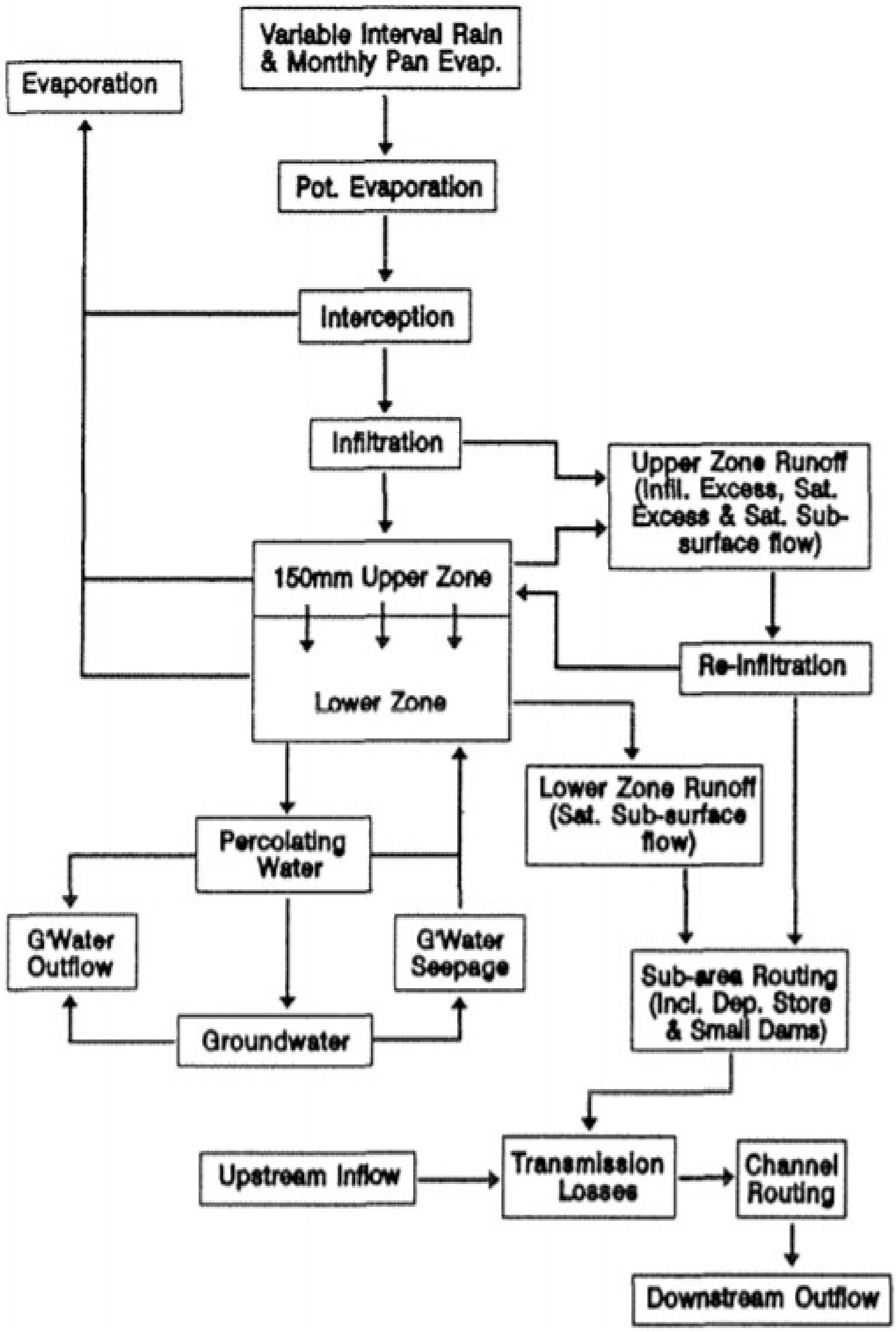
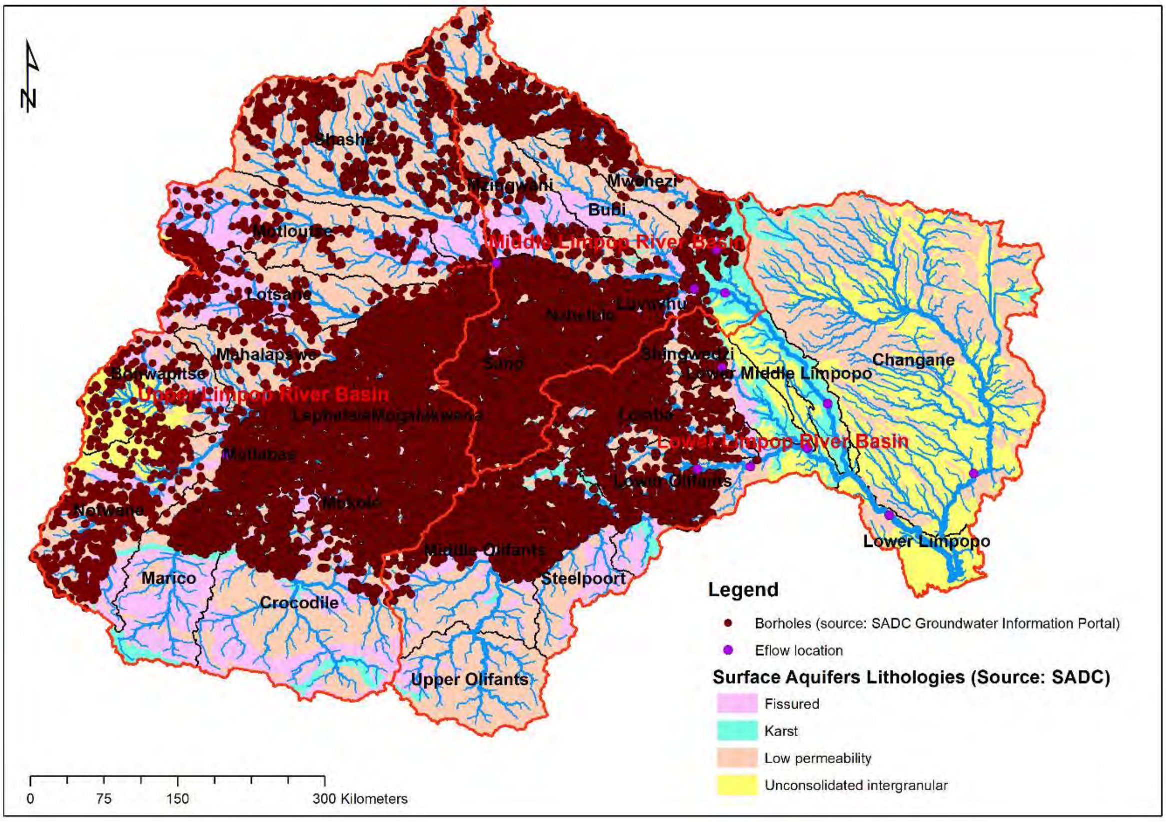
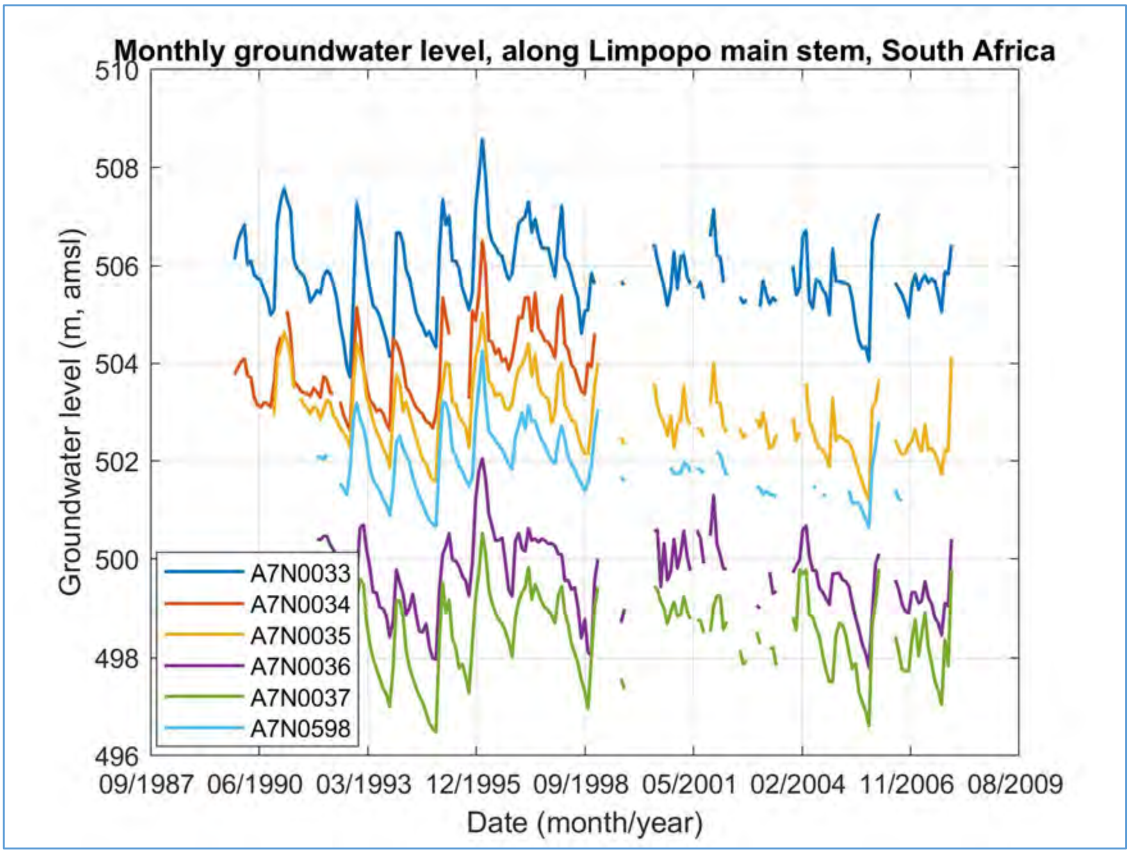
Annexure I



FLOW DIAGRAM FOR THE VARIABLE TIME INTERVAL (VTI) MODEL (SOURCE: HUGHES (1995))



ALL BOREHOLES IN LIMPOPO RIVER BASIN FROM SADC GROUNDWATER INFORMATION PORTAL



GROUNDWATER LEVEL TIME-SERIES ALONG THE MAIN STEM OF LIMPOPO-TULI KAROO AQUIFER

3 WATER QUALITY

3.1 BACKGROUIND, RATIONALE AND OBJECTIVES

Water quality can be defined as the combined effect on a 'user' of the physical attributes and chemical constituents of a waterbody or sample of water.

The idea of water "quality" is a human construct, implying value or usefulness, with the quality of any sample of water being dependent on the point of view of the 'user'. Water quality differs from continent to continent, and region to region, because of differences in climate, geomorphology, geology and soils, and biotic composition. The variables used to measure water quality can be grouped into three categories – physical, chemical, and microbiological.

In this overview of the water quality on the Limpopo River basin, the 2013 Limpopo Monograph study (Rossouw 2013) was used as the basis for identifying the historical data availability and the post 2013 water quality data. The focus of this report is on the major tributaries and at the selected sites on the mainstem Limpopo River as identified for the 2013 Monograph study. The available data for data analysis is provided as well as the other variables that may be of concern in the sub-basins and the mainstem river. These mainly relate to the presence of inorganic (metallic) and organic (pesticides, fertilizers, etc.) toxicants.

The objective of this report is therefore to provide a summary of the available data / information to undertake the e-flow water quality assessment, identify the data gaps and provide insight into the data analysis for inclusion into the conditional probability tables (CPTs) that are crucial to the development of the Bayesian risk model. The approach that will be followed is demonstrated using a case study for one of the sites.

3.2 WATER QUALITY ASESSMENT APPROACH APPROACH

Site selection

To allow for direct comparison, the sites selected for this study correspond with the 2013 Monograph water quality study sites. For the purposes of constructing the Bayesian Network models, the sites were further grouped into 11 risk regions based on several factors including land-use, hydrology, ecoregion level, etc. These risk regions together with the tributaries and position of the sites are presented in Table 3.1.

Assessment of water quality parameters

The assessment of the fitness of use for the water will be undertaken using the water quality criteria that was developed to for the 2013 Monograph study. The major categories of water use in the mainstem Limpopo River and the lower reaches of its tributaries were identified as potable water use, agricultural water use (including irrigation and livestock/wildlife watering and aquatic ecosystems. A generic classification scheme based on 'good - blue', 'tolerable - green', 'poor – amber and 'unsuitable - red' was developed for seven water quality parameters (Table 3.2).

TABLE 3.1: SUMMARY OF THE MAIN TRIBUTARIES PER RISK REGION THAT FORM PART OF THE WATER QUALITY ASSESSMENT FOR THE LIMPOPO BASIN E-FLOW STUDY

RISK REGIONS	MAJOR TRIBUTARIES	PLACE
RR1	Marico Crocodile (West) Ngotwane Mainstem	A3R004Q01at Molatedi Dam A2H128Q01at Leeudrift at weir Makgophana Bridge - confluence with Limpopo A5H006Q01at Sterkloop on the Botswana border
RR2	Matlabas Mokolo Lephalala Mogalakwena Motloutse	A4H004Q01at Haarlem East Confluence with Limpopo A4H013Q01at Moorddrift/Vught A5H008Q01at Ga-Seleka Village A6R009Q01at Leniesrus / Aden – A6R002Q01 Glen Alpine Dam Confluence with Limpopo
RR3	Shashe	Confluence with Limpopo
RR4	Umzingwani Sand Nzhelele Mainstem @ LmEWR02	BL8 (Zhove Dam) Confluence with Limpopo A8R001 at Nzhelele Dam Mapungubwe A7H008Q01at Beit Bridge
RR5	Luvuvhu Mainstem @ LmEWR04	A9H011Q01at Pafuri E-31 at Pafuri
RR6	Mwanedzi	Confluence with Limpopo
RR7	Olifants	B7H015Q01at Mamba
RR8	Letaba	B8H018Q01at Engelhardt Dam / KNP
RR9	Shingwedzi	B9H002Q01at Silvervis Dam/KNP
RR10	Elephantes Mainstem @ LmEWR05 Mainstem @ LmEWR07	E-546 d/s of Massingir Dam Confluence with Limpopo E-33 at Combumune Chokwe

Assessment of toxicants using a species sensitivity distribution approach

A species sensitivity distribution (SSD) is a probabilistic model for the variation of the sensitivity of biological species for one toxicant or a set of toxicants. The toxicity endpoint considered may be acute or chronic in nature. The models are probabilistic in that in its basic form the species sensitivity data are only analysed with regard to their statistical variability. The aim of an SSD analysis is to determine a chemical concentration protective of most species in the environment. Usually a point estimate known as the HC5 (hazardous concentration for 5% of species), or the 95% protection level (Van Straalen and Van Rijn 1998) is calculated. SSDs are constructed using a cumulative plot of logarithmically transformed toxicity endpoints (e.g. NOECs or LC50s) against rank assigned percentiles for each value to which a statistical distribution is fitted.

The level of protection chosen for deriving the guideline trigger levels for the Australian and New Zealand water quality guidelines, was protection of 95% of species with a 95% level of certainty, at least where there were sufficient data to satisfy the requirements of the method. The Dutch use a 95% level of protection with 50% certainty (95,50), whereas the Danish suggests a 95,95 approach. There will always be the criticism that 95% level of protection may not protect normal ecosystem functions and may not protect important or keystone species (ANZECC 2000). This type of criticism can be levelled at any approach. It can be overcome by increasing the level of protection to 99% but this would markedly increase the level of uncertainty in the tail of the distribution. For the purposes of this project, HC1 and HC5 with varying levels of certainty will be calculated for all the toxicants of concern, using both the acute (LC50) and chronic (EC50) data sets. For the purposes of this project the four fitness for use classes (Table 2) are allocated percentile hazard concentrations (HCp's), or conversely protection concentrations with different levels of certainty for each class. An example of the SSD for copper is presented in Figure 1. The SSD was used to calculate the cut-off values for each of the four fitness for use (i.e. risk classes) at the 95% certainty for HC1 and the 5%, 25% and 50% point-wise percentiles for HC5 were calculated using a bootstrap regression (501 iterations) with data superimposed (closed circles). The data used for the construction of the SSD are acute toxicity effect concentration (LC50) endpoints for copper, n=25, extracted from the USEPA Aquatic Toxicity Information Retrieval (ECOTOX) database. A brief summary of the selection of the different HCp's and corresponding fitness for use classes is given below:

- The 99% level with 50% certainty (HC1, 50) represents conditions in a "Good" class.
- The 95% level of protection and between 75 and 95% certainty (HC5, 5-25) represents a slightly modified class – "Tolerable" system. A 95% level of protection, should be sufficient to protect the ecosystem provided keystone species are considered (it should be emphasised that increasing the certainty level from 50% to 95%, i.e. 95,95 results in a condition which, in practice, would actually protect considerably more than 95% of species in most cases and frequently over 99%).
- The 95% level of protection and between 50 and 75% certainty (HC5, 25-50) represents a moderately modified class – "Poor" system.
- The 95% level of protection with less than 50% certainty (HC5,>50) represents an unacceptably modified class – "Unacceptable" system.

TABLE 3.2: FITNESS FOR USE BOUNDARY VALUES FOR SELECTED VARIABLES

Variable	Units	Good (Blue)	Tolerable (Green)	Poor (Amber)	Unacceptable (Red)	Sensitive user group
EC	mS/m	40	150	370	>370	Irrigation & Domestic
pH (lower)		6.5		<6.5		Domestic
pH (upper)		8.5		>8.5		Domestic
Fluoride	mg/l	0.7	1.0	1.5	>1.5	Domestic
Iron	mg/l	0.5	1.0	5.0	>5.0	Domestic
Sulphate	mg/l	200	400	600	>600	Domestic
Nitrate	mg/l	0.7	1.75	3.0	>3.0	Aquatic
Orthophosphate	mg/l	0.025	0.075	0.125	>0.125	Aquatic

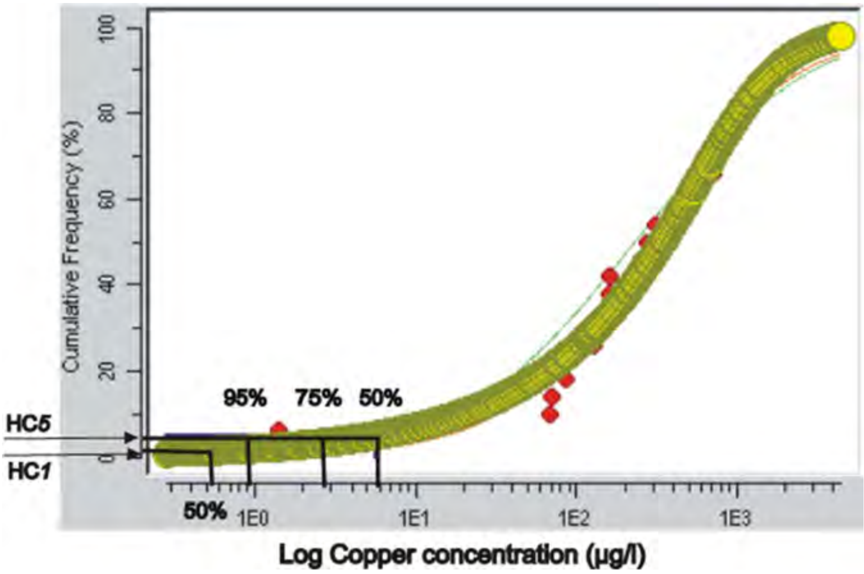


FIGURE 3.1: A SPECIES SENSITIVITY DISTRIBUTION (SSD) FOR COPPER WITH THE FOUR FITNESS-FOR-USE (RISK) CLASSES

The SSD-derived classes for two metals and two organochlorine pesticides are presented in Table 3.3. These four toxicants are to demonstrate the allocation of classes for the example case study for the assessment of classes. The classes will in turn provide the cut-off values that are applied in the CPTs of the Bayesian network risk model that is being developed to determine the e-flows of the Limpopo system.

TABLE 3.3. ASSESSMENT CLASSES FOR THE SELECTED TOXICANTS BASED ON HC'S AT DIFFERENT LEVELS OF CERTAINTY, DERIVED FROM SSD CURVES. CONCENTRATIONS IN µG/L.

Assessment Class		Good	Tolerable	Poor	Unacceptable	
Hazard concentrations		<HC*1* (50)	HC*5* (5-25)	HC*5* (25-50)	>HC*5* (50)	n
Copper	Acute	< 39.6	39.7 - 56.3	56.4 - 64.7	>64.7	38
	Chronic	< 1.9	2 - 3.5	3.6 - 8.4	>8.4	12
Zinc	Acute	<5	5.1 - 20.1	20.2 - 43.5	>43.5	37
	Chronic	<19.7	19.8 - 22.5	22.6 - 47	>47	5
DDT	Acute	< 0.3	0.03 - 0.37	0.37 - 0.52	0.52 - 0.63	29
	Chronic	Not enough data available				
Lindane	Acute	< 2.17	2.18 - 2.68	2.69 - 3.56	>3.56	29
	Chronic	Not enough data available				

3.3 AVAILABLE WATER QUALITY DATA FOR THE MAINSTEM LIMPOPO RIVER AND ITS MAJOR TRIBUTARIES

Mainstem Limpopo River

There are four monitoring sites in the mainstem of the Limpopo River in South Africa. These sites reflect the influence of the water quality of major tributaries on the Limpopo River. Water quality data are available for two of the sites. The summary water quality of these sites is presented in Tables 3.4 and 3.5 and trends are depicted in Figures 3.2 and 3.3.

TABLE 3.4. SUMMARY OF THE WATER QUALITY AT STERKLOOP FROM 1980 – 2018 (DOWNSTREAM OF THE CONFLUENCE OF THE MARICO AND CROCODILE RIVERS). DATA ARE EXPRESSED AS MEAN (MIN – MAX).

Site:	Limpopo River at Sterkloop
Site ID:	A5H006Q01
Sampling period	1980 - 2018
TDS mg/L	165 (46 - 539)
EC mS/m	25.8 (7.3 – 95.5)
pH	7.71 (6.15 – 8.71)
Na mg/L	20.4 (2.9 – 84.9)
Mg mg/L	9 (1.6 – 32)
Ca mg/L	14.8 (2.84 – 43.8)
K mg/L	3.02 (0.58 – 9.8)
F mg/L	0.28 (0.05 – 0.86)
Cl mg/L	27.1 (3.5 – 161)
SO_4^{2-} mg/L	16.6 (2 – 89.7)
TAL mg/L	68 (11.3 – 176)
NO_2 + NO_3 mg/L	0.082 (0.005 – 1.72)
PO_4^{2-} mg/L	0.015 (0.003 – 0.96)
Total P mg/L	0.092 (0.023 – 0.169)
NH_4 mg/L	0.0253 (0.02 – 0.4)

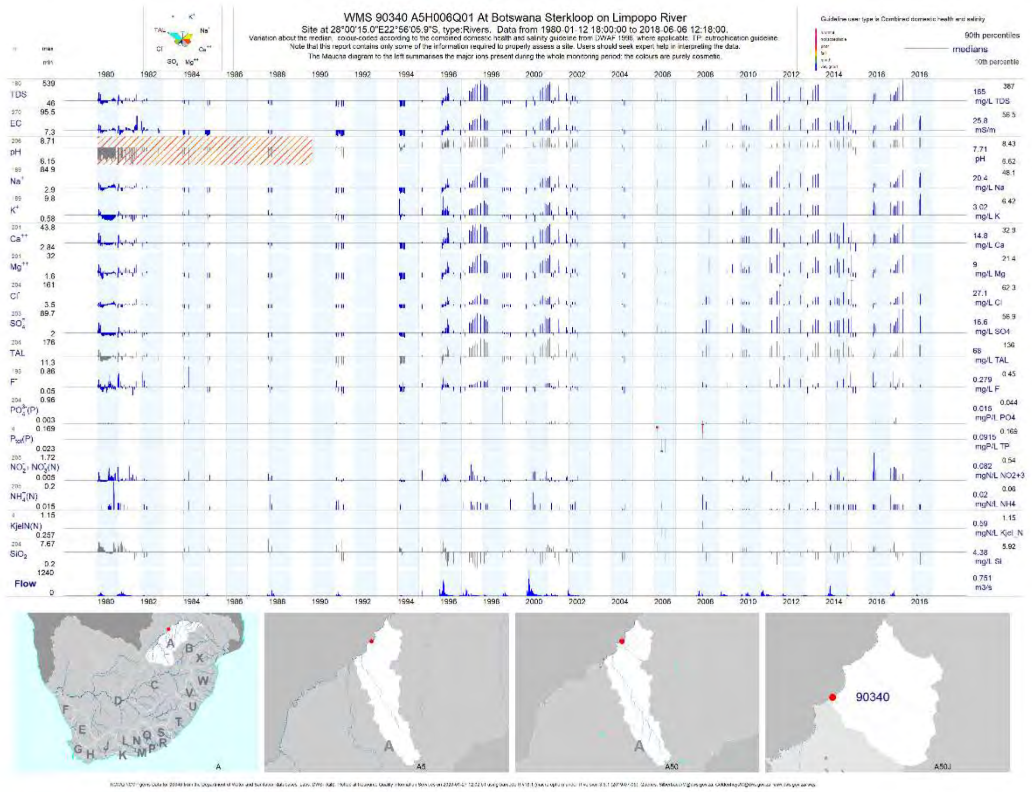


FIGURE 3.2. SUMMARY AND TIME SERIES OF WATER QUALITY DATA FOR THE LIMPOPO RIVER (A5H006Q01 AT STERKLOOP ON THE BOTSWANA BORDER).

TABLE 3.5. SUMMARY OF THE WATER QUALITY OF THE LIMPOPO RIVER DOWNSTREAM OF BEIT BRIDGE FROM 1993 - 2018. DATA ARE EXPRESSED AS MEAN (MIN – MAX).

Site	Limpopo River downstream of Beit Bridge
Site ID:	A7H008Q01
Sampling period	1993 - 2018
TDS mg/L	333 (44.2 - 920)
EC mS/m	55.8 (6.1 – 163)
pH	8.21 (7.03 – 9.5)
Na mg/L	46.7 (3.68 – 208)
Mg mg/L	16 (2.66 – 62.1)
Ca mg/L	31.3 (4.45 – 58.8)
K mg/L	5 (0.15 – 8.3)
F mg/L	0.3 (0.025 – 1.56)
Cl mg/L	69.1 (3.8 – 296)
SO_4^{2-} mg/L	34.2 (1.5 – 133)
TAL mg/L	122 (4 – 251)
$NO_2 + NO_3$ mg/L	0.05 (0.005 – 1.59)
PO_4^{2-} mg/L	0.027 (0.003 – 5)
Total P mg/L	0.2 (0.062 – 44)
NH_4 mg/L	0.05 (0.015 – 5)

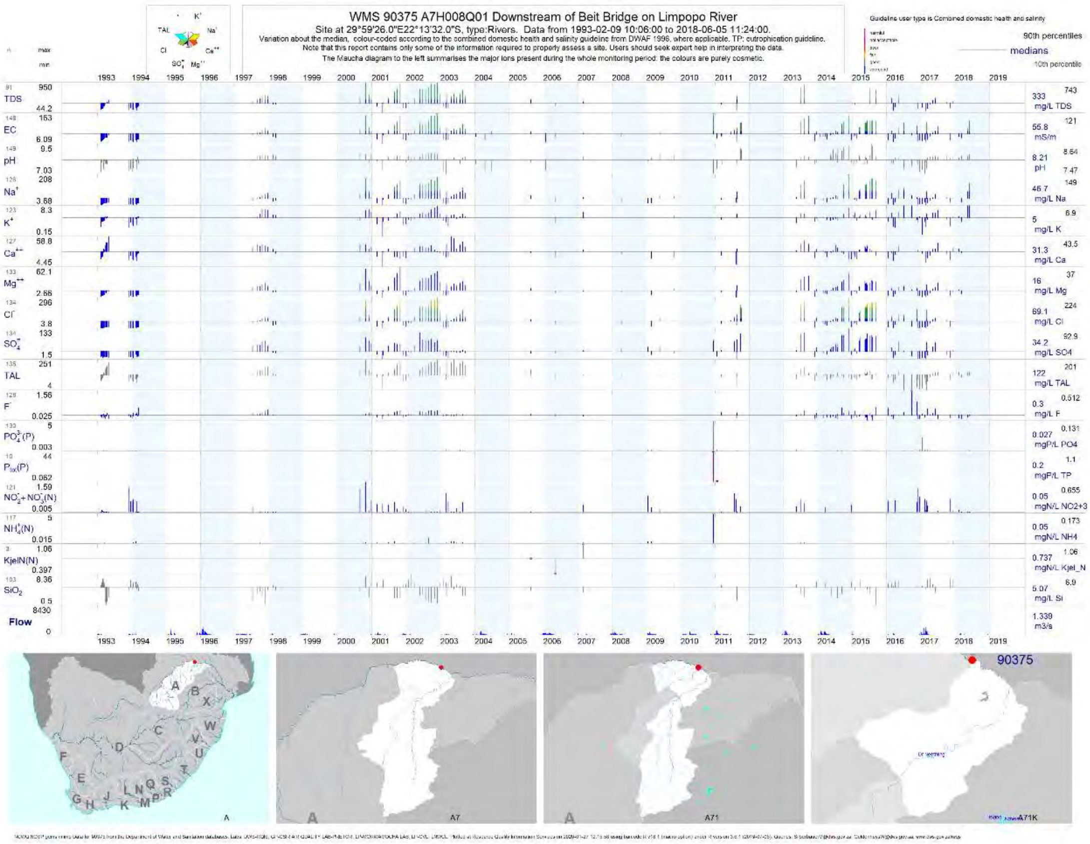


FIGURE 3.3. SUMMARY AND TIME SERIES OF WATER QUALITY DATA FOR THE LIMPOPO RIVER (A7H008Q01 DOWNSTREAM OF BEIT BRIDGE).

Marico River

The catchment of the Marico River is 13 208 km^2. The source of the Marico River is a large dolomitic spring near the Rustenburg area in the North West Province. The Marico River is regarded as an ideal reference system with minimal impact of anthropogenic activities (Kemp et al. 2017; Wolmarans et al. 2017). However, the water quality of two of its major tributaries, namely, the Klein Marico River and the Sterkstroom, is defined as 'fair' to 'poor' (RHP 2005). The Marico and has a diverse mineral-rich geological setting ranging from sandy loam in the south to clay loam in the northern parts (Du Preez et al. 2018). The river has stopped flowing in the low-flow seasons (June-November) with highest flows in the wet and high-flow season (December-May). The majority (95%) of the rainfall occurs between October and April.

Several dams also prevent the continual flow of water into the Limpopo River. This includes the Molatedi dam (201 million m^3) which supplies water to Gaborone, in Botswana. The Marico River also runs through the Marico Dam (27.0 million m^3). The main purpose of these dams was to store water for irrigation of surrounding agricultural areas. Other large dams on the Marico include Kromellenboog, Uitkyk, Klein-Marico, Sehujwane, and Madikwe.

Main sources of water quality disturbances are related to agricultural activities e.g. return flow during irrigation (Du Preez et al. 2018). Even though certain metal concentrations exceed water quality guidelines, they high levels are regarded to be natural due to the unique geology and lithology of the region (Kemp et al. 2017). A summary of the routine monitoring data is presented in Table 3.6 provides a summary of the main water quality variables and the time series data are presented graphically in Figure 3.4. Additional water quality and metal data are available in the references listed above. The resource quality objectives (RQOs) for Molatedi Dam are also provided (Government Gazette 2017).

TABLE 3.6. SUMMARY OF THE WATER QUALITY OF THE MARICO RIVER 1988 - 2017. DATA *ARE* EXPRESSED AS *MEAN (MIN – MAX)*. RESOURCE QUALITY OBJECTIVES (RQO'S) FOR MOLATEDI DAM ARE INDICATED.

Site	Marico River at Molatedi Dam near the dam wall	RQOs for Molatedi Dam
Site ID:	A3R004Q01	
Sampling period	1988 - 2017	
TDS mg/L	212 (94 – 448)	
EC mS/m	26.1 (11.8 - 57)	≤ 55 mS/m (95th percentile)
pH	8.25 (6.98 - 8.82)	6.5 - 9.0 (95th percentile)
Na mg/L	6.55 (2.1 – 20.1)	
Mg mg/L	16.1 (3.8 – 42.8)	
Ca mg/L	18.9 (6.1 – 34.5)	
K mg/L	5.58 (1.6 -11.2)	
F mg/L	0.34 (0.1 – 0.8)	
Cl mg/L	5.1 (1.5 – 16.5)	
SO_4^{2-} mg/L	9.3 (1.5 – 39.7)	
TAL mg/L	123 (49.3 – 245)	
NO_2 + NO_3 mg/L	0.084 (0.02 – 1.47)	≤ 0.7 mg/l (95th percentile)
PO_4^{2-} mg/L	0.015 (0.003 – 0.171)	≤ 0.015 mg/l (95th percentile)
Total P	4.263 (0.006 – 0.287)	≤ 0.055 mg/l (50th percentile)
NH_4 mg/L	0.025 (0.015 – 0.603)	

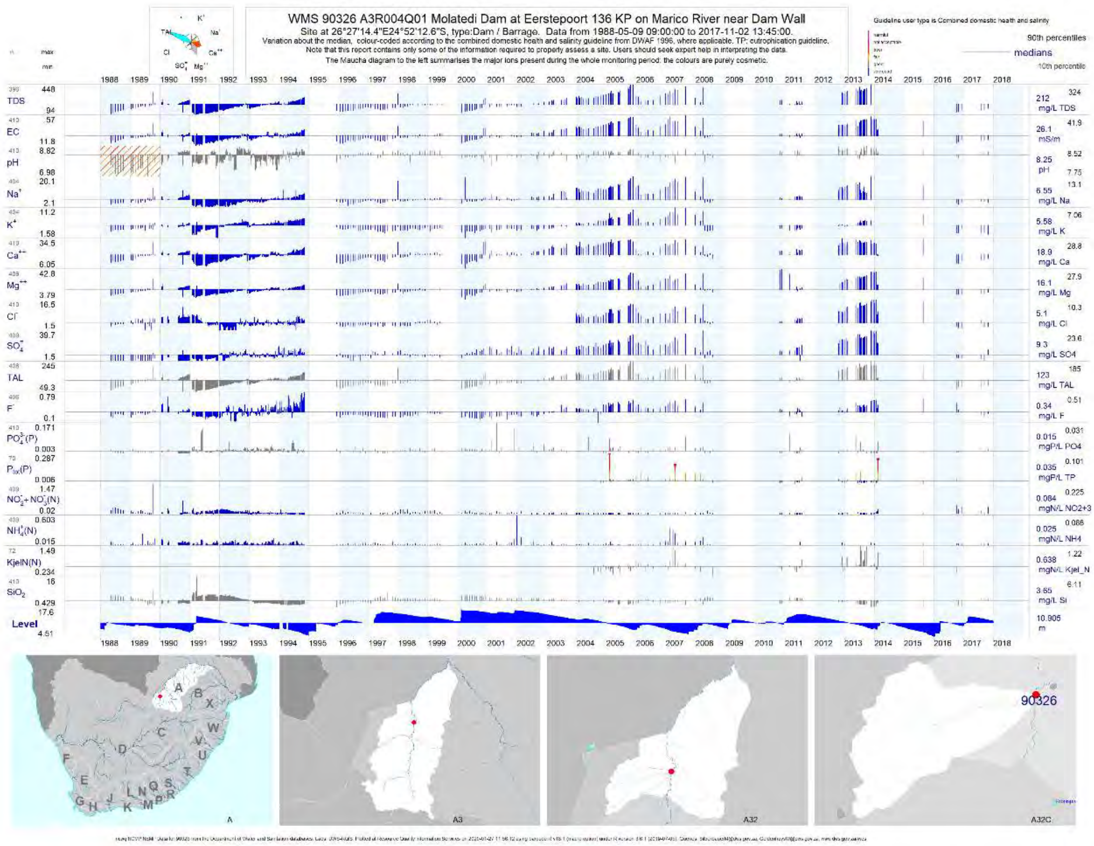


FIGURE 3.4 SUMMARY AND TIME SERIES OF WATER QUALITY DATA FOR THE MARICO RIVER (A3R004Q01 AT MOLATEDI DAM NEAR THE DAM WALL).

Crocodile River

The Crocodile River is one of the two main rivers tributaries of the Limpopo River. The Crocodile River originates in the Witwatersrand hills in the Gauteng province. The geological setting of the Crocodile River is very similar to that of the Marico River with sandy loam in the southern parts and deep clay loam in the northern parts closer to its confluent with the Limpopo River. The river then follows the course through three provinces (Gauteng, North West, and Limpopo) until it flows into the greater Limpopo River that forms the border between Botswana and South Africa. The river has a catchment area of 29 572 km^2 which is over twice as large as the Marico River. The Crocodile River is the tributary with second largest catchment area and has many human activities in its catchment area, which add to the pressures on the water quality. The high number of dams on the Crocodile River can prevent the continual flow of the river through the year especially in the dry and low-flow season (June-November). The large dams on the Crocodile River include Roodeplaat (41.2 million m^3). Vaalkop (56 million m^3). Roodekoppies (103 million m^3) and Klipvoor (42.1 million m^3) and in addition, the Hartebeespoort (186 million m^3). Many of the dams' face water quality problems (especially the Hartebeespoort Dam) and is mainly due to the water quality disturbances in the catchment area such as urbanisation industrial and mining activities (Walsh and Wepener 2009). Downstream of Hartbeespoort Dam, return flows from large-scale irrigation schemes influence the water quality (Du Preez et al. 2018) negatively. while large platinum and chromium smelter activities in the Rustenburg region has an impact on the water quality of the Hex River, a large tributary of the lower reaches of Crocodile River (Labuschagne et al. 2020). Table 3.7 provides a summary of the main water quality variables and the time series data are presented graphically in Figure 3.5. Additional water quality and metal data are available in the references listed above. The resource quality objectives (RQOs) for the lower Crocodile River are also provided (Government Gazette 2017).

TABLE 3.7. SUMMARY OF THE WATER QUALITY OF THE CROCODILE RIVER 2004 - 2018. DATA EXPRESSED AS MEAN (MIN – MAX). RESOURCE QUALITY OBJECTIVES (RQO'S) ARE INDICATED.

Site	Crocodile River at Leeudrift at weir	RQOs for the lower reaches of the Crocodile River (A24J)
Site ID:	A2H128Q01	
Sampling period	2004 - 2018	
TDS mg/L	525.7 (322.5 – 694.3)	
EC mS/m	74 (43.9 – 97.5)	≤ 85 mS/m mg/l (95th percentile)
pH	8.40 (6.58 – 9.04)	6.5 (5th percentile) - 8.5 (95th percentile)
Na mg/L	68.0 (37.6 – 96.1)	≤ 80 mg/l (95th percentile)
Mg mg/L	26.4 (15.4– 43.2)	
Ca mg/L	43 (26.2 – 70.9)	
K mg/L	8.2 (4.4 – 10.1)	
F mg/L	0.47 (0.21– 1.64)	
Cl mg/L	87 (40 – 144.6)	≤ 100 mg/l (95th percentile)
SO_4^{2-} mg/L	73.1 (41.7 – 167.7)	≤ 100 mg/l (95th percentile)
TAL mg/L	173.9 (102.7 – 243.6)	
$NO_2 + NO_3$ mg/L	0.94 (0.025 – 3.87)	≤ 1.0 mg/l (50th percentile)
PO_4^{2-} mg/L	0.105 (0.005 – 0.442)	≤ 0.06 mg/l (50th percentile)
NH_4 mg/L	0.053 (0.015 – 0.295)	
Turbidity		10% variation from background levels
Escherichia coli (*E.coli*)		130 counts/100 ml (95th percentile)
Atrazine		≤ 0.078 mg/l

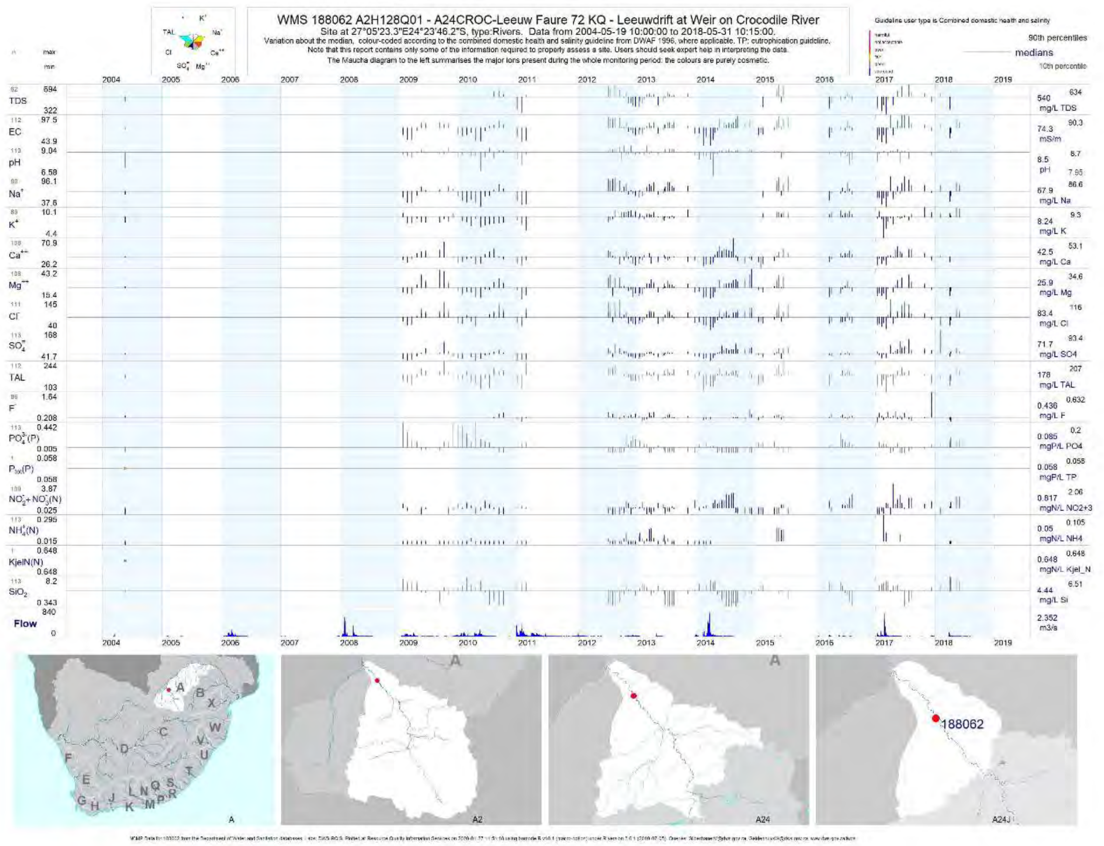


FIGURE 3.5. SUMMARY AND TIME SERIES OF WATER QUALITY DATA FOR THE CROCODILE RIVER (A2H128Q01 – AT LEEUDRIFT).

Matlabas River

The Matlabas River is a relatively small tributary of the Limpopo River compared to the Marico and Crocodile Rivers with a catchment size of 3 448 km^2. This makes the catchment 1.4% of the entire Limpopo basin. Although this catchment is smaller, it has some unique characteristics as it contains some of the most pristine mires and peatlands in South Africa. The Matlabas River flows through the Marakele National Park, which is part of the Central Highlands Peatland Eco-Region. The Matlabas River is ephemeral due to frequent dry spells and a high number of dams prevent this. In addition, the peat also absorbs a lot of water and thus for the river to flow, rainfall needs to exceed peat infiltration capacity (Bootsma et al. 2019). The main geological setting of the Matlabas River is underlain sandstone bedrock, which is due to the Matlabas Subgroup in the Waterberg Supergroup that include shale and mudstone. Main water quality disturbances include erosion and interrupted flow of the river resulting in small dams and sections in the river. The Matlabas River has the least amount of development on it when compared to the other tributaries, which minimizes the anthropogenic effects on the river. Table 3.8 provides a summary of the main water quality variables and the time series data are presented graphically in Figure 3.6. Additional water quality and metal data are available in the references listed above.

TABLE 3.8. SUMMARY OF THE WATER QUALITY OF THE MATLABAS RIVER 1971 - 2018. DATA *ARE* EXPRESSED AS MEAN (MIN – MAX).

Site	Matlabas River at Haarlem East
Site ID:	A4H004Q01
Sampling period	1971 - 2018
TDS mg/L	36.7 (9 - 406)
EC mS/m	5.4 (1.5 – 58.6)
pH	7.13 (4.43 – 8.48)
Na mg/L	3.5 (0.22 – 94.7)
Mg mg/L	1.6 (0.47 – 13.3)
Ca mg/L	2.9 (0.5 – 10.8)
K mg/L	0.6 (0.15 – 4.66)
F mg/L	0.1 (0.025 – 0.67)
Cl mg/L	5 (1.5 – 87.9)
SO_4^{2-} mg/L	2 (0.6 - 13)
TAL mg/L	16.7 (2 – 152)
NO_2 + NO_3 mg/L	0.02 (0.02 – 1.4)
PO_4^{2-} mg/L	0.01 (0.003 – 0.181)
NH_4 mg/L	0.0253 (0.02 – 0.4)

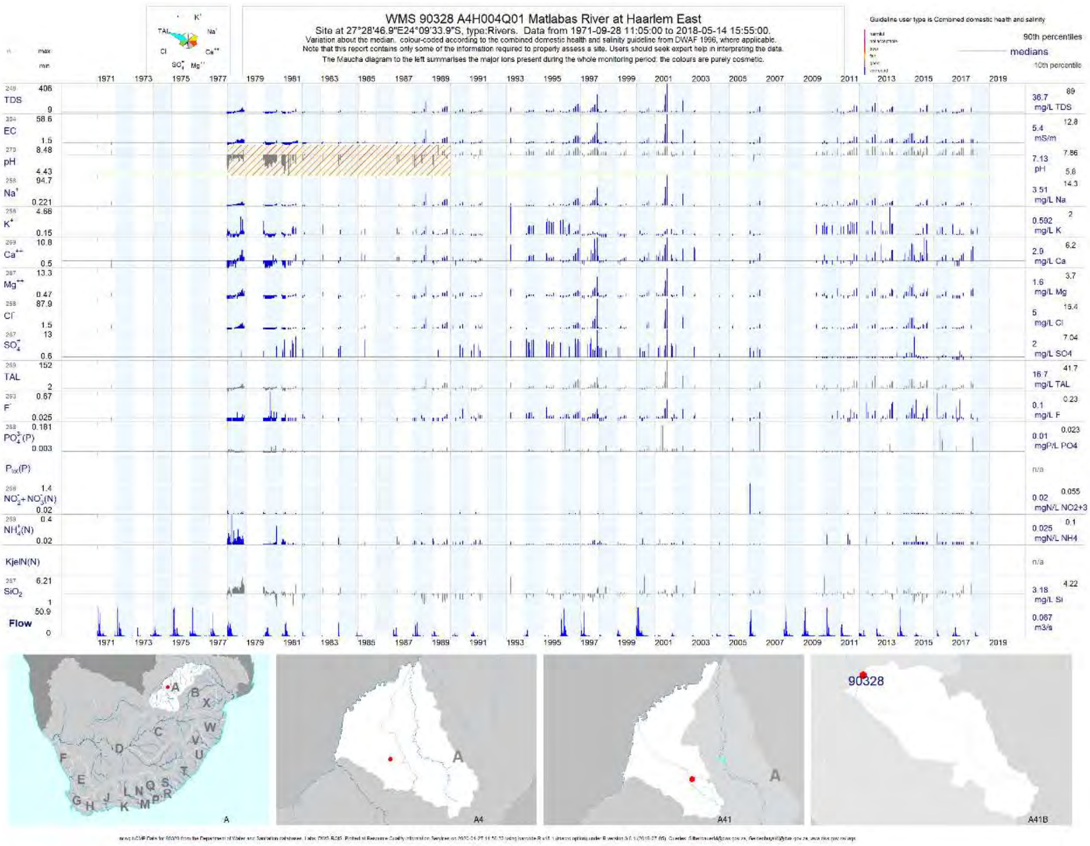


FIGURE 3.6. SUMMARY AND TIME SERIES OF WATER QUALITY DATA FOR THE MATLABAS RIVER (A4H004Q011 – AT HAARLEM EAST).

Mokolo River

The Mokolo River flows through the Waterberg region in the Limpopo Province. The Mokolo River collects much of the drainage of the Waterberg Massif, which it then discharges, into the Limpopo River. The Mokolo River originates at the confluence of the Sand River and the Grootspruit River and has a catchment size of 7 616 km^2. Other tributaries of the Mokolo include Klein Sand River, Sandspruit, Sondagsloop, Loubadspruit, Sterkstroom, Brakspruit, Malmanies, Bulspruit, Rietspruit, Sandloop, Poer se Loop and the Tambotie River. The Mokolo Dam is the only large dam on the system. Some development along the catchment has resulted in mining activities, two power stations, agriculture in the northern reaches and game farming. These are the main contributors to water quality disturbances on the river along with intensive in-stream sand mining (De Klerk et al. 2016). These authors also found that pH is a very important variable to monitor and manage within the Mokolo River due to the knock-on effect it may have on, inter alia, metal pollution and nutrient enrichment. Other parameters of significance were alkalinity and sulphate levels. The geological setting of the Mokolo River ranges from extensive rock formation through lowveld areas with deep sand beds that are intensely mined. The Mokolo River tends to flood in the high-flow season where the major flooding areas are downstream from the Mokolo Dam, which leads into the Mokolo floodplains.

The main water quality disturbances are agricultural irrigation, which make up 87% of the water use in the catchment. The other contributors to water quality disturbances are industrial, mining, power generation, domestic water supply and alien invasive species. Recently, Mogashane et al. (2020) recorded high levels of polycyclic aromatic hydrocarbons in sediments of the upper reaches of the Mokolo River. Table 3.9 provides a summary of the main water quality variables and the time series data are presented graphically in Figure 3.7. Additional water quality and metal data are available in the references listed above. The resource quality objectives (RQOs) for the lower Mokolo River are also provided (Government Gazette 2017).

Lephalale River

The Lephalale River also known as the Palala River is a smaller tributary of the Limpopo River with a catchment size of 4 868 km^2. The Lephalale River originates in the Limpopo Province and has a significant role in providing water resources to much of the Lephalale Wilderness. The geological setting is mostly rocky crustal formations from the base of the Waterberg. The surrounding rock bed is rich in minerals and is referred to as the Bushveld igneous complex and Waterberg Supergroup. The Lephalale River is less developed along the catchment resulting in less anthropogenic disturbances for water quality. The Lephalale municipality however does permit extractive mining to occur along with agricultural and residential usage of the resources making water quality disturbing factors like the other tributaries in the area. Table 3.10 provides a summary of the main water quality variables and the time series data are presented graphically in Figure 3.8. Additional water quality and metal data are available in the references listed above.

TABLE 3.9. SUMMARY OF THE WATER QUALITY OF THE CROCODILE RIVER 2004 - 2018. DATA EXPRESSED AS MEAN (MIN – MAX). RESOURCE QUALITY OBJECTIVES (RQO'S) INDICATED.

Site	Mokolo River at Moorddrift/Vught	RQOs for the lower reaches of the Mokolo River (A42H&J)
Site ID:	A4H013Q01	
Sampling period	1994 - 2018	
TDS mg/L	58.6 (35.3 – 364)	
EC mS/m	8.8 (5.5 – 52.5)	≤ 30 mS/m mg/l (95th percentile)
pH	7.5 (6.87 – 8.41)	6.5 (5th percentile) - 8.5 (95th percentile)
Na mg/L	6.65 (3.2 – 52.9)	≤ 20 mg/l (95th percentile)
Mg mg/L	2.5 (0.75 – 24.2)	
Ca mg/L	4.44 (1.25 – 77)	
K mg/L	1.13 (0.32 – 4.95)	
F mg/L	0.13 (0.025 – 0.592)	
Cl mg/L	87 (3.7 – 118)	
SO_4^{2-} mg/L	3.4 (0.6 – 30.4)	≤ 20 mg/l (95th percentile)
TAL mg/L	23.4 (5 – 176)	
NO_2 + NO_3 mg/L	0.02 (0.02 – 2.1)	≤ 0.05 mg/l (50th percentile)
PO_4^{2-} mg/L	0.011 (0.003 – 0.114)	≤ 0.01 mg/l (50th percentile)
NH_4 mg/L	0.02 (0.02 – 0.729)	
Turbidity		10% variation from background levels
Atrazine		≤ 0.078 mg/l
Aluminium		≤ 0.062 mg/l (95th percentile)
Manganese		≤ 0.15 mg/l (95th percentile)
Iron		≤ 0.1 mg/l (95th percentile)
Lead (hard water)		≤ 0.0057 mg/l (95th percentile)
Copper		≤ 0.0048 mg/l (95th percentile)
Nickel		≤ 0.07 mg/l (95th percentile)
Cobalt		≤ 0.05 mg/l (95th percentile)
Zinc		≤ 0.002 mg/l (95th percentile)

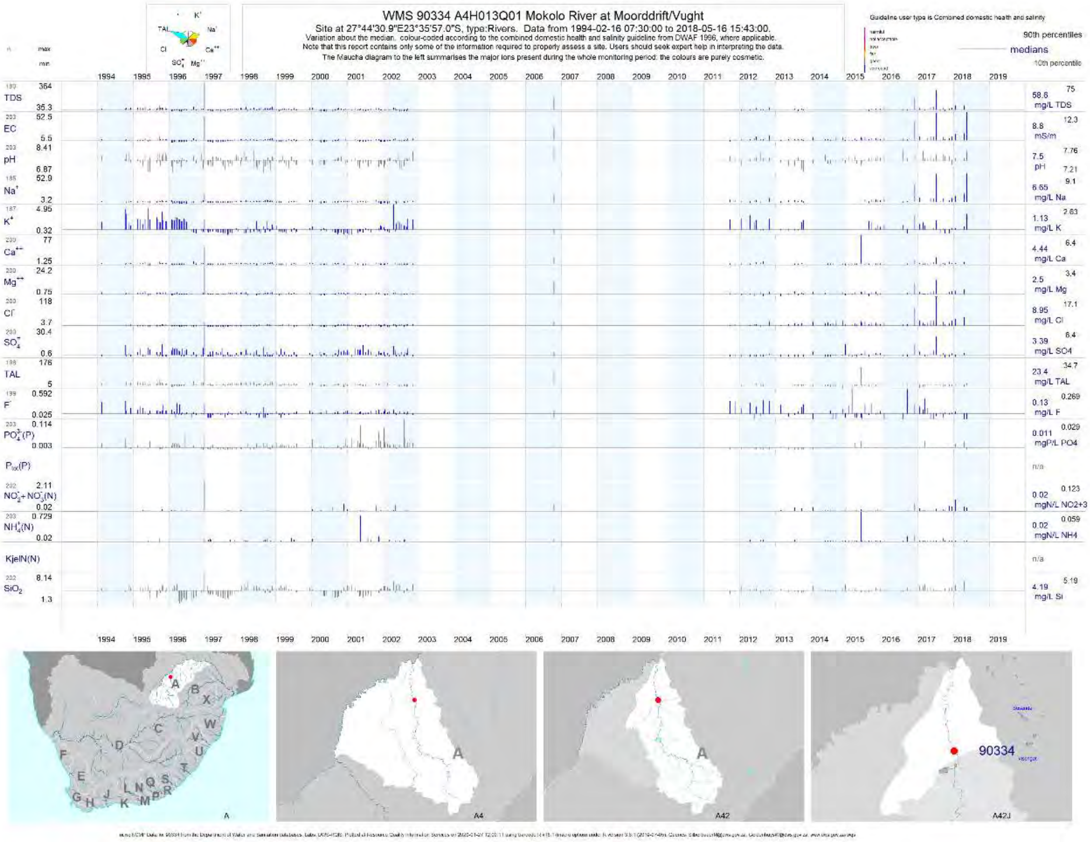


FIGURE 3.7. SUMMARY AND TIME SERIES OF WATER QUALITY DATA FOR THE MOKOLO RIVER (A4H013Q01 – AT MOORDRIFT/FUGHT).

TABLE 3.10. SUMMARY OF THE WATER QUALITY OF THE LEPHALALA RIVER 1971 - 2018. DATA *ARE* EXPRESSED AS *MEAN* (*MIN – MAX*).

Site	Lephalale River at Ga-Seleka Village
Site ID:	A5H008Q01
Sampling period	1995 - 2018
TDS mg/L	72.4 (14 - 343)
EC mS/m	11.2 (2.7 – 54.5)
pH	7.7 (error – 9.17)
Na mg/L	8.3 (1 – 54.2)
Mg mg/L	3 (0.5 – 15.4)
Ca mg/L	6.4 (1.4 – 37.3)
K mg/L	1.02 (0.15 – 6.71)
F mg/L	0.15 (0.025 – 0.612)
Cl mg/L	12.1 (3.2 – 230)
SO_4^{2-} mg/L	6 (0.44 - 450)
TAL mg/L	28.1 (4 – 134)
NO_2 + NO_3 mg/L	0.218 (0.02 – 6.01)
PO_4^{2-} mg/L	0.02 (0.005 – 6.6)
NH_4 mg/L	0.02 (0.015 – 3)

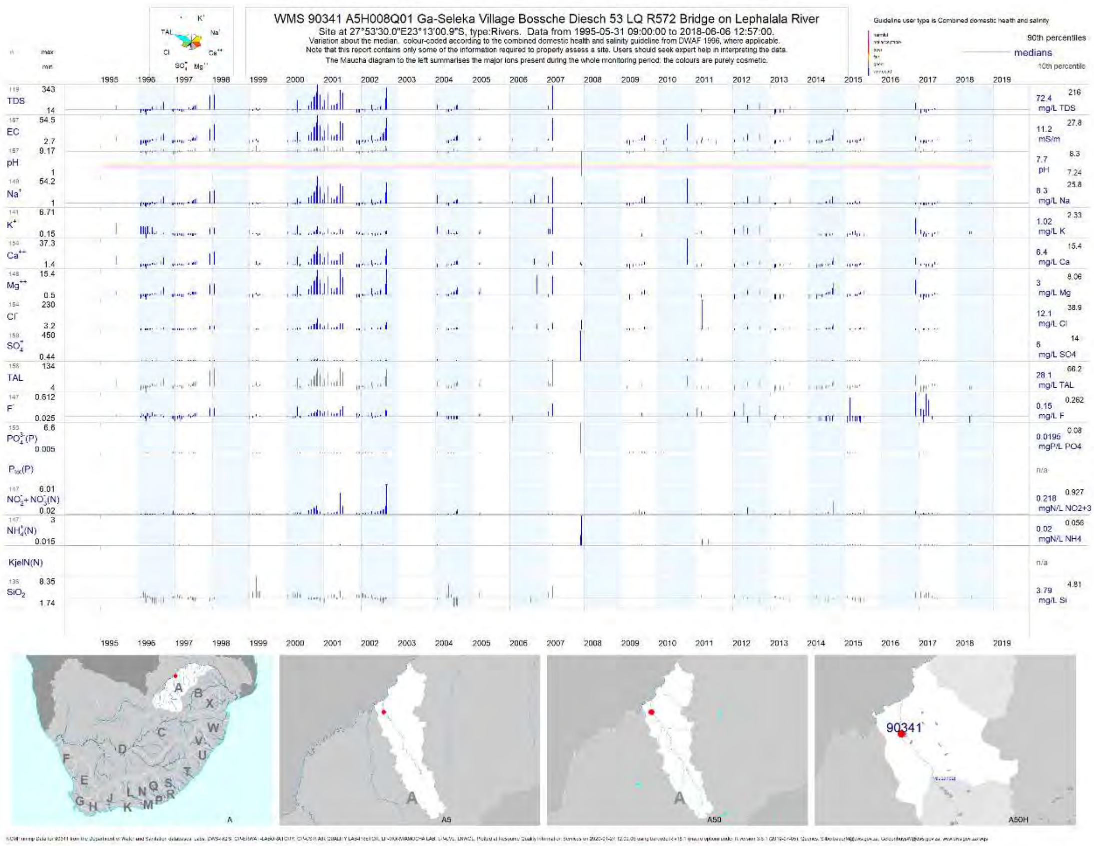


FIGURE 3.8. SUMMARY AND TIME SERIES OF WATER QUALITY DATA FOR THE LEPHALALA RIVER (A5H008Q01 AT GA-SELEKA VILLAGE).

Rivers in Botswana

The 2013 Monograph study concluded that the sub-basins of rivers from Botswana were not likely to contribute significantly to the water quality of the Limpopo River. Since 2013, there were no published water quality data for the four river systems from Botswana. The water quality reported by Rossouw (2013) remain the only available data for these systems (Table 3.11).

TABLE 3.11. WATER QUALITY DATA OF SUB-BASINS IN BOTSWANA. DATA ARE 75TH PERCENTILES.

Sub-basin	Station	EC	pH	pH	F	Fe	SO_4^{-2}	PO_4^{-2}	NO_3^-
		mS/m	Lower	Upper	mg/l	mg/l	mg/l	mg/l	mg/l
Notwane	Makgophana Bridge	71.0	6.94	7.35	0.79	1.78	28.06	11.41	65.42
Mahalapye	All points	38.0	7.03	7.60	0.27	0.54	9.0	4.20	13.40
Motloutse	All points	138.0	6.73	8.38	0.09	0.35	529.34	0.000	21.27
Letlakane	All	338.7	6.95	7.33	2.0	1.86	238.00	0.50	105.92

Rivers in Zimbabwe

Similar to the Botswana sub-basins no new water quality data could be sourced following the 2013 Limpopo Monograph study.

TABLE 3.12. WATER QUALITY DATA OF FOUR SUB-BASINS IN ZIMBABWE. DATA 75TH PERCENTILES.

Sub-basin	Station	EC	pH	pH	F	Fe	SO_4^{-2}	PO_4^{-2}	NO_3^-
		mS/m	Lower	Upper	mg/l	mg/l	mg/l	mg/l	mg/l
Mzingwane (lower)	BL8 (Zhove Dam)	23.3	7.74	8.06	No data	0.113	21.5	0.056	0.111
Mtshabezi	BR15	19.2	7.3	7.74		0.28	19	0.04	0.22
Shashe	At confluence	No data							

Luvuvhu River

The Luvuvhu River is located in the extreme north-eastern corner of South Africa (Kleynhans 1996) covering an area of 5 941 km2 (Singo et al. 2012) and flows for about 200 km through a diverse range of landscapes before it joins the Limpopo River near Pafuri in the Kruger National Park (Kleynhans 1996; Odiyo et al. 2014). This catchment receives one cycle rainfall that occurs in the upper reaches and extends from October of the previous year ending in April of the following year, with a little rainfall in the lower reaches around the KNP and the dry season from May to September (Singo et al. 2012; Odiyo et al. 2014).

The land-use activities include commercial forestry (exotic tree plantations of pine and eucalyptus), agriculture, conservation areas and urban (Odiyo et al. 2014). Poor agricultural practices, urbanization and the pollutants have been threatening the suitability and /or deteriorating the water quality in the catchment, becoming an environmental challenge in the catchment (Bapela 2001; Gumbo et al. 2016). Mining in the tributaries of the Luvuvhu River (i.e. the Mutale River) results in metal contamination (Gerber et al. 2015). Gerber et al. (2016) have also recorded the highest levels in South Africa of the malaria vector-control organochlorine pesticide, DDT in sediment and fish of the system. Table 3.13 provides a summary of the main water quality variables and the time series data are presented graphically in Figure 3.9. Additional water quality and metal data are available in the references listed above.

TABLE 3.13. SUMMARY OF THE WATER QUALITY OF THE LUVUVHU RIVER 1983 - 2017. DATA *ARE* EXPRESSED AS MEAN (MIN – MAX).

Site	Luvuvhu River at Pafuri (KNP)
Site ID:	A9H011Q01
Sampling period	1983 - 2017
TDS mg/L	102 (47.7 – 657)
EC mS/m	14.8 (7.6 – 97.55)
pH	7.84 (5.9 – 9.09)
Na mg/L	9.7 (3.5 – 1239)
Mg mg/L	5.86 (2.2 – 40.4)
Ca mg/L	8.22 (4.3 – 31)
K mg/L	1.07 (0.06 – 8.15)
F mg/L	0.12 (0.025 – 1.09)
Cl mg/L	13.6 (4.8 – 148)
SO_4^{2-} mg/L	4.2 (0.375 – 29.9)
TAL mg/L	46 (9.7 – 351)
$NO_2 + NO_3$ mg/L	0.062 (0.005 – 1.83)
PO_4^{2-} mg/L	0.017 (0.003 – 7.27)
Total P mg/L	0.06 (0.05 - 7.78)
NH_4 mg/L	0.04 (0.015 – 1.4)

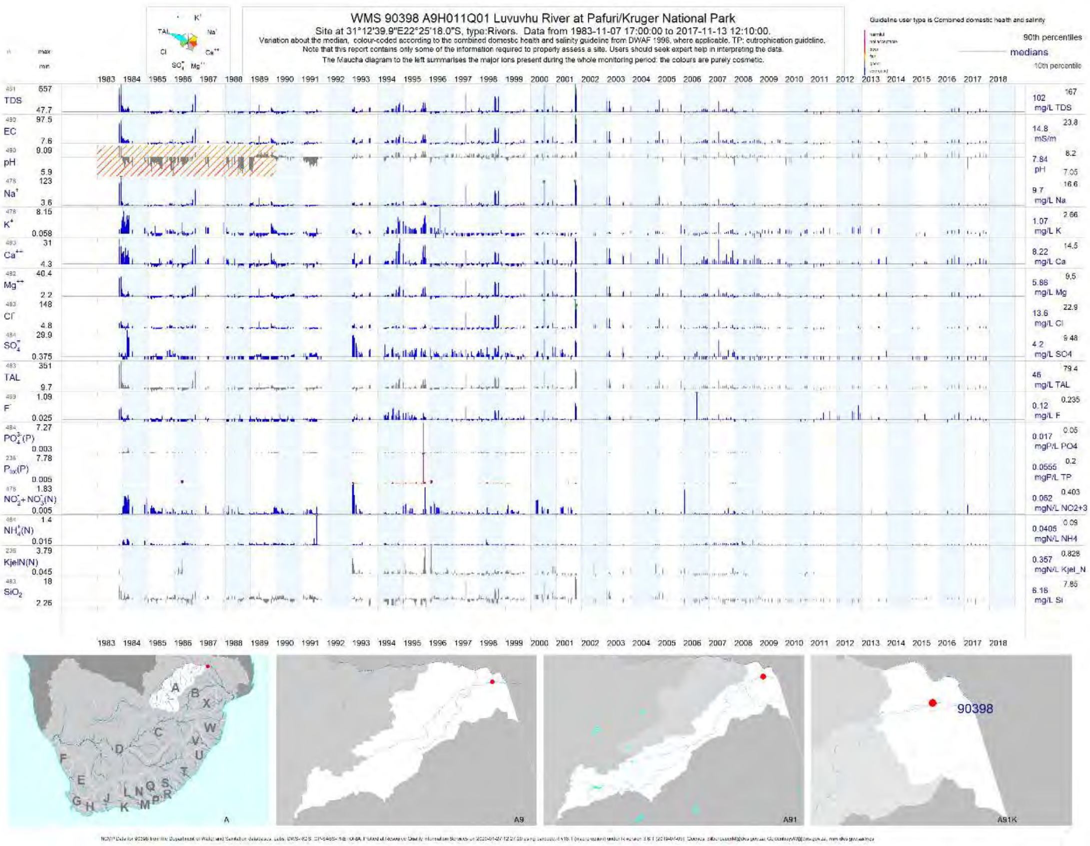


FIGURE 3.9. SUMMARY AND TIME SERIES OF WATER QUALITY DATA FOR THE LUVUVHU RIVER (A9H011Q01 AT PAFURI, KNP).

Shingwedzi River

The Shingwedzi River originates near the town of Malamule (Limpopo Province, South Africa) and is a non-perennial river. It is one of the tributaries of the Olifants River (Rio dos Elephantes in Mozambique) and drains one of the drier sub-catchments of the Limpopo River Catchment. It is relatively a small catchment covering an area of 5 300 km2 with a hot and dry climate, and forms part of the summer rainfall region of South Africa and typified by dry winters (Fouché and Vlok 2012). The major tributaries of the Shingwedzi are Mphongolo, Phugwane and Shisha rivers in South Africa as well a small Mozambican portion, located in low rainfall areas and therefore only have seasonal flows during the wet summer months of each year (Ashton et al. 2001).

The Shingwedzi sub-catchment consist predominantly of large areas of granitic and gneissic rock of the crystalline Basement Complex. The land in this catchment has been using for small and artisanal gold mining operations, subsistence agriculture and wildlife conservation in South Africa as well as Mozambique (Ashton et al. 2001). The upper (South Africa) reaches of the Shingwedzi sub-catchment is managed by the Department of Water Affairs (DWA) and the Olifants River downstream of the Shingwedzi-Olifants confluence is the responsibility of Mozambique (Ashton et al. 2001). Water quality in the Shingwedzi is influenced mainly by rural settlements and activities related to subsistence agriculture (Fouche and Vlok 2010). Table 3.14 provides a summary of the main water quality variables and the time series data are presented graphically in Figure 3.10. Additional water quality and metal data are available in the references listed above.

TABLE 3.14. SUMMARY OF THE WATER QUALITY OF THE SHINGWEDZI RIVER 1983 - 2018. DATA *ARE* EXPRESSED AS MEAN (*MIN – MAX*).

Site	Shingwedzi River at Silvervis Dam (KNP)
Site ID:	A9H002Q01
Sampling period	1983 - 2018
TDS mg/L	268 (54 – 1510)
EC mS/m	33.5 (7.4 – 205)
pH	8.23 (6.29 – 8.8)
Na mg/L	20.4 (3.6 – 251)
Mg mg/L	13.2 (0.75 – 91.3)
Ca mg/L	23.6 (4.1 – 92.5)
K mg/L	5.6 (2.34 – 85.3)
F mg/L	0.21 (0.025 – 0.73)
Cl mg/L	16.7 (3.6 – 580)
SO_4^{2-} mg/L	7.3 (1 – 92.1)
TAL mg/L	138 (2 – 557)
$NO_2 + NO_3$ mg/L	0.097 (0.005 – 8.04)
PO_4^{2-} mg/L	0.025 (0.003 – 0.489)
Total P mg/L	0.1 (0.01 – 2.91)
NH_4 mg/L	0.06 (0.015 – 19.8)

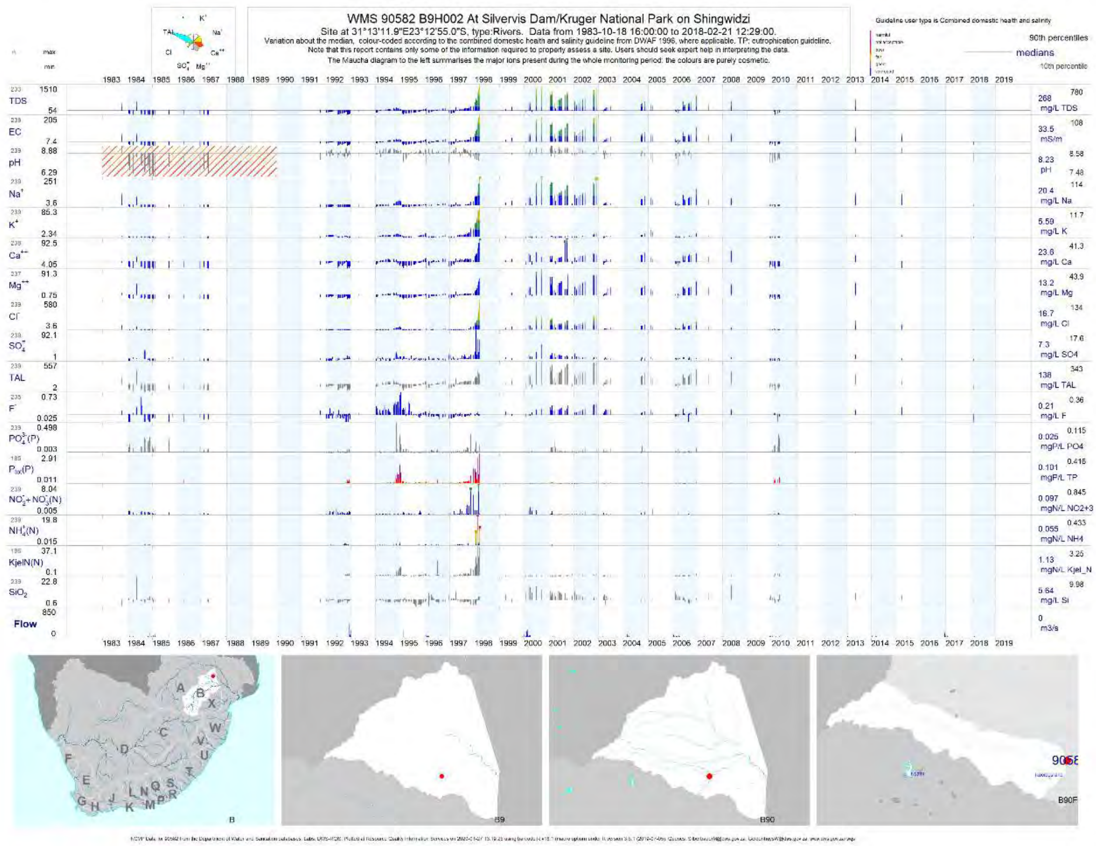


FIGURE 3.10. SUMMARY AND TIME SERIES OF WATER QUALITY DATA FOR THE SHINGWEDZI RIVER (A9H002Q01 AT SILVERVIS DAM, KNP).

Letaba River

The Letaba River is in the Limpopo Province of South Africa, covering an area of 13 400 km2. The major tributaries are the Klein-Letaba and Molotsi Rivers. At the Mozambique border it flows into the Olifants River and from there into the Massingir Dam in Mozambique (Heritage et al. 1997; Moon and Heritage 2001). The catchment is classified as semi-arid catchment, receiving between 500 and 1800 mm of rainfall in the western part (and mountainous), falling to 450 mm and 700 mm in the east (Heritage et al. 2001; Williams et al. 2008; Katambara and Ndiritu 2009). Approximately 75% of the geology consists of granite and gneiss, volcanic rocks followed by sedimentary rocks; this combined with soils has generate extensive areas of land with few limitations for agriculture (Heritage et al. 1997). The Letaba River system is subjected to numerous anthropogenic activities such as water abstraction, flow regulation, commercial agriculture, and forestry (Moon and Heritage 2001), and these factors influence both water quantity and quality (Gerber et al. 2015a). Gerber et al. (2015b, 2016) demonstrated that both metals and organochlorine pesticides are present in the system. Table 3.15 provides a summary of the main water quality variables and the time series data are presented graphically in Figure 3.11. Additional water quality and metal data are available in the references listed above. The resource quality objectives (RQOs) for the Letaba River in the KNP are also provided (Government Gazette 2016a).

TABLE 3.15. SUMMARY OF THE WATER QUALITY OF THE LETABA RIVER 1983 - 2018. DATA ARE MEAN (MIN – MAX). RESOURCE QUALITY OBJECTIVES (RQO'S) INDICATED.

Site:	Letaba River at Engelhardt dam, KNP	RQOs for the Letaba River in the KNP (EWR7)
Site ID:	B8H018Q01	
Sampling period	1983 - 2018	
TDS mg/L	297 (81 – 912)	
EC mS/m	41.2 (13.6 – 130)	≤ 55 mS/m mg/l (95th percentile)
pH	8.26 (6.08 – 8.91)	
Na mg/L	32.5 (5.5 – 161)	
Mg mg/L	15.3 (3.7 – 60.1)	
Ca mg/L	22 (6.3 – 63.1)	
K mg/L	4.4 (1.79 – 9.77)	
F mg/L	0.26 (0.025 – 0.8)	
Cl mg/L	34.1 (9.54 – 188)	
SO_4^{2-} mg/L	9.25 (1.6 – 41.9)	
TAL mg/L	132 (29.6 – 456)	
$NO_2 + NO_3$ mg/L	0.094 (0.005 – 7.05)	
PO_4^{2-} mg/L	0.019 (0.003 – 0.445)	≤ 0.025 mg/l (50th percentile)
Total P mg/L	0.118 (0.015 – 0.661)	
NH_4 mg/L	0.072 (0.015 – 6.53)	
Turbidity		To be included once data are available
Toxicants		95th percentile to remain in TWQR

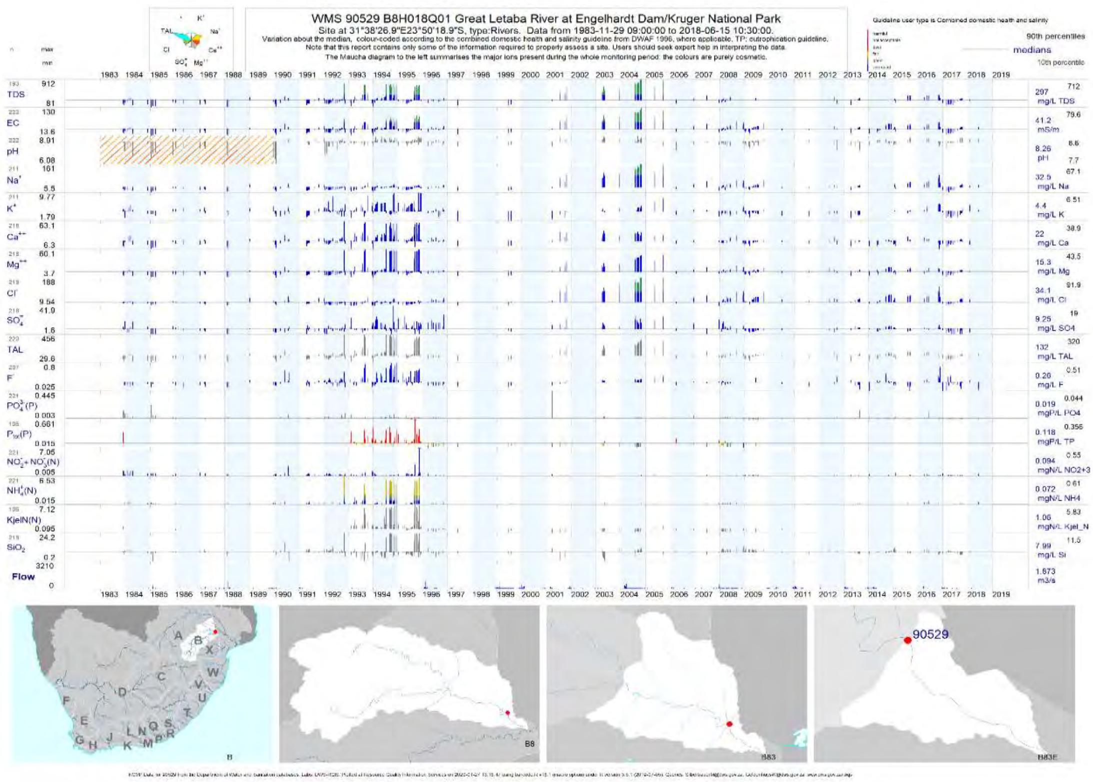


FIGURE 3.11. SUMMARY AND TIME SERIES OF WATER QUALITY DATA FOR THE LETABA RIVER (B8H018Q01 AT ENGELHARDT DAM, KNP).

Olifants River

The Olifants River Basin is situated in the northeast of South Africa, traverses the KNP, and is joined by the Limpopo River in Mozambique. It has the largest sub-catchment of the Limpopo River, with an area of 54,475 km2 and is divided into five regions (McCartney et al. 2004; McCartney and Arranz 2007). This catchment has a complex geology composed mainly by granite rock type. The Olifants River is widely regarded as one of the most polluted system in South Africa because of intensive anthropogenic activities such as mining, agricultural practices water use for afforestation, as well as domestic and industrial purposes (Wepener et al. 1999; De Villiers and Mkwelo 2009; Heath et al. 2010).

Several studies have been undertaken on the Olifants Rivers system in South Africa to evaluate the cocktail of pollutants/stressors in the water (De Villiers and Mkwelo 2009; Gerber et al. 2016a), sediments (Gerber et al. 2015a), aquatic organisms (Bowden et al. 2016; Gerber et al. 2015b, 2017, 2018), vegetables (Genthe et al. 2018), human health risk associated with the pollution of the river and consumption of its resources (Gerber et al. 2016b) and also the bioaccumulation on the food web (Verhaert et al. 2019). Table 3.16 provides a summary of the main water quality variables and the time series data are presented graphically in Figure 3.12. Additional water quality and metal data are available in the references listed above. The resource quality objectives (RQOs) for the Letaba River in the KNP are also provided (Government Gazette 2016a).

TABLE 3.16. SUMMARY OF THE WATER QUALITY OF THE OLIFANTS RIVER 1983 - 2018. DATA EXPRESSED AS MEAN (MIN – MAX). RESOURCE QUALITY OBJECTIVES (RQO'S) INDICATED.

Site	Olifants River at Mamba weir, KNP	RQOs for the Olifants River in the KNP (EWR16)
Site ID:	B7H015Q01	
Sampling period	1983 - 2018	
TDS mg/L	428 (54.9 – 2000)	
EC mS/m	57.8 (7.88 – 250)	
pH	8.22 (6.52 – 9.3)	
Na mg/L	42.4 (2.95 – 187)	
Mg mg/L	29.9 (1.69 – 193)	
Ca mg/L	32.4 (4.36 – 120)	
K mg/L	5.97 (0.15 – 80.4)	
F mg/L	0.51 (0.025 – 4.72)	
Cl mg/L	44.4 (1.5 – 246)	
SO_4^{2-} mg/L	75.5 (2 – 1290)	
TAL mg/L	148 (20.1 – 308)	
$NO_2 + NO_3$ mg/L	0.264 (0.005 – 6.86)	
PO_4^{2-} mg/L	0.02 (0.003 – 1.12)	
Total P mg/L	0.1 (0.009 – 2.66)	
NH_4 mg/L	0.05 (0.015 – 2.06)	
Water quality		Must be in a category ≥ C (62)
Sediment load		Must not negatively influence habitat state
Toxicants		Toxicity must not pose a threat to ecosystem

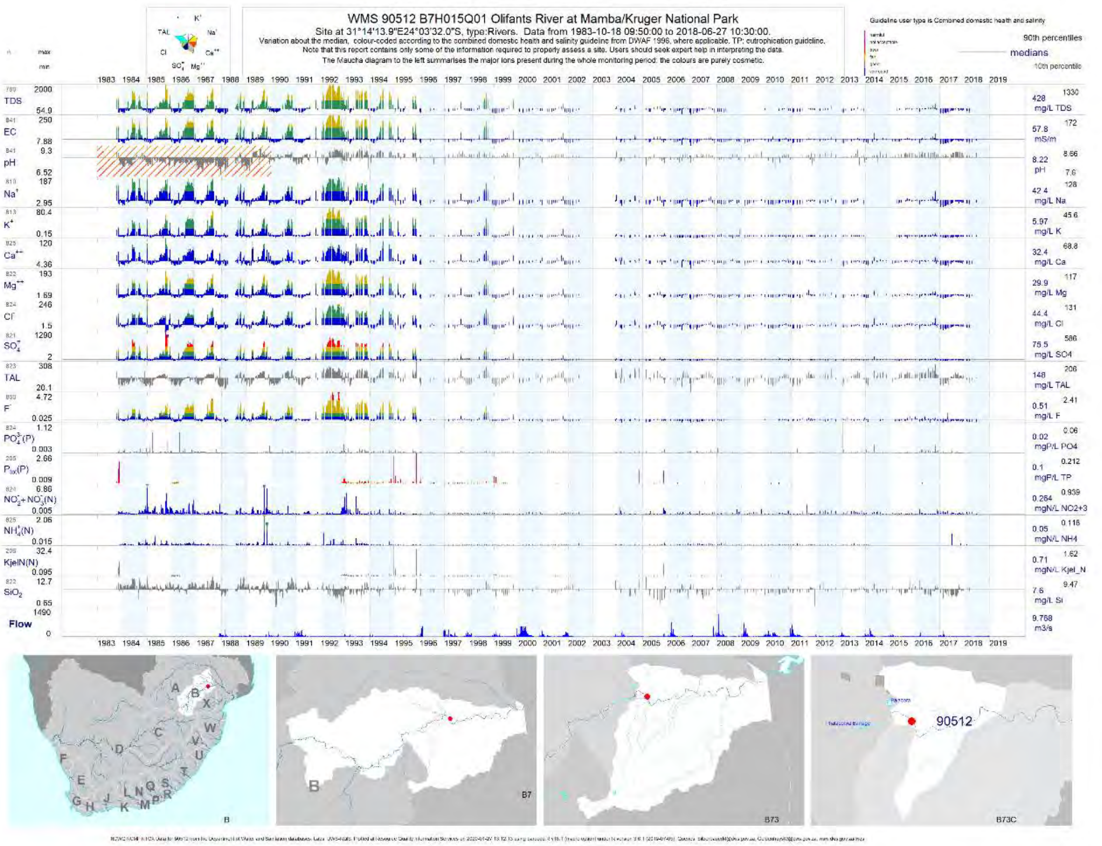


FIGURE 3.12. SUMMARY AND TIME SERIES OF WATER QUALITY DATA FOR THE OLIFANTS RIVER (B7H015Q01 AT MAMBA WEIR, KNP).

Smaller tributaries in South Africa

The sub-basins of the Mogalakwena and Nzhelele rivers were included in the 2013 Monograph water quality assessment. The conclusion was that these systems did not have a significant impact on the water quality of the mainstem of the Limpopo River. The data available for these two systems are limited on the WMS system and included in 2013 Monograph. For the purposes of this review they have been excluded, however for the E-flows determination additional samples could be analysed to bolster the available data.

Rivers in Mozambique

There is no information available for the Shingwedzi River in Mozambique.

The Changane River is a river in Mozambique situated in Gaza Province and the eastern most tributary of the Limpopo River. It joins the Limpopo near the coast downstream of Chibuto town (Chilundo et al. 2008). The river drains the wetlands of Banhine National Park, covering 6 557 055 km^2 (15, 9% of the Limpopo Basin). It flows through a dry region, with an annual rainfall is as low as 400 mm (Nagabahatla et al. 2008). Chibuto is a floodplain wetland of the Changane River, serving primarily as an agroecosystem. The adjacent Changane is brackish and the salinity gradient has an influence on the hydrology since the Changane River Valley is close to sea level (Nagabahatla et al. 2008).

According to Chilundo et al. (2008), the Changane River has poor water quality, with parameters such as total hardness, TDS, EC, chloride and SAR values above the Mozambican standards and

WHO guidelines. This should be viewed with caution as the Changane River has naturally high salt concentrations (due the natural geology of this area) and has elevated nutrients, which has been ascribed to the presence of organic rich coastal wetlands.

The only water quality data available are those that were collected and reported in the 2013 Monograph (Rossouw 2013).

TABLE 3.17. WATER QUALITY DATA OF SAMPLING SITES IN MOZAMBIQUE. DATA REPRESENT THE 75TH PERCENTILES.

Sub-basin	Station	EC	pH	pH	F	Fe	SO_4^{-2}	PO_4^{-2}	NO_3^-
		mS/m	Lower	Upper	mg/l	mg/l	mg/l	mg/l	mg/l
Limpopo	E-31 at Pafuri	42.50	6.70	7.90	No data	No data	53.27	No data	5.000
Limpopo	E-33 at Combumune	60.80	6.80	7.94	No data	No data	42.80	No data	6.810
Olifants /Elephantes	E-546 d/s of Massingir Dam	53.90	7.07	7.80	No data	No data	151.86	No data	5.000

3.4 EXAMPLE OF ASSESSING WATER QUALITY WITHIN THE BAYESIAN NETWORK MODELS TO DERIVE E-FLOWS FOR THE LIMPOPO BASIN

The evidence used for the Bayesian Network models are obtained from available literature (as outlined in this report) and field studies that supplement data where the need arises. The input nodes of the Bayesian networks require that these measurable water quality parameters be ranked based on the risk to the endpoint. Conditional probability tables (CPTs) determine the interactions between a combination of parent nodes and a child node. In this section, the ranking of water quality parameters using the assessment classes for physicochemical water quality parameters (Table 3.2) and toxicants (Table 3.3) are demonstrated. The Olifants River site at Mamba Weir in the KNP will be used as case study. Physio-chemical data are from the SANPAKS water quality monitoring programme and the toxicants based on data from Gerber et al. (2015) and Verhaert et al. (2017).

TABLE 3.18: EXPOSURE AND EFFECT VARIABLE (INPUT NODE) DESCRIPTIONS, JUSTIFICATIONS, RISK INPUT RANKS AND REFERENCES FOR THE ENDPOINT "MAINTENANCE OF WATER QUALITY USER GROUP WELL-BEING". FOR MAMBA WEIR THIS IS RELATES TO "AQUATIC ECOSYSTEM WELL BEING".

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Input nodes description (node name)	Rank	Score	Narrative criteria for measure	Numerical criteria (units)	Justification	References
Suitability of nitrateforo maintenance of aquatic ecosystem well-being	Zero	0	Good nitrate	0.7 mg/L	Nitrate tolerances of aquatic biota	Table 3.2 assessment classes
	Low	2	Tolerable nitrate	1 mg/L		
	Moderate	4	Poor nitrate	1.5 mg/L		
	High	6	Unacceptable nitrate	>1.5 mg/L		
Suitability of ortho-phosphate concentrations for maintenance of aquatic ecosystem well-being	Zero	0	Good nitrate	0.025 mg/L	Tolerance of aquatic biota to phosphates	Table 3.2 assessment classes
	Low	2	Tolerable ortho-phosphate	0.075 mg/L		
	Moderate	4	Poor ortho-phosphate	0.125 mg/L		
	High	6	Unacceptable ortho-phosphate	>0.125 mg/L		
Suitability of copper concentrations for maintenance of aquatic ecosystem well-being	Zero	0	Good copper <HC1 (50)	<0.39 µg/L	Tolerance of aquatic biota to copper	Table 3.3 assessment classes
	Low	2	Tolerable copper HC5 (5-25)	0.39 – 56.3 µg/L		
	Moderate	4	Poor copper HC5 (25-50)	0.39 – 56.3 µg/L		
	High	6	Unacceptable copper >HC5 (5)	0.39 – 56.3 µg/L		
Suitability of Lindane concentrations for maintenance of aquatic ecosystem well-being	Zero	0	Good lindane <HC1 (50)	<2.2 µg/L	Tolerance of aquatic biota to Lindane	Table 3 assessment classes
	Low	2	Tolerable lindane HC5 (5-25)	2.2 – 2.68 µg/L		
	Moderate	4	Poor lindane HC5 (25-50)	2.69 – 3.56 µg/L		
	High	6	Unacceptable lindane >HC5 (50)	>3.56 µg/L		

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TABLE 3.19 AN EXAMPLE OF CALCULATING THE WATER QUALITY INPUT RANKS BASED ON DATA FROM MAMBA WEIR AND RANKING BASED ON TABLE 3.18 DESCRIPTIONS.

Variable	Concentration	Ranked risk value
Nitrates	< 0.2 mg/L	0
Orthophosphate	0.014 mg/L	0
Copper	2.1 µg/L	2
Lindane	0.57 µg/L	0

3.5 CONCLUSIONS AND RECOMMENDATIONS

There are adequate water quality data available for most of the South African sites in the Limpopo Basin and the major tributaries to contribute the necessary information for E-flow determination at the selected sites. These data are mainly from the Water Management System of the Department of Water Affairs. SANPARKS also have monitoring data for the rivers flowing through the Kruger National Park. Data for some of the sites, e.g. Luvuvhu, Mogalakwena and Nzhelele Rivers, are not recent and need to be supplemented during the field survey. Interrogation of available data sources revealed a lack of available data on the sub-basins in the neighbouring countries is. The outdated water quality data reported in the 2013 Monograph needs to be supplemented with new data from field sampling.

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4 GEOMORPHOLOGY AND HYDRAULICS

4.1 LIMPOPO CATCHMENT DRAINAGE

The Limpopo River catchment (412,938 km^2) is one of the larger catchments in southern Africa and drains the northern parts of South Africa, the southern sections of Botswana, Zimbabwe and Mozambique (Knight, 2020). The catchment has a long evolutionary history that experienced various changes over time due to tectonic uplift. The Limpopo Basin used to drain a large part of central Africa, which included the Okavango, Cuando, upper Zambezi, Kafue, and Luangwa Rivers (Figure 4.1). This provided large volumes of sediment that formed the extensive Mozambique coastal plain. The crustal flexure during the late Cretaceous to early Tertiary along the Okavango-Kalahari-Zimbabwe Axis (OKZ, see Figure 4.1) severed the link with these tributaries and resulted in a large endorheic system that deposited the sediment (largely sand) as the Kalahari sequence. This sediment as was no longer routed via the Limpopo River (Moore and Larkin, 2001). This resulted in a large reduction in flow and sediment to the modern Shashe and Limpopo Rivers (Moore and Larkin, 2001). This is evident in the wide Shashe Riverbed despite its relatively small modern-day catchment. Similarities in fish species between the Limpopo and Zambezi River provides further evidence of this former link (Moore and Larkin, 2001).

Evidence of various regional erosional sequences are evident: the African erosion surface forming the higher lying plateaus within the drainage basin; followed by the Post-African I and II erosional events that are due to the Africa Super Swell uplift events 20 and 5 million years ago (McCarthy and Rubigde, 2005). Uplift during these events might have been as much as 900 m along the east and 250 m along the west of the continent on the Kaapvaal Craton and possibly the Limpopo belt and Zimbabwe Craton (Figure 2; McCarthy and Rubigde, 2005). This led to new erosional cycles due to the steepening of the river profiles. This rejuvenation propagated up the Limpopo River through landscape incision, resulting in headward erosion through nickpoint retreat and localised steepening of the river long profile (Partridge and Maud, 1987). These erosional sites are visible along more resistant rock types where gorges and waterfalls form. The rejuvenation and associated erosion led to increased sedimentation along the Limpopo River and tributaries, contributing to the depositional Limpopo Cone or paleo delta along the coastal zone in Mozambique. The size of this delta is relatively small due to the erosional effect of the Agulhas Current and Delagoa Bight Lee Eddy dispersing sediment southwards (Partridge and Maud, 1987; Wenau et al., 2020).

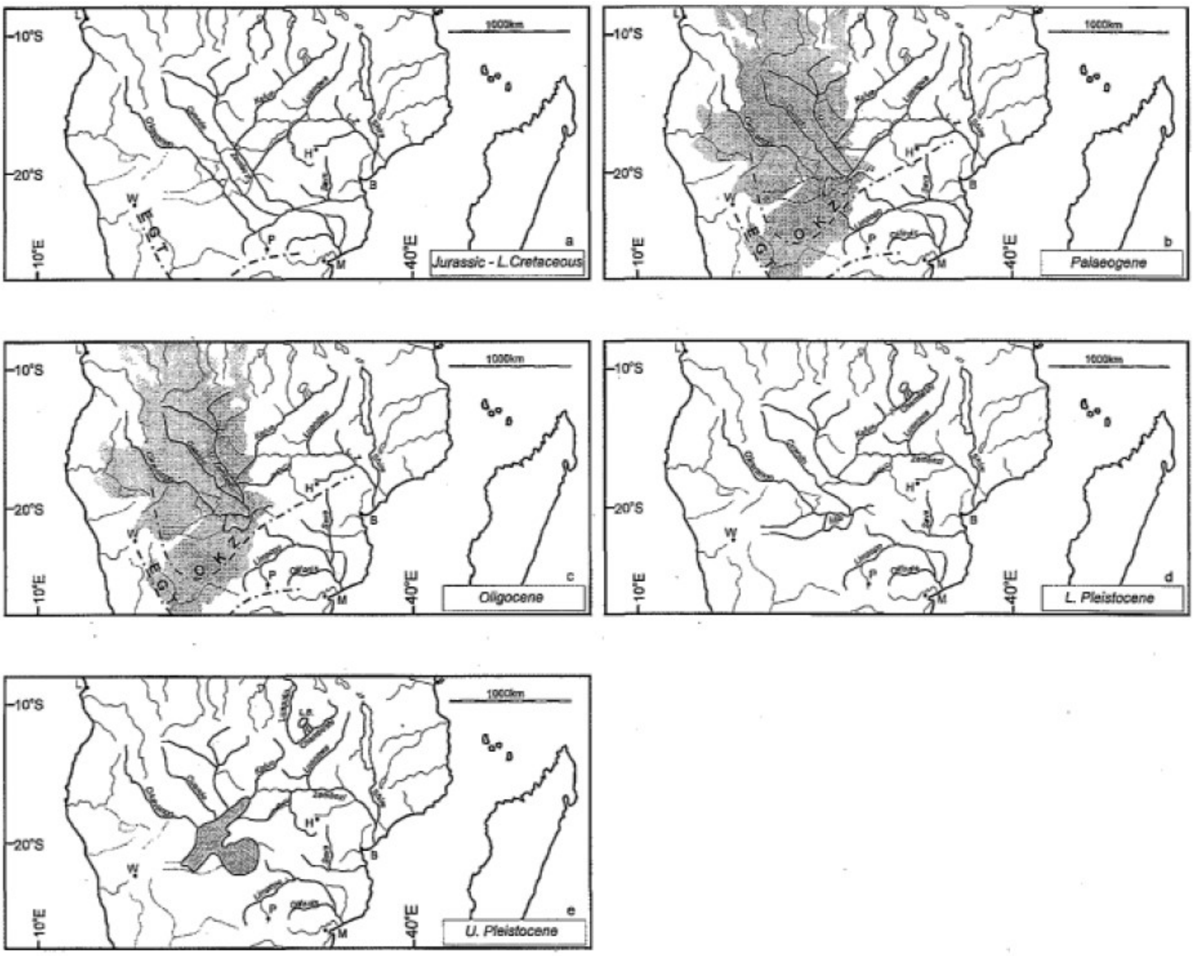

FIGURE 4.1: CHANGES TO THE DRAINAGE PATTERN OF THE LIMPOPO RIVER SINCE THE UPLIFT IN THE PALEOGENE. THE SHADED AREAS INDICATE SAND DEPOSITS THAT FORMED DUE TO CHANGES IN DRAINAGE (MAPS BY MOORE AND LARKIN (2001))

4.2 GEOLOGY AND LITHOLOGY OF THE LIMPOPO BASIN

The Limpopo basin consists of the Karoo Igneous Province (flood basalts), Kaapvaal Craton (igneous rocks) and the Limpopo Belt (Figure 4.2; Schüürman et al., 2019). The main formations are the Beit Bridge Complex (ganitic gneisses, metapelites, quartzites, carbonates and amphibolites), the Transvaal Supergroup (quartzites, carbonites, banded iron formations, basalts and andesites) and the Bushveld Complex (layered ingenious intrusion) (Figure 4.2; Schüürman et al., 2019). Figure 4.3 shows the surface rock types within the Limpopo basin.

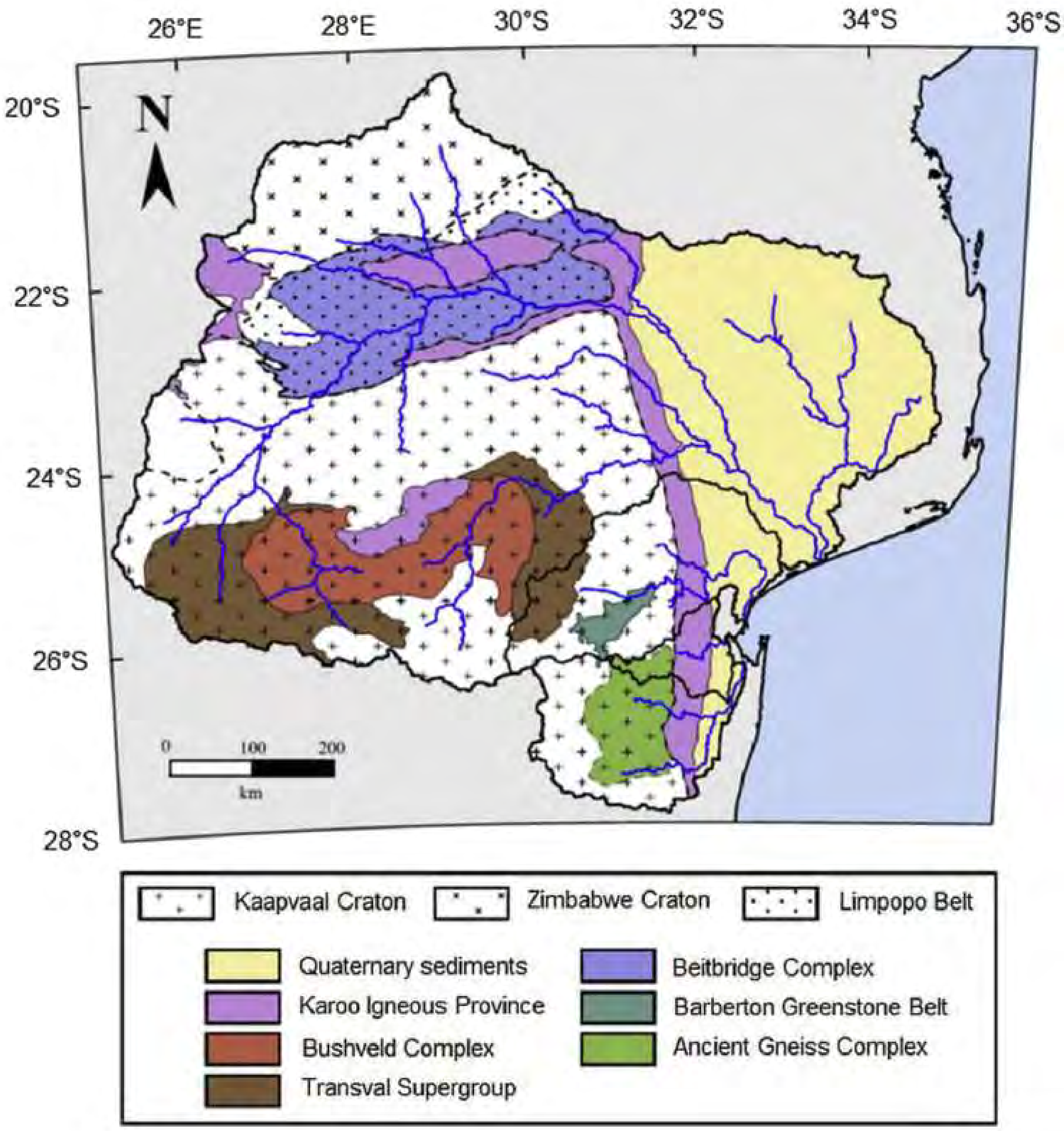

FIGURE 4.2: THE GEOLOGY OF THE LIMPOPO BASIN (MAP BY (SCHÜÜRMAN ET AL., 2019)

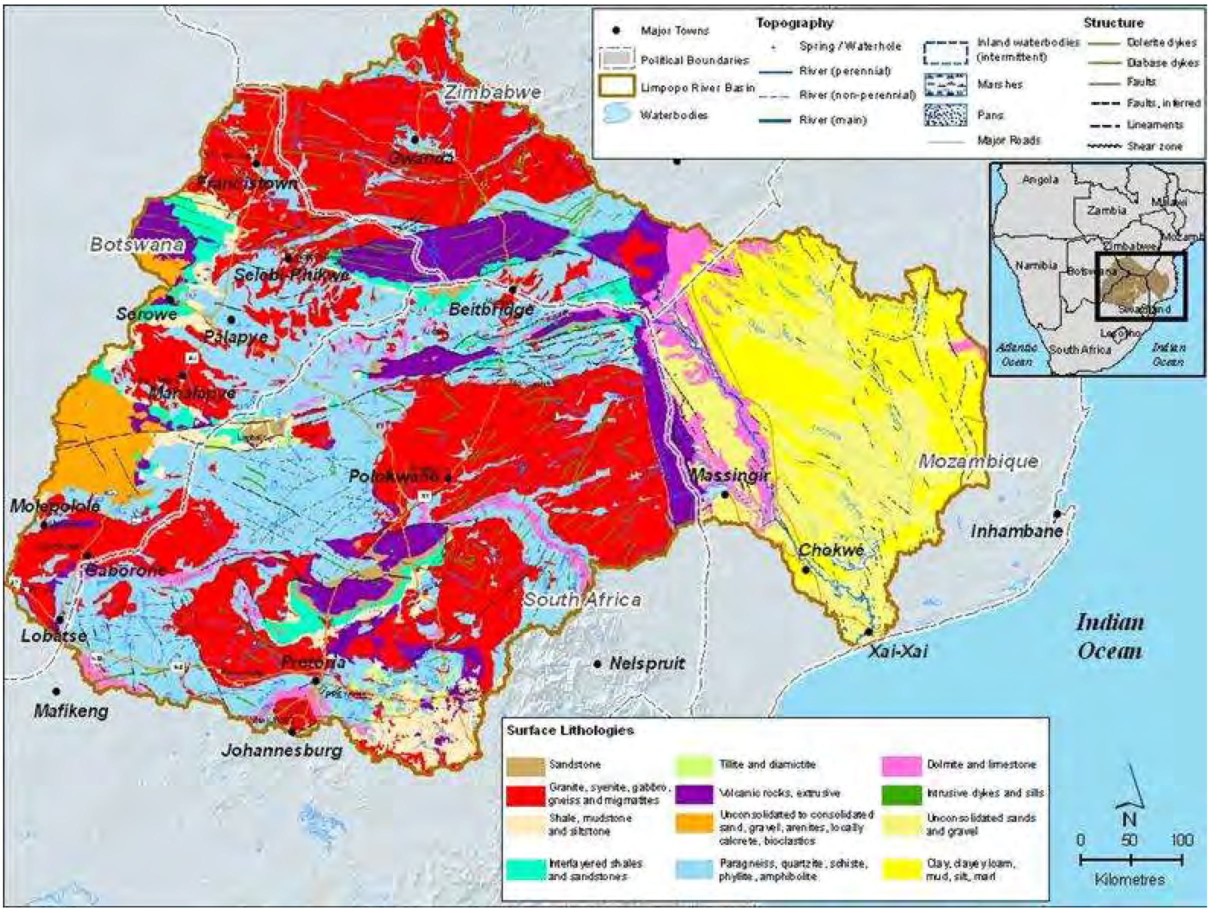

FIGURE 4.3: SURFACE LITHOLOGY OF THE LIMPOPO BASIN (TAKEN FROM LIMPOPO RIVER AWARENESS KIT, 2020; DATA BY SADC 2010)

4.3 TOPOGRAPHY OF THE LIMPOPO BASIN

The Limpopo basin can be defined as an undulating landscape of plains, with interspersed ranges of hills and mountains (Limpopo River Awareness Kit, 2020). There are two main plains: the uplands of the South African highveld, Botswana and Zimbabwe; the lowlands of the South African lowveld and Mozambique coastal plain (Figure 4.4). Highpoints are as follows per country: South Africa 2 328 m; Botswana 1 510 m; Zimbabwe 1 609 m; Mozambique 530 m with the most dramatic topography largely in South Africa and the least dramatic topography found in Mozambique.

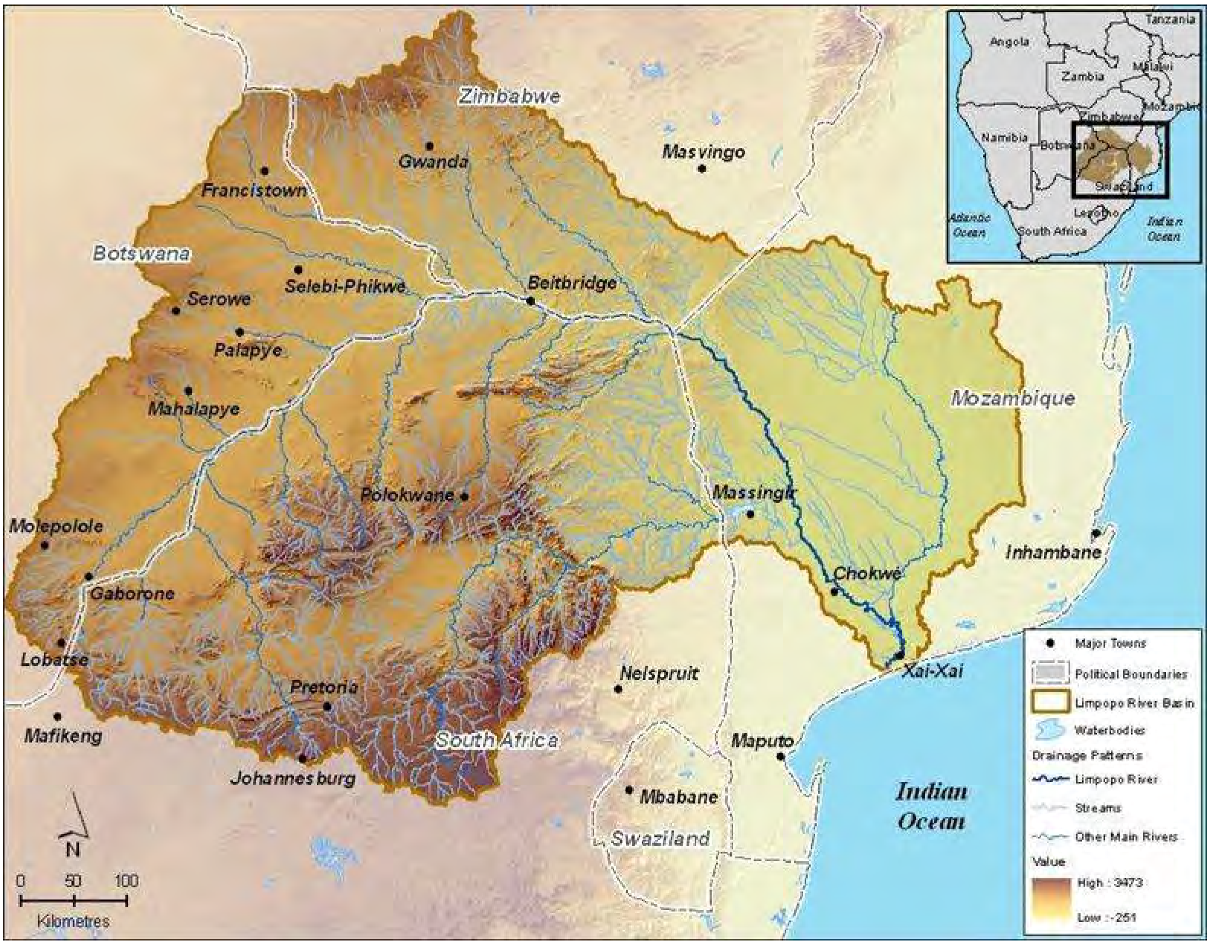

FIGURE 4.4: ELEVATION OF THE LIMPOPO BASIN (TAKEN FROM LIMPOPO RIVER AWARENESS KIT, 2020)

4.4 GEOMORPHOLOGY OF THE LIMPOPO BASIN AND ITS RIVERS

The Limpopo basin spans a wide range of geomorphic provinces or landscapes such as plateaus, escarpments, hills, mountains and plains (Bridges, 1990). Figure 4.5 shows the broad geomorphic provinces with South Africa being classified as Middleveldt (which includes the Highveld Plateau, the Great Escarpment) and Natal Coastland (lowveld), Botswana and Zimbabwe as Zambia-Zimbabwe Plateau, and Mozambique as Natal Coastland and coastal plains (Figure 4.5). The Limpopo valley separates the northern plateau (Zambia-Zimbabwe Plateau) from the southern plateau (Middleveldt). The Kalahari Basin borders the western part of the Limpopo catchment. The Great Escarpment marks the transition from the plateau to the Natal Coastland and coastal plains (Bridges, 1990).

FIGURE 4.5: BROAD GEOMORPHIC PROVINCES OF THE LIMPOPO BASIN (TAKEN FROM LIMPOPO RIVER AWARENESS KIT, 2020, MAP DATA BY BRIDGES (1990)

A more in-depth classification of the geomorphic provinces of South Africa (Figure 4.6) was developed by Partridge et al. (2010). The main features, such as relief, geomorphic features, river gradient, valley width, sediment storage potential and geology, of the various geomorphic provinces are summarised in Table 4.1.

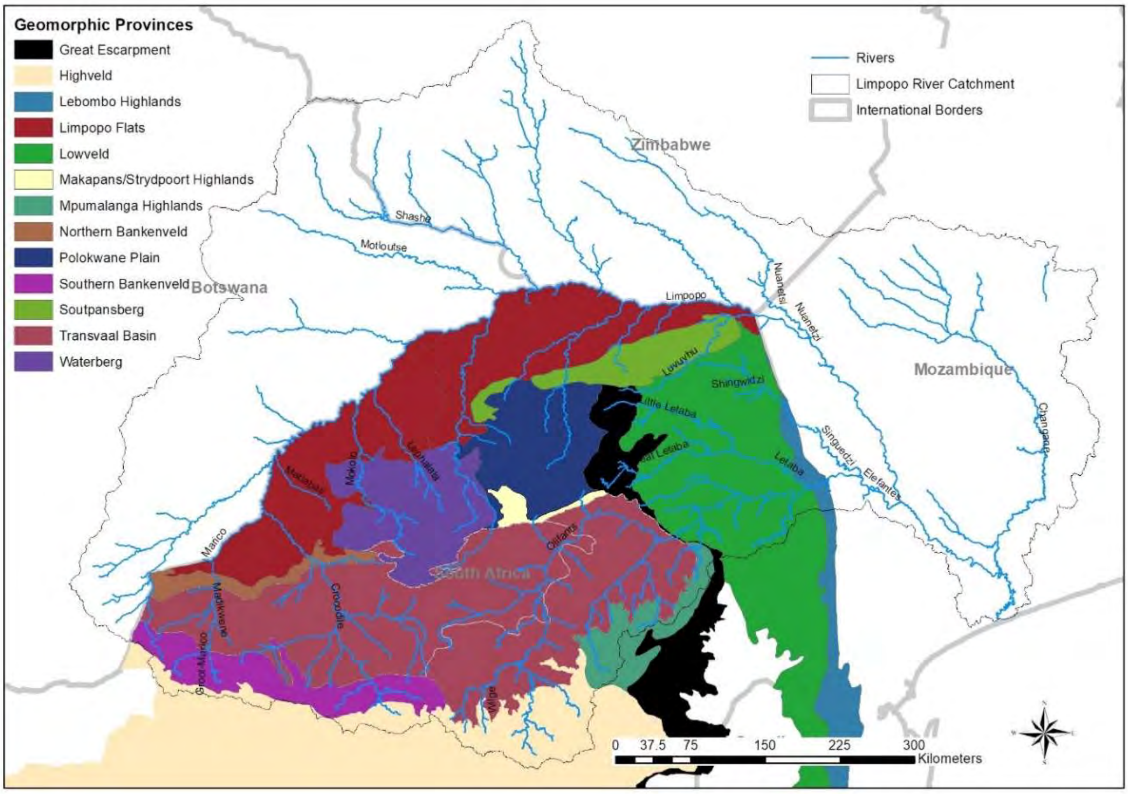

FIGURE 4.6: GEOMORPHIC PROVINCES OF SOUTH AFRICA (PARTRIDGE ET AL., 2010)

TABLE 4.1: SUMMARY OF THE GEOMORPHIC PROVINCES FOR SOUTH AFRICA (PARTRIDGE ET AL., 2010)

GEOMORPHIC PROVINCE	DESCRIPTION	GEOLOGY	SEDIMENT STORAGE
Great Escarpment	This escarpment forms a large step (300 to 2000 m vertically) between the inland plateau and the lowveld. Steep topography, steep river profiles, incised narrow valleys, mostly on bedrock with waterfalls.	Granite-gneisses and sedimentary strata of the Transvaal Supergroup	Very low
Highveld	Gently undulating, shallow open valleys with minimal incision. Broad valleys and moderate river gradients.	Karoo sequence, Ventersdorp lavas and dolomite	Low to very low
Lebombo Highlands	Continuous range of hills and low mountains. Rivers cross this range orthogonally in deep, steep gorges.	Acid lavas (rhyolite)	Low to moderate
Limpopo Flats	Fault controlled trough with inselberg studded plain with gentle slope. Meandering channels with broad low gradient valley. Local steepening on harder rock types of the Limpopo Belt.	Granites, gneisses, Limpopo Belt	High
Lowveld	Excavated by erosion, low undulating plains with localised koppies. Narrow to wide valley with steep to moderate river slope.	Granitic rocks	Moderate
Makapans Highlands	High relief mountain with short, steep, and narrow valleys.	Quartzite and dolomite	Low to very low
Mpumalanga Highlands	Ridge-and-valley topography with quartzite ridges creating narrow gorges. Narrow valleys with steep river slope. Source area of many perennial rivers and wetlands.	Pretoria Group, Malmani dolomites and quartzite ridges	Very low
Northern and southern Bankenveld	Parallel quartzite ridges (e.g. Magaliesberg, Daspoort and Timeball Hill) and shale-filled valleys, trellis drainage pattern. Southern Bankenveld has narrow valleys with steep river slope and northern Bankenveld has wide valleys and flat river slope.	Quartzite ridges and shale in valleys	Southern Bankenveld – low to very low Northern Bankenveld – medium to high
Polokwane Plain	Broad open valleys interspaced with numerous rocky koppies.	Granite-gneiss with schist pods	Moderate to low
Soutpansberg	Mountain range with tilting ridges and larger rivers crossing the mountain perpendicularly leading to narrow gorges, often steep flat floored valleys following fault lines. Moderate valley width and steep stepped profiles.	Soutpansberg Group quartzites, lava and shale	Low
Transvaal basin	The western part has considerable topographical diversity with a ridge encircling a relatively flat landscape with some steep hills, gentle to medium river profiles in broad valleys. To the east parallel ridges of high relief; steep river profiles and moderately narrow valleys.	Bushveld Complex (mainly norite, granite and felsite)	Western part: Moderate to high Eastern part: low to very low
Waterberg	Plateau remnants (pre-rifting residuals) separated by deeply incised, structurally controlled valleys. Rivers range from narrow stepped deeply incised to wide gentle sandy valleys.	Waterberg sandstones, conglomerates, and shales	Moderate to low

The Limpopo River has an unusual river longitudinal profile as it does not have the typical concave longitudinal shape from headwater to mouth. It has a gentle slope where it drains the Plateau (upper basin zone), followed by steepening where it crosses the Escarpment (mid basin zone) followed by a flatter lower reach that flows through the (lower basin/coastal zone Figure 4.7). Figure 4.8 shows the various tributary confluences along the Limpopo longitudinal profile.

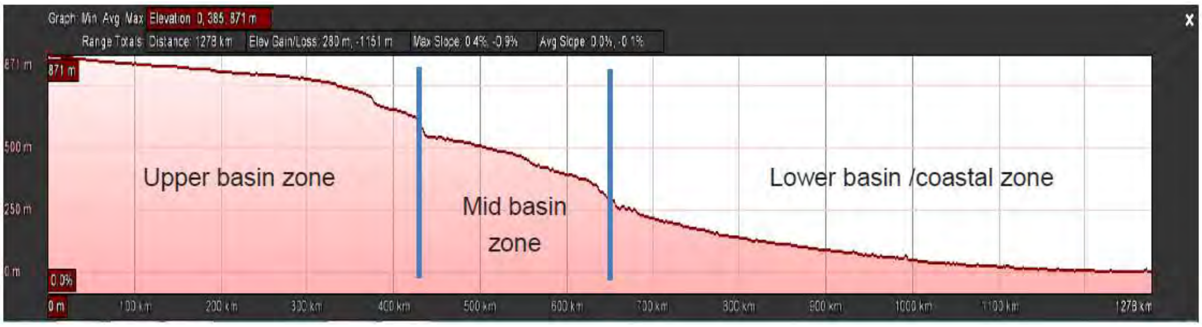

FIGURE 4.7: LONGPROFILE OF THE LIMPOPO RIVER (LIMPOPO RIVER BASIN MONOGRAPH, 2013)

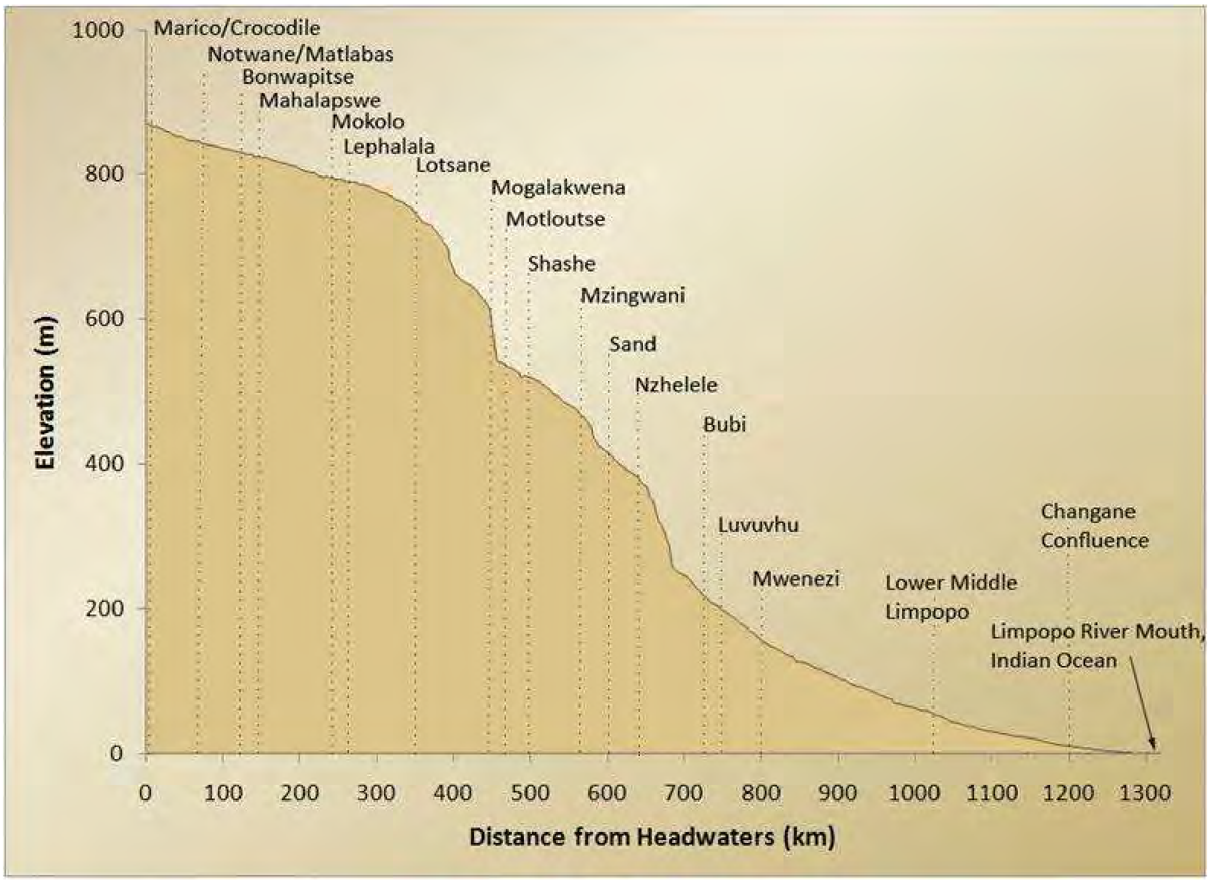

FIGURE 4.8: LONGITUDINAL PROFILE OF THE LIMPOPO RIVER AND THE LOCATIONS OF TRIBUTARIES JOINING THE MAIN STEM (FROM THE LIMPOPO RIVER AWARENESS KIT, 2020)

Knight (2020) used the Australian River Styles Framework to classify the geomorphology of the main rivers of the drainage basin (Figure 4.9). Topography, tectonics, and lithology explain the variation in geomorphology. The main reach geomorphic groupings were:

- bedrock, rapids, and deep pools.
- moderate sinuosity, sand bed, sand sheets and lateral bars.
- low sinuosity, fine-grained sand beds, sand sheets, benches, and flood outs.

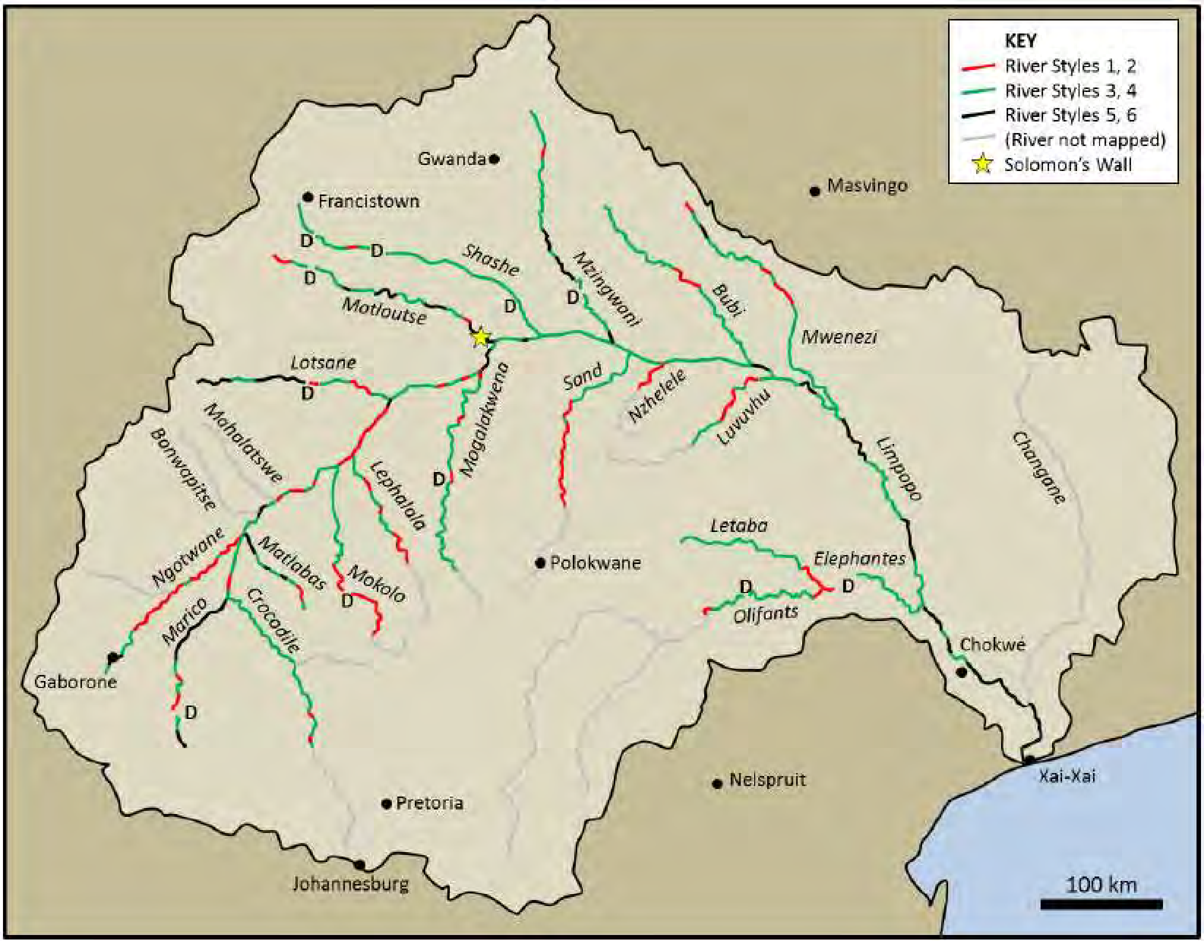

FIGURE 4.9: MAIN RIVER GEOMORPHOLOGY OF THE PERENNIAL LIMPOPO DRAINAGE NETWORK (TAKEN FROM KNIGHT (2020)). THE RED SECTIONS INDICATE BEDROCK, RAPIDS AND DEEP POOLS; GREEN SECTIONS INDICATE REACHES WITH MODERATE SINUOSITY, SAND BED, SAND SHEETS AND LATERAL BARS; BLACK REACHES SHOW REACHES WITH LOW SINUOSITY, FINE GRAINED SAND BEDS, SAND SHEETS, BENCHES AND FLOOD OUTS

Another geomorphic classification, based on the South African classification system (Rowntree and Wadeson, 1999), is presented in Figure 4.10. This hierarchical classification system is based on river gradient, which explains valley setting and river characteristics. The main zonal classifications are described by Rowntree and Wadeson (1999) as:

- Transitional zone – 'moderately steep stream dominated by bedrock or boulder bed. Reach types include plain-bed, pool-rapid or pool-riffle. Confined or semi-confined valley floor with limited flood plain development'.
- Upper foothill zone – 'moderately steep, cobble-bed or mixed bedrock and cobble-bed channel, with plain-bed, pool-riffle or pool-rapid reach types. Length of pools and riffles/rapids similar. Narrow flood plain of sand, gravel or cobble often present'.
- Lower foothill zone – 'lower gradient mixed bed alluvial channel with sand and gravel dominating the bed, may be locally bedrock controlled. Reach types typically include pool-riffle or pool-rapid, sand bars common in pools. Pools of significantly greater extent than rapids or riffles. Flood plain often present'.
- Lowland river zone – 'low gradient alluvial fine bed channel, typically regime reach type. May be confined, but fully developed meandering pattern within a distinct flood plain develops in unconfined reaches where there is an increased silt content in bed or banks.

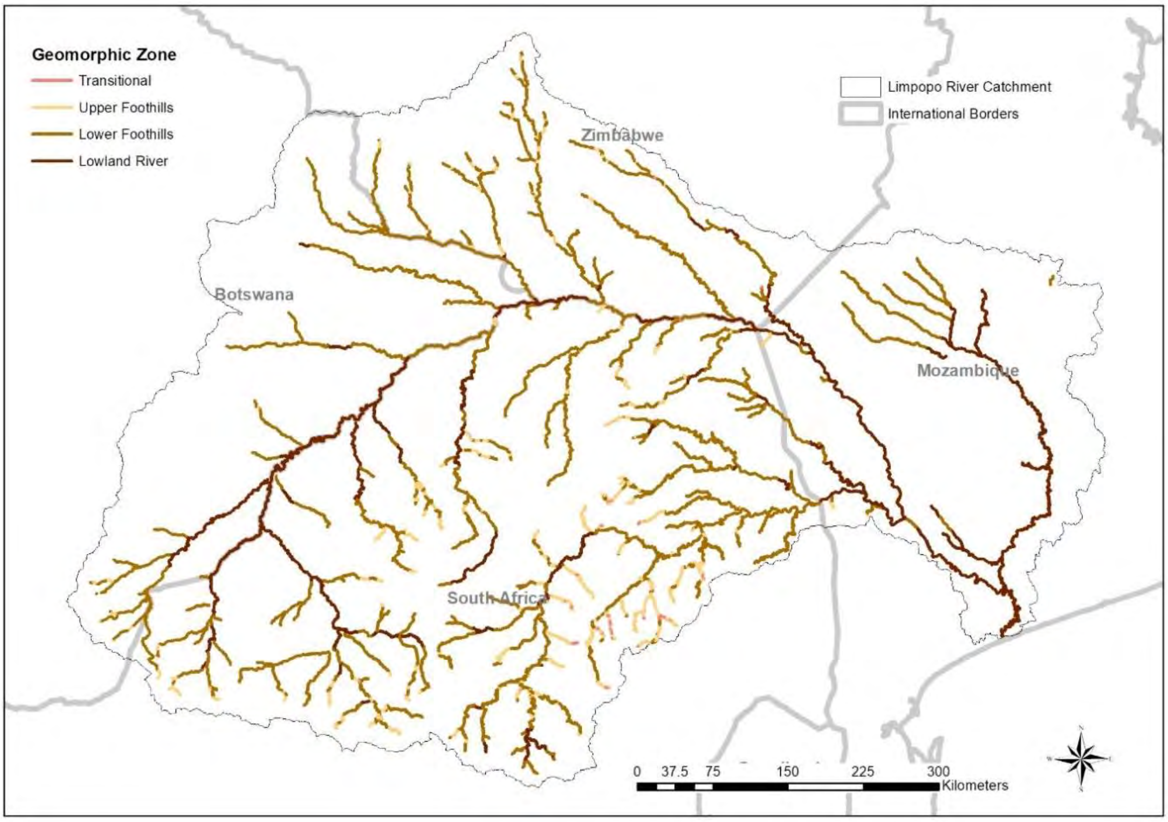

FIGURE 4.10: GEOMORPHIC ZONES OF THE LIMPOPO RIVER AND ITS TRIBUTARIES (GEOMORPHIC ZONE DATA FROM THE NBA 2018)

These two geomorphic classification systems show similar trends with steeper confined valleys with bedrock-controlled sections alternate with more gentle sloping alluvial channels in less confined valleys. There is a general trend of valley widening and lower river slope for the lower reaches of the drainage network.

4.5 LAND DEGRADATION, SOIL EROSION AND SEDIMENT LOAD

Land degradation and associated soil erosion varies across the Limpopo Basin, with areas of high to extreme soil erosion supplying significant volumes of sediment to the basin (Figure 4.11). The FAO (2004) summarises the degradation as follows:

- No degradation - lower northeast part of the Limpopo River Basin in Zimbabwe and Mozambique and in a north–south zone roughly following the Escarpment and associated mountains.
- Slight degradation - upper Limpopo River Valley; most of the adjacent southwest catchment in South Africa, and in southeast Zimbabwe. Most of these areas coincide with private farms. Most of the remainder of Mozambique also falls into this class.
- Moderate degradation in northeast Botswana and adjacent Zimbabwe, a north–south zone covering northeast South Africa (including the Kruger National Park) and the southern tip of the catchment.
- High degradation - southwest upper catchment in Botswana and in an area southwest from Pretoria.

- Extreme degradation - three areas in the Limpopo Province of South Africa, corresponding with densely populated communal areas (former homelands of Venda and Lebowa).

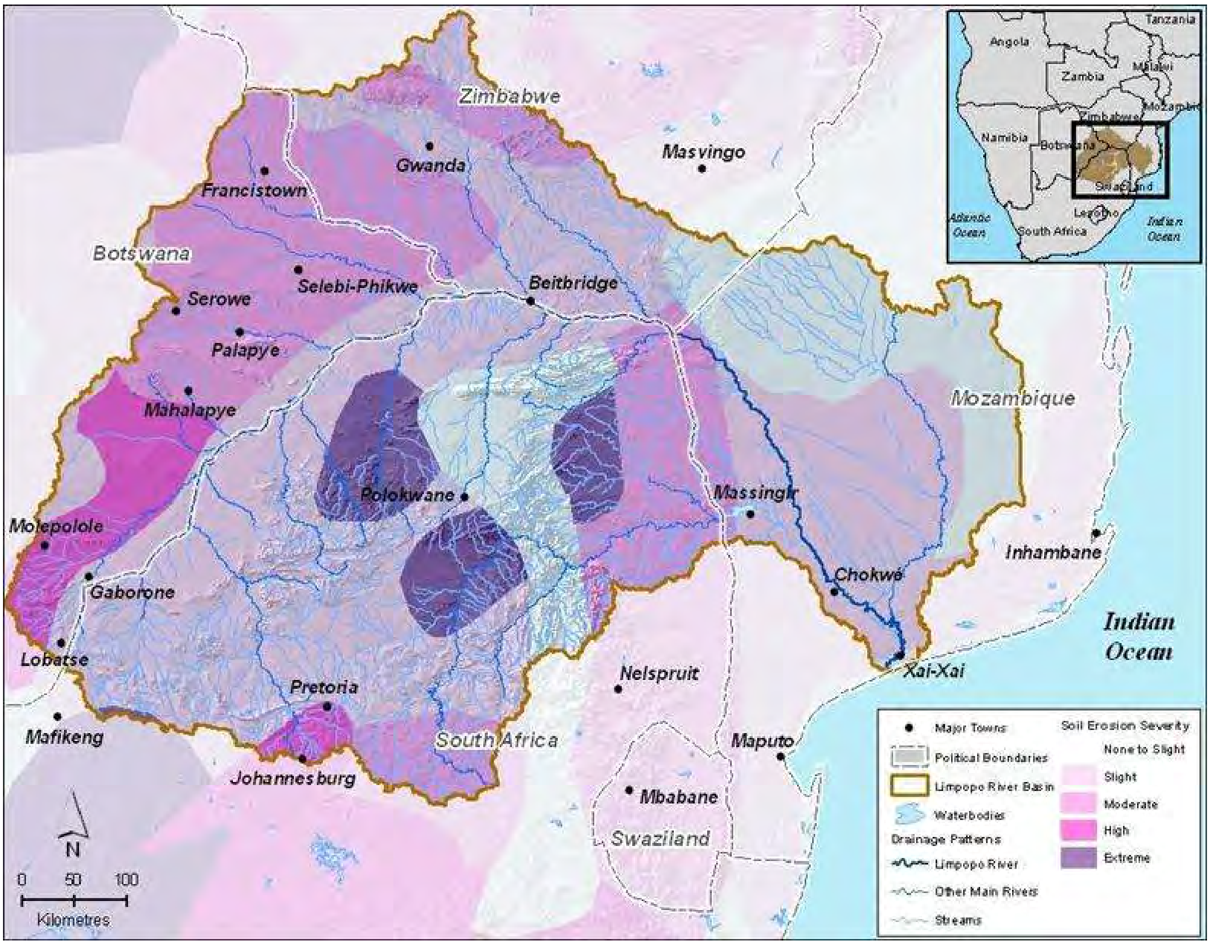

FIGURE 4.11: EROSION SEVERITY IN THE LIMPOPO BASIN (TAKEN FROM LIMPOPO RIVER AWARENESS KIT, 2020, MAP DATA BY OLDEMAN ET AL. (1991))

Sediment load data for the Limpopo main stem and some of the tributaries are presented in Figure 4.12. Some of the tributaries have relatively high loadings in relation to the Limpopo mainstem. This is possibly due to high erosion rates in sections of the sub-catchments (as shown for sections of South Africa in Figure 4.11) and subsequent sediment storage along the tributaries and mainstem Limpopo (such as in channel or on floodplains) or behind dams and weirs.

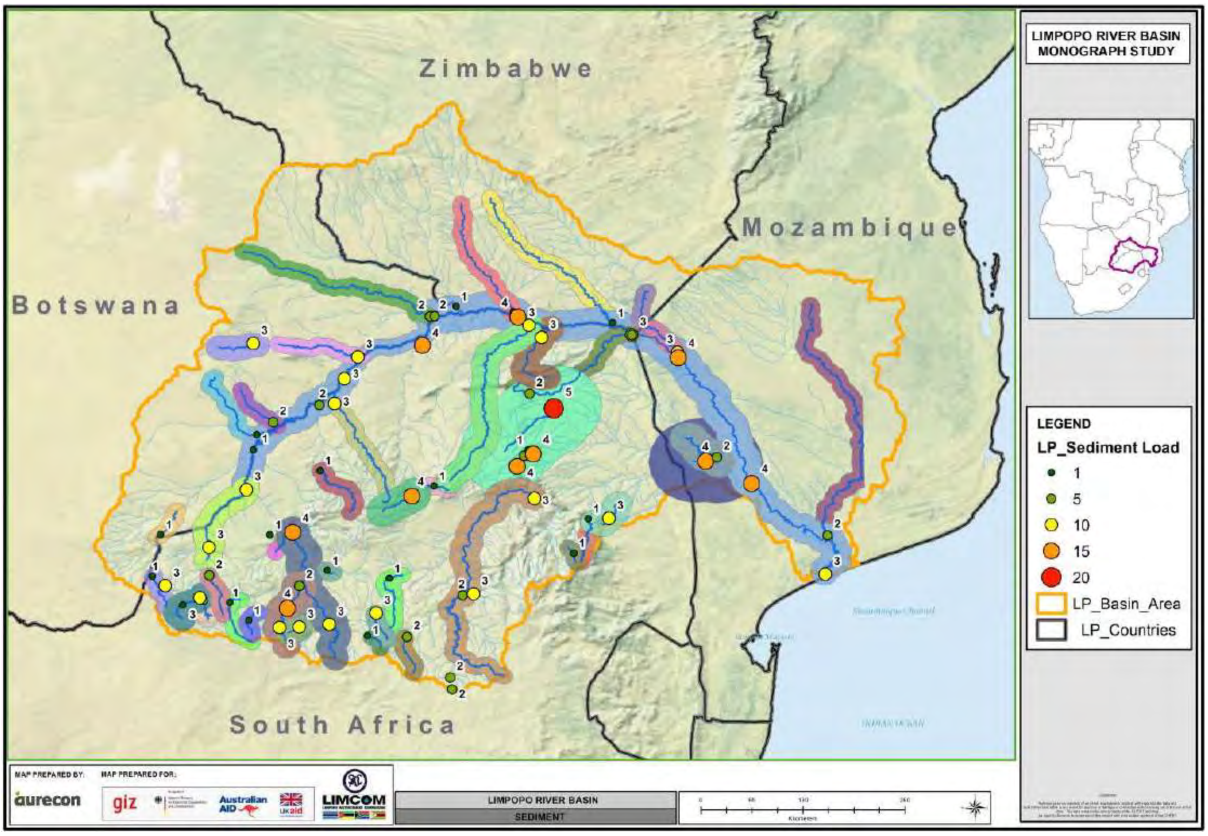

FIGURE 4.12 SEDIMENT LOAD VALUES FOR THE LIMPOPO RIVER AND ITS TRIBUTARIES (ROSSOW, 2013)

4.6 LONGTUDINAL CONNECTIVITY IN LIMPOPO DRAINAGE BASIN

The natural sediment yield for the Limpopo basin is estimated at ~60 $t.km^{-2}.yr^{-1}$ which is low on a global scale, largely due to the relatively low topography, dry climate and resistant rock types (Milliman and Farsworth, 2011). Estimates of the modern day sediment yield of the Limpopo River claims a 80 % reduction due to sediment trapping by dams (Milliman and Farsworth, 2011). The suspended sediment yield for the Limpopo Basin has been reduced from 33 to 6Mt/yr and total dissolved solids from 6.2 to 1.3 Mt/yr (Milliman and Farsworth, 2011).

There are 101 reservoirs in the Limpopo basin ranging in volume from 0.4 – 2260 MCM (Figure 4.13; Lehner et al., 2011). This database excludes smaller farm dams and weirs that are used for water abstraction along many of the watercourses. There are no reservoirs along the mainstem of the Limpopo River, with all the reservoirs located along its tributaries. There are several weirs located along the middle and upper Limpopo River. Weirs are common along its tributaries.

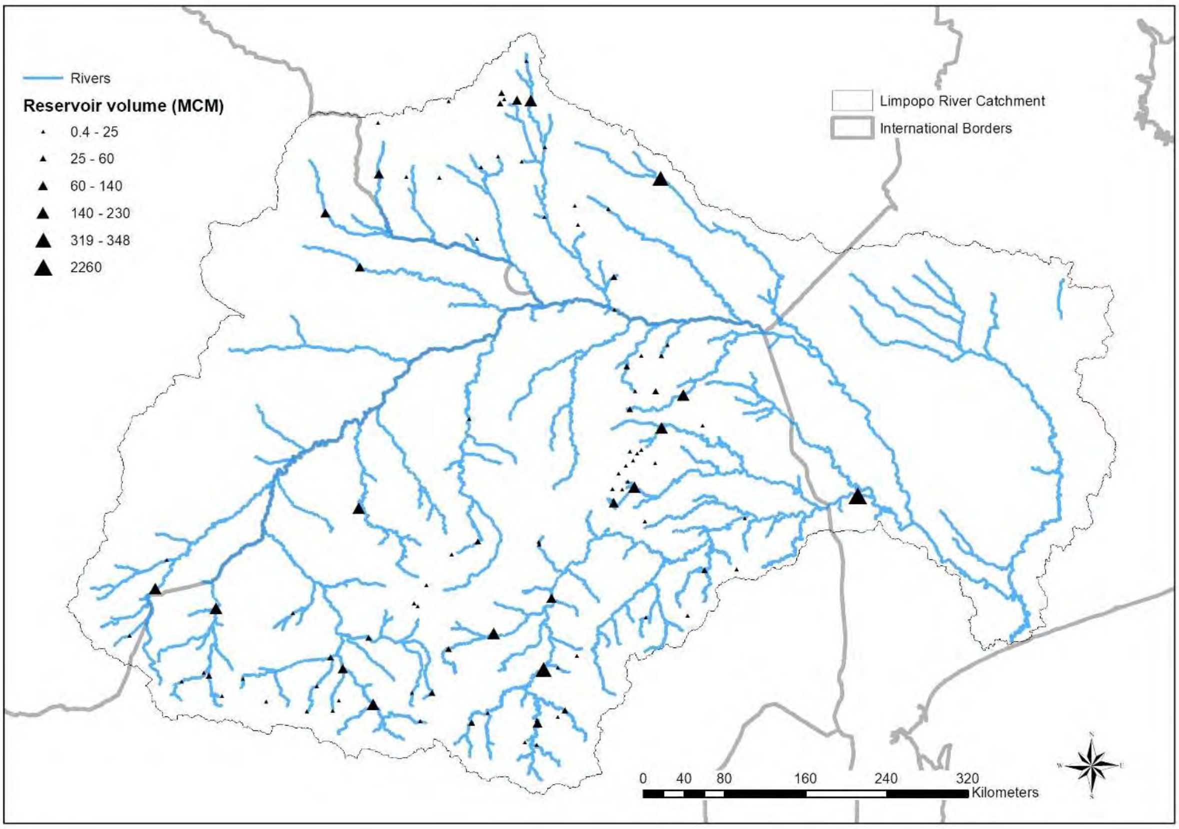

FIGURE 4.13: RESERVOIR LOCATION AND SIZE IN THE LIMPOPO RIVER CATCHMENT (RESERVOIR DATA FROM LEHNER ET AL. (2011))

4.7 PHYSICAL HABITAT TEMPLATE DYNAMICS IN THE LIMPOPO BASIN

The Sabie River in the Kruger National Park received much geomorphic research attention over the years and is typical of many of the bedrock-controlled rivers draining the Limpopo Basin. The main channel types for the Sabie River were described as bedrock (planforms: anastomosing, pool rapid and single thread), mixed (planforms: anastomosing, braided, single thread) and alluvial (planforms: braided and single thread) sections with a range of channel planforms (Heritage et al., 2001a; Rountree et al., 2001). The low gradient, mixed-bed rivers of the lowveld are sensitive to metamorphosis, where large floods scour sediment to expose bedrock and subsequent drier years lead to sedimentation, drowning out the bedrock template, such as pool-rapid sequences becoming braided channels (Rountree et al., 2001).

Heritage et al. (2001) studied the effect of contemporary flow regimes on the mixed-bed Sabie River. The used rated sections along the river reach to assess the inundation frequency of the various morphological units over a 62-year period. Unlike the temperate rivers of the northern hemisphere, the Sabie River channel composition was not linked to a single channel forming or bankful discharge. The relationship between flow and morphological units and processes were grouped in active perennial (dry season base flows), seasonal (high base flows, freshes and smaller floods) and low frequency flows (floods with 10-50 year return period). The morphology of the active channel is shaped by processes related to the perennial and seasonal flows, whereas the macro channel morphology is shaped by the low-frequency high magnitude events. The low-frequency events are responsible for resetting the active channel morphology.

Similarly, smaller floods lead to localised patterns of deposition and stripping, whereas large events support more general widespread stripping (Entwistle et al., 2015; Heritage et al., 2015; Rountree et al., 2000). Flood magnitude and frequency play a role in the extent and depth of stripping, with frequent large floods resulting in the removal of sedimentary layers and bedforms on bedrock

(Heritage et al., 2015). This leads to dramatic changes in morphology and habitat type and availability at a site, but maintains habitat diversity at the reach scale (Heritage et al., 2015).

Bedrock plays a key role in determining the channel type along the river profile, with rock acting as a gradient and hydraulic control (Entwistle et al., 2015). Flow velocities are highest along narrow alluvial zones compared to wider bedrock anastomosing reaches, despite the steeper gradient of the bedrock sections (Entwistle et al., 2015). This results in sediment stripping of the alluvial sections during larger flow events (resulting in highly variable habitat dynamics), with limited erosion along the anastomosing sections (low variability of habitat) (Entwistle et al., 2015).

Unconsolidated geomorphic features along alluvial sections are eroded during the rising limb and rebuilt during the falling limb of flood events (Entwistle et al., 2015). The presence of uneven protruding bedrock creates high hydraulic diversity during floods and supports greater channel and habitat diversity compared to alluvial sections (Milan et al., 2018). Despite highly variable outcomes of the large flood events, sections with a bedrock influence will support processes that ensure a range of physical habitat (Milan et al., 2018).

For the more arid rivers of the low veld, climate change predictions show that cyclone activity and associated extreme flooding is likely to increase due to the southward shift of the 26 C isotherm (Fitchett and Grab, 2014), possibly resulting in more frequent sediment stripping events (Milan et al., 2018). The likely influence on the habitat diversity and riparian vegetation stability is depicted in Figure 4.14. This model suggests a move towards more exposed bedrock with an increase in extreme flood flows.

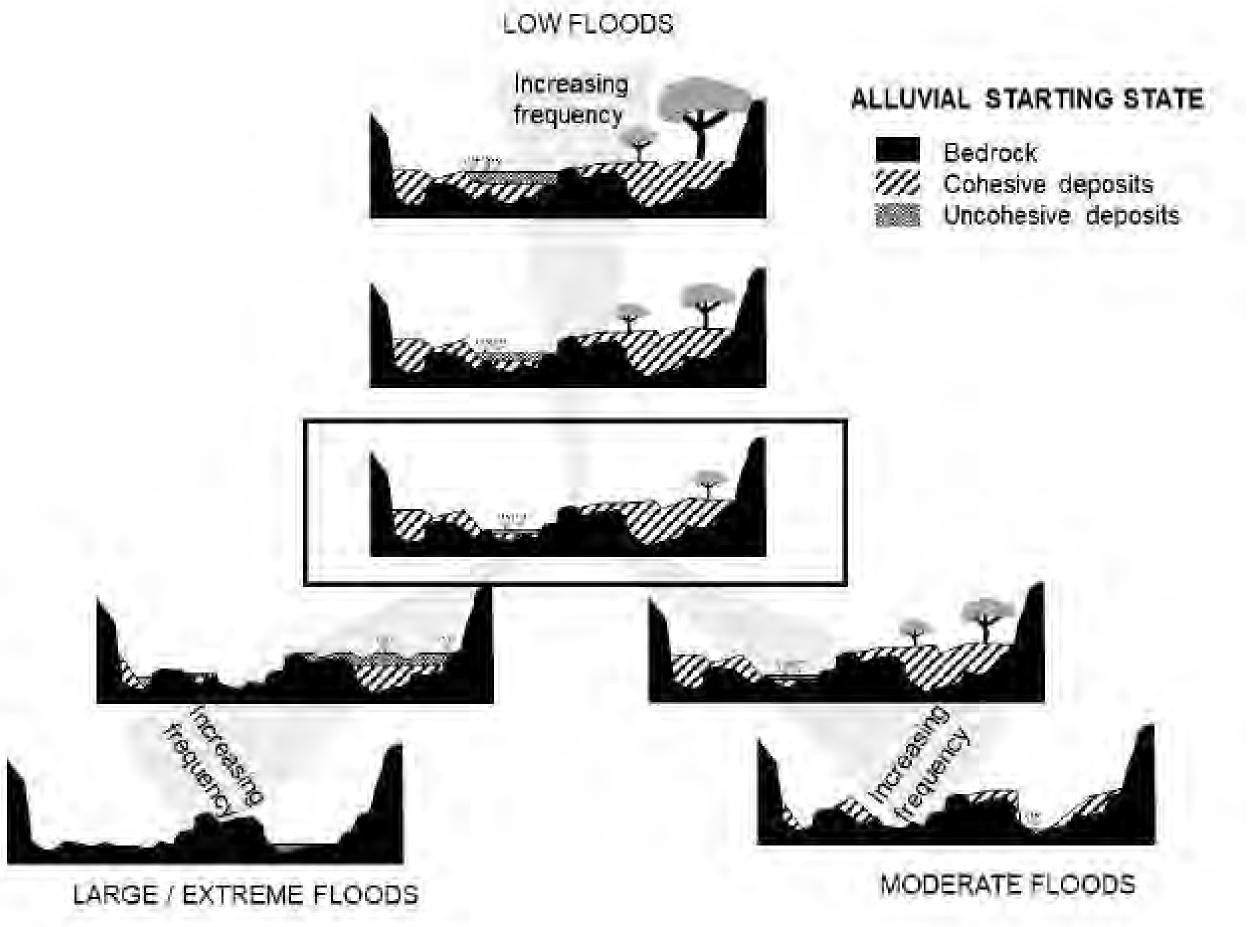

FIGURE 4.14: THE EFFECT OF AN INCREASE IN VARIOUS FLOOD MAGNITUDES ON A BEDROCK CONTROLLED RIVER REACH (TAKEN FROM MILAN ET AL. (2018))

4.8 PREVIOUS BASIN-SCALE EWR STUDIES ON GEOMORPHOLOGY AND HYDRAULICS

A previous EWR was carried out for the Limpopo basin in 2013 (Limpopo River Basin Monograph, 2013). Key geomorphic and hydraulic information (Limpopo River Basin Monograph (2013) and Kleynhans (2013)) for the sites shown in Figure 4.15 is presented in this section.

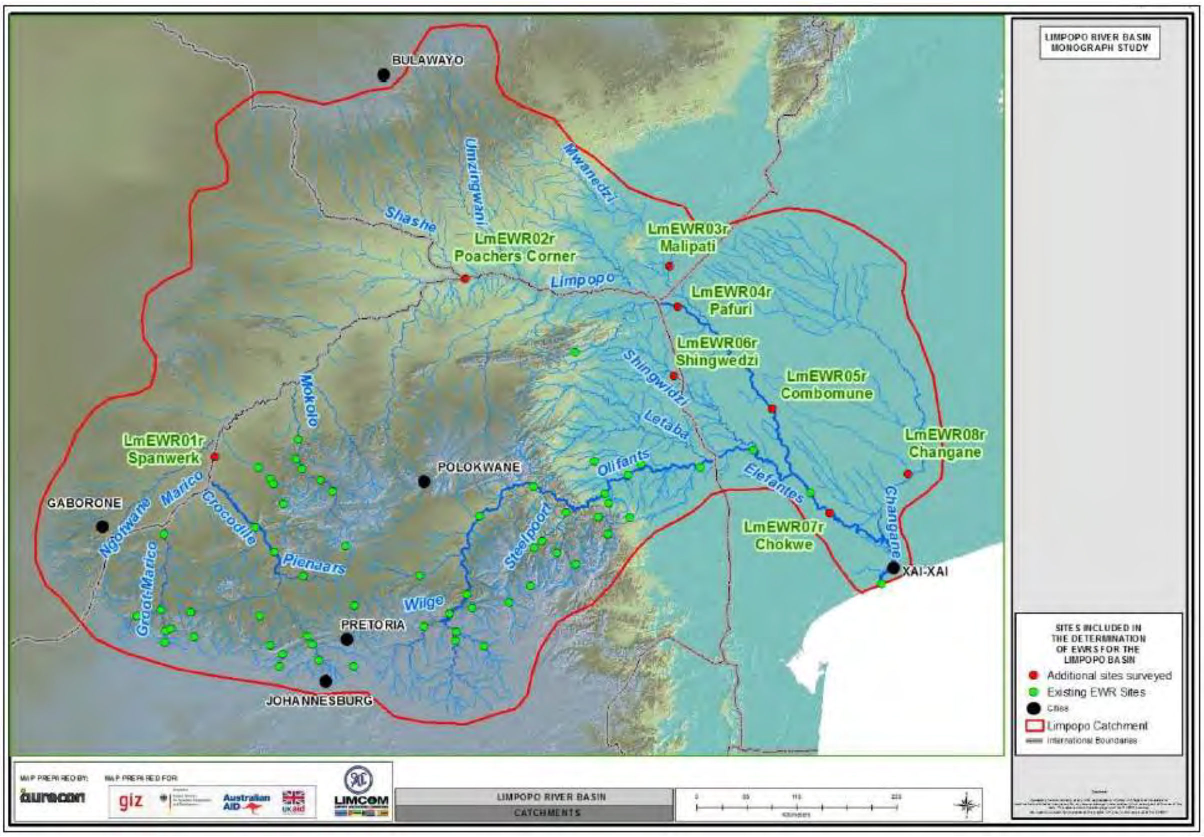

FIGURE 4.15: LOCATION OF THE PREVIOUS EWR SITES FOR THE BASIN-WIDE EWR STUDY (LIMPOPO RIVER BASIN MONOGRAPH, 2013).

Method used to develop hydraulic models for the previous EWR studies

Flow velocity, discharge and bed topography were captured along a single transect per site. Flow velocity data were measured with a handheld Marsh McBirney Flo-Mate 2000 electromagnetic current meter (Kleynhans, 2013). Where depths exceeded 1,5 m, velocity was not measured at 60% of depth (point at which average flow velocity for the column can be observed) but measured at the surface and multiplied by 0.85 to calculate average velocity. Depth and topographical data, including water surface and river bed slope, along with other points of interest were surveyed with a total station (Kleynhans, 2013).

Higher flows were modelled using the Mannings equation and used to develop a rating curve. The rating curve was expressed using Equation 1 as it is commonly used in hydraulic work in Southern Africa (James and King, 2010).

Equation 1

$$y = aQ^{b} + c$$

The hydraulic habitat distributions for various levels was modelled using HABFLO (Hirschowitz et al., 2007). Depth-velocity classes are specified below and illustrated in Figure 4.16.

SVS Slow / very shallow

SS Slow / shallow

SD Slow / deep

FVS Fast / very shallow

FS Fast / shallow

FI Fast / intermediate

FD Fast / deep

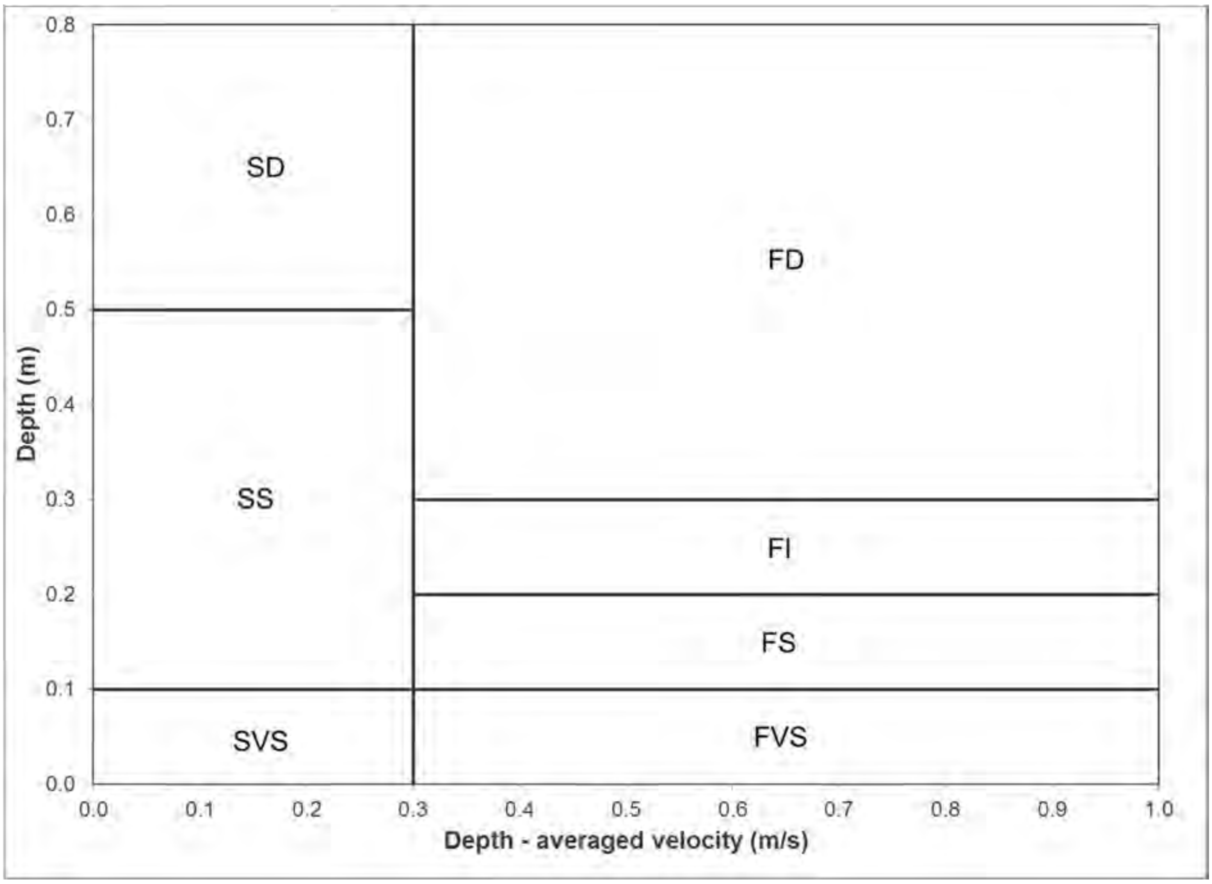

FIGURE 4.16: DEPTH VELOCITY CLASSES USED TO QUANTIFY HYDRAULIC HABITAT

LmEWR01r on the Limpopo River at Spanwerk upper Limpopo River (855 masl), Limpopo plain ecoregion, sweet bushveld vegetation

The site falls in a pool dominated reach, where dykes form a geological control and maintains the pool water level (Figure 4.17). Small weirs are created to lift the water level along rocky sections, as was the case at the site. The dyke forms an anastomosing bedrock run/rapid with 4 main channels and is 200 m in length to the head of the next pool (Figure 4.18). Small vegetated islands were present where sediment is deposited on and around higher bedrock points/protrusions. These bedrock sections are not common along this reach. Large trees (Sycamore Figs (*Ficus sycomorus*), Jackal Berries (*Diospyros mespiliformis*) and *Acacia* spp.) line the edges of the macro channel, with sedges, reeds and grasses growing along the lower and more active banks. Grazing was more intense on the left bank (Botswana side) of the River.

The hydraulic assessment was done along a single transect just upstream of where the single channel (low gradient pool) transitions into several steeper channels. Water levels were artificially high due to the small weir just downstream of the cross section. The observed flow was 1.426 m^3/s, corresponding to a maximum depth of 0.801 m. The rating cure has less certainty at higher flows due to the multi-channel complexity at the site and lack of observed high flows. Higher flows were modelled using the Mannings equation and used to develop a rating curve (Table 4.2, 4.3 and Figure 4.19). Velocity depth frequency distributions are shown in Figure 4.20.

FIGURE 4.17: LOCATION OF THE TRANSECT LINE (RED LINE) AND DIRECTION OF FLOW AT LMEWR01R ON THE LIMPOPO RIVER AT SPANWERK

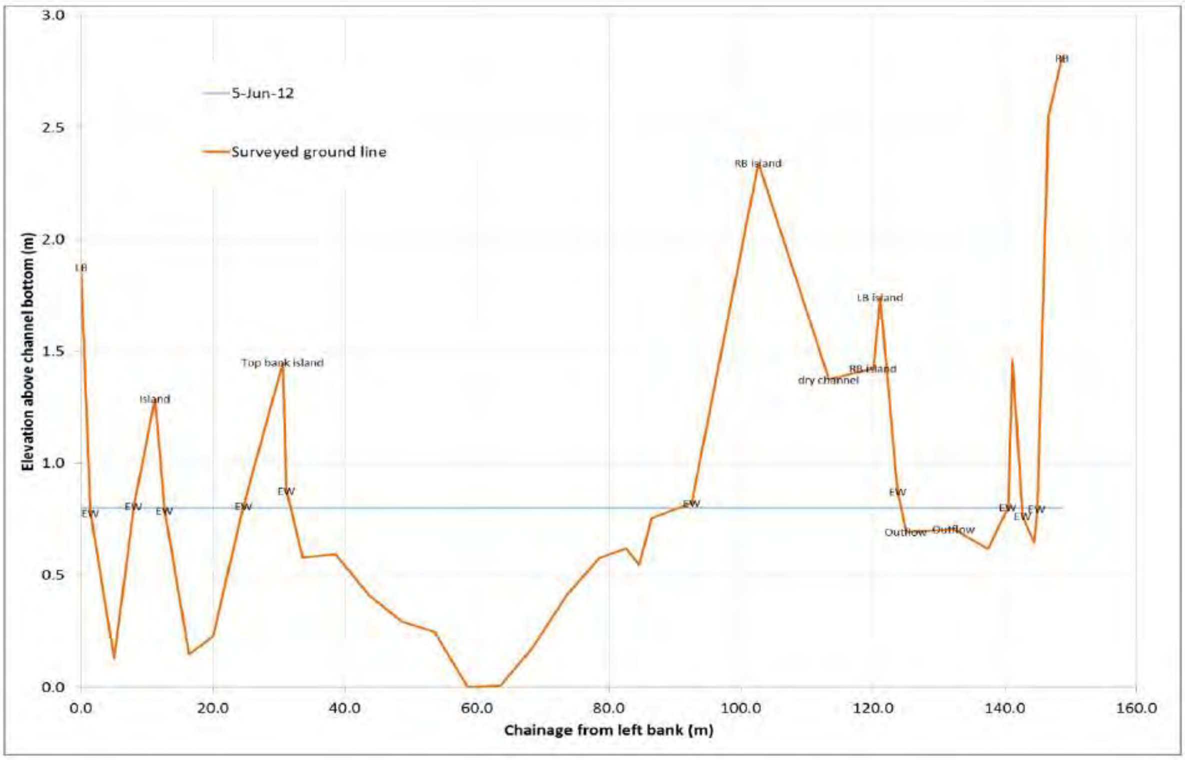

FIGURE 4.18: CHANNEL CROSS SECTION AT LMEWR01R ON THE LIMPOPO RIVER AT SPANWERK

TABLE 4.2: OBSERVED AND MODELLED DATA USED TO DERIVE THE RATING CURVE

DATE	DEPTH (M)	MANNINGS N	ENERGY GRADIENT	DISCHARGE (M^3/S)	VELOCITY (M/S)	COMMENT
Zero flow	0.58	N/A	N/A	0.000	0.000	Modelled
Tuesday, June 05, 2012	0.80	0.033	0.00010	1.426	0.093	Observed
Flood 1	1.80	0.045	0.00400	182.231	1.370	Modelled

TABLE 4.3: EQUATION TO THE RATING CURVE DERIVED FOR THE SITE

Power Fit: $y=ax^b + c$	
COEFFICIENT DATA:	
a =	0.195
b =	0.352
c =	0.580

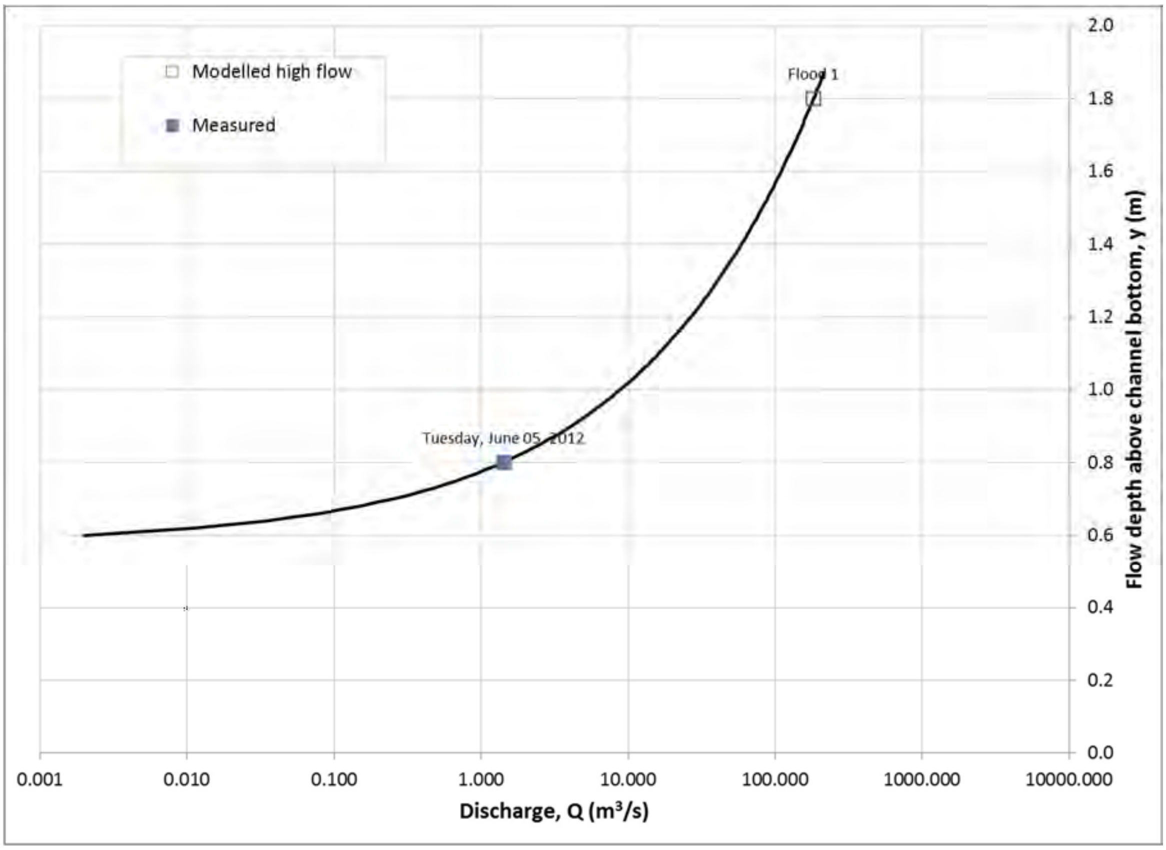

FIGURE 4.19 : RATING CURVE DERIVED FOR SPANWERK

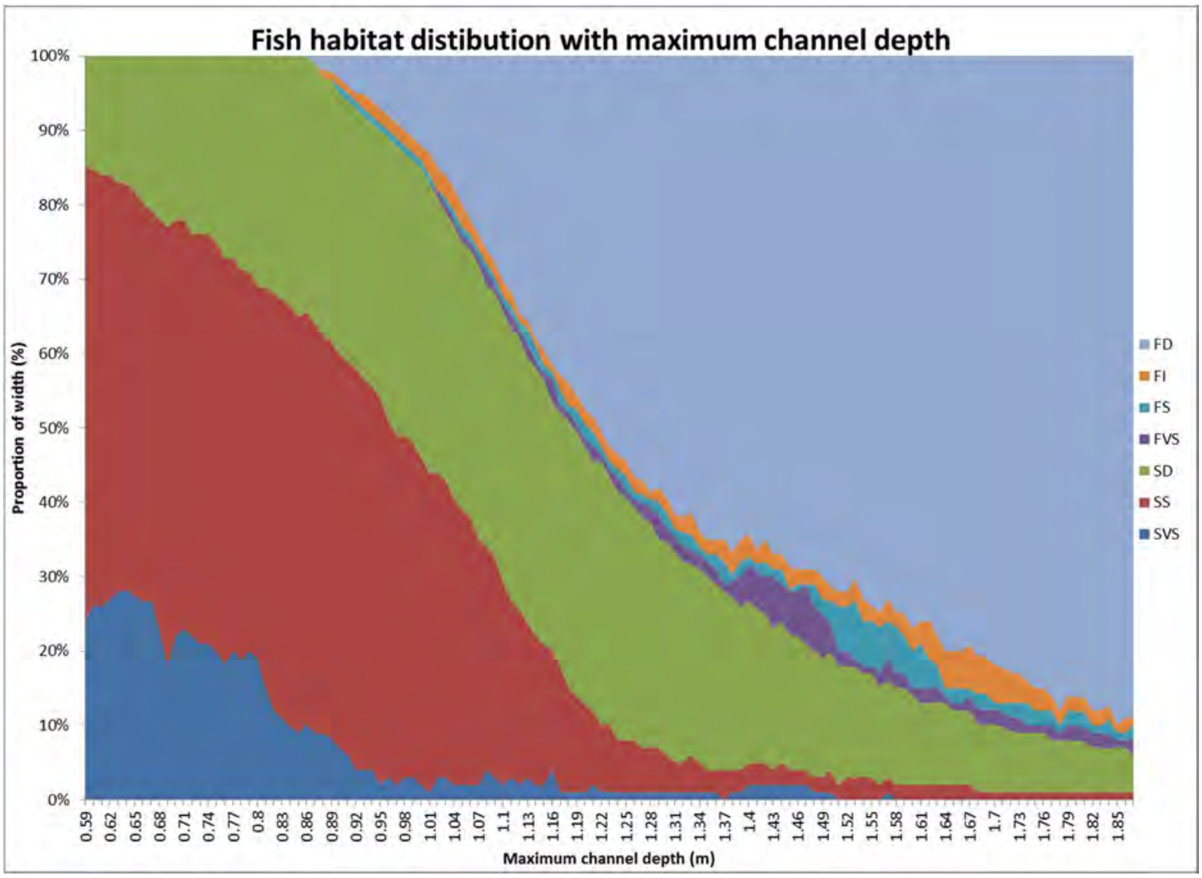

FIGURE 4.20 : FISH HABITAT DISTRIBUTION VERSUS MAXIMUM DEPTH IN THE CHANNEL AT SPANWERK

LmEWR02r: Limpopo at Poachers Corner

The site lies in the middle of the Limpopo Plain Ecoregion at an elevation of 514 masl. It is located downstream of the Shashe River confluence that used to link with the Okavango and Zambezi River drainage system (Moore and Larkin, 2001). The site is located upstream of a resistant dyke that forms a local base level control and forces subsurface flows to the surface (Figure 4.20). During low flow, the reach consists of a flat sandy bed, a wandering channel connecting smaller localised pools (Figure 4.21). Areas with slow flowing water has filamentous algae mats covering the sandy bed material. The macro channel is dominated by large trees (e.g. *Ficus sycamorous*) and the benches and banks along the active channel has sedges and grasses growing in open areas (Figure 4.22 and 4.23). Herbaceous vegetation is in a better condition on the RSA side but degraded by livestock on the left bank (Zimbabwe). Water abstraction for irrigation is common upstream of the site.

The site consists mainly of a smooth sand bed with a rocky hill on the left bank, vegetated with trees, and a sandy right bank vegetated with trees and bush. There were two points where the cross-section encountered surface water, one in the actively flowing channel along the left bank and one in a pool near the centre of the channel. The water levels for the two points differed by 7 cm, showing that the permeable sand ensures water levels remain similar across the channel. The observed flow was 0.081 m^3/s, corresponding to a maximum depth of 0.060 m on the cross section (Table 4.4). The confidence in the flow depth modelling was low due to the square shape of the channel and the sand bed nature of the site (the model is developed for coarser grained riffle habitats; Table 4.5). The rating curve and flow depth frequency distributions for Poachers corner are presented in Figures 4.24 and 4.25.

FIGURE 4.21: OBLIQUE AERIAL VIEW OF THE LIMPOPO RIVER AT THE POACHERS CORNER SITE. THE CROSS SECTION AND FLOW DIRECTION ARE INDICATED ON THE IMAGE

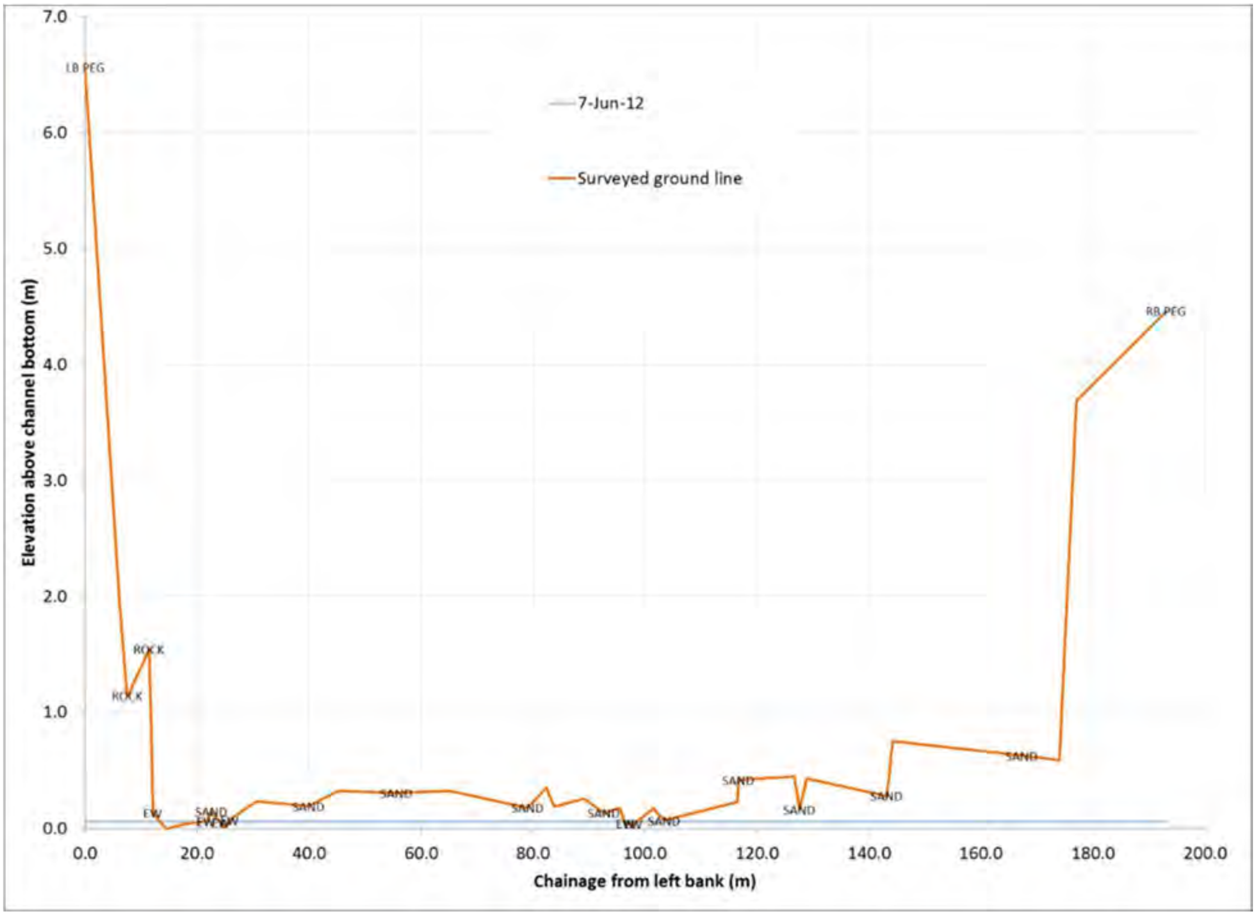

FIGURE 4.22: CHANNEL CROSS SECTION AT POACHERS CORNER

FIGURE 4.23: SATELLITE VIEW OF THE POACHERS CORNER CROSS-SECTION

TABLE 4.4: OBSERVED AND MODELLED DATA USED TO DERIVE THE RATING CURVE

DATE	DEPTH (M)	MANNIN GS N	ENERGY GRADIENT	DISCHARGE (M^3/S)	VELOCIT Y (M/S)	COMME NT
Zero flow	0.00	N/A	N/A	0.000	0.000	Modelled
Thursday, June 07, 2012	0.06	0.008	0.00152	0.081	0.395	Observed
Flood 1	1.00	0.023	0.00089	109.899	0.996	Modelled
Flood 2	3.00	0.028	0.00089	892.132	1.994	Modelled

TABLE 4.5: EQUATION TO THE RATING CURVE DERIVED FOR THE SITE (INTERCEPT AT 110M^{3}S AND 1M DEPTH)

Power Fit: $y = ax^b + c$		
COEFFICIENT DATA:	LOWER PART	UPPER PART
a =	0.160	0.077
b =	0.390	0.538
c =	0.000	0.040

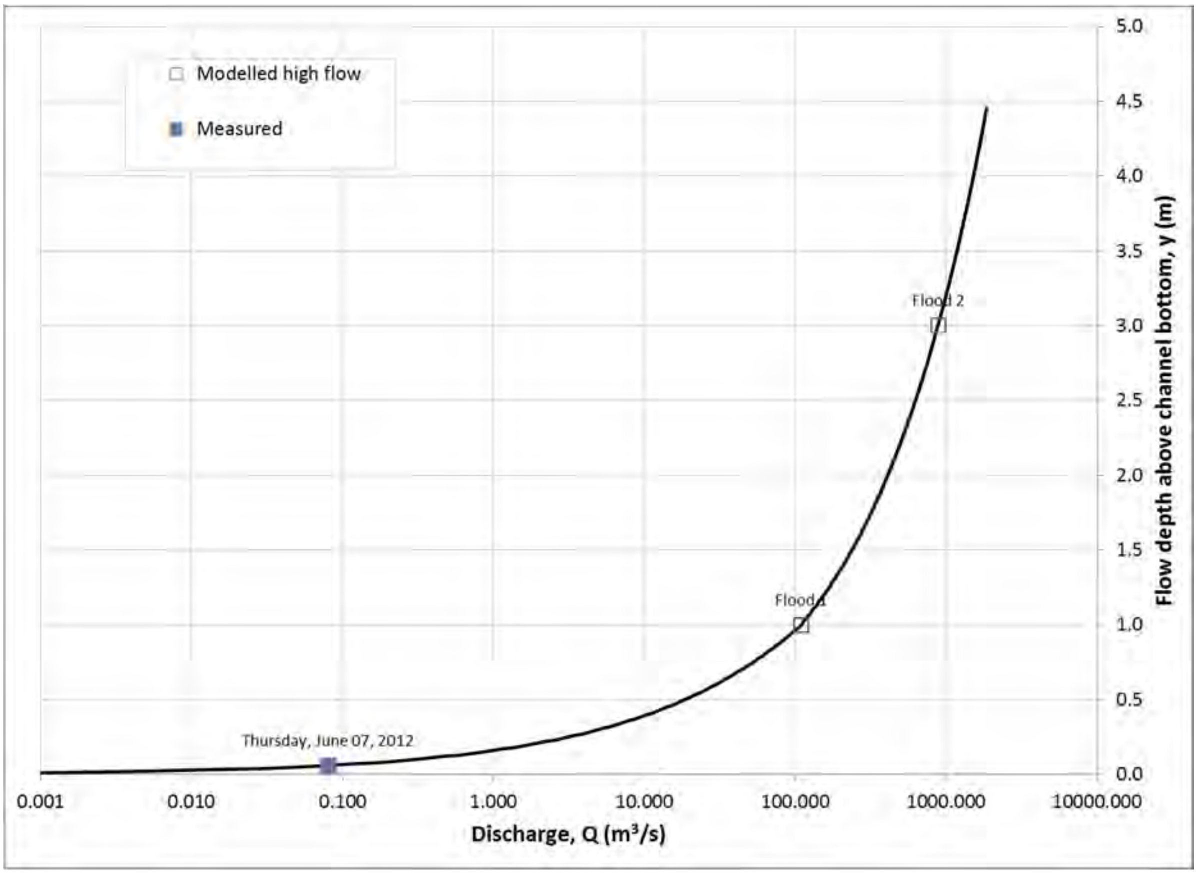

FIGURE 4.24 RATING CURVE DERIVED FOR POACHERS CORNER

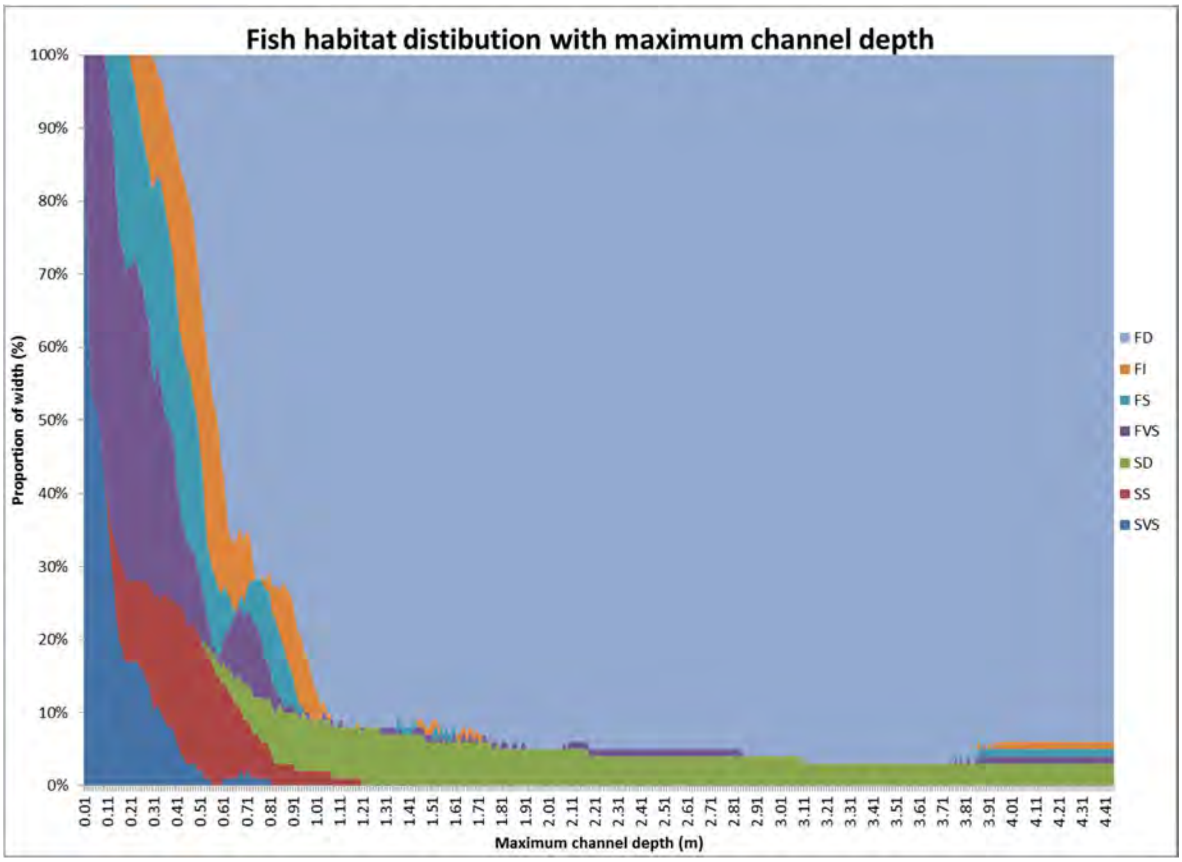

FIGURE 4.25: FISH HABITAT DISTRIBUTION VERSUS MAXIMUM DEPTH IN THE CHANNEL

LmEWR03r on the Nuanetzi River at Malipati

This site is located on a northern tributary, the Nuanetzi River, draining Zimbabwe. The reach is characterised by a low gradient sand bed channel with pool riffle sequences and localised bedrock sections (Figure 4.26, 4.27 and 4.28). Pools are long, 2 -4 m deep and maintained by bedrock, both through increased turbulence (scouring) during high flows and forcing flows to the surface during low flows. The low flow channel wanders within the larger macro channel and appears to be fixed in position (based on historical imagery). The macro channel banks are dominated by large trees (e.g. *F. sycamorous*). Sedges and grasses are present along the lower margin but overgrazing and trampling by livestock at the site results in bare banks, despite its proximity to the Gonarezhou National Park. The bed consists mostly of coarse sand and smaller pebble deposits, separated by shorter bedrock sections (Figure 4.26 and 4.27). Filamentous algae mats are common in slow flowing water.

The site is located upstream of a bedrock outcrop along the left bank, leading to the channel narrowing. Two cross sections were surveyed to model the contraction of the channel, but only the upstream section was used for the hydraulic rating curve (Figure 4.29 and Table 4.6 and 4.7). The observed flow was 0.560 m^3/s, with a maximum depth of 0.165 m. The confidence in the flow depth modelling was low due to the sand bed nature of the site (the model is developed for riffle habitats). The velocity flow frequency distribution is presented in Figure 4.30.

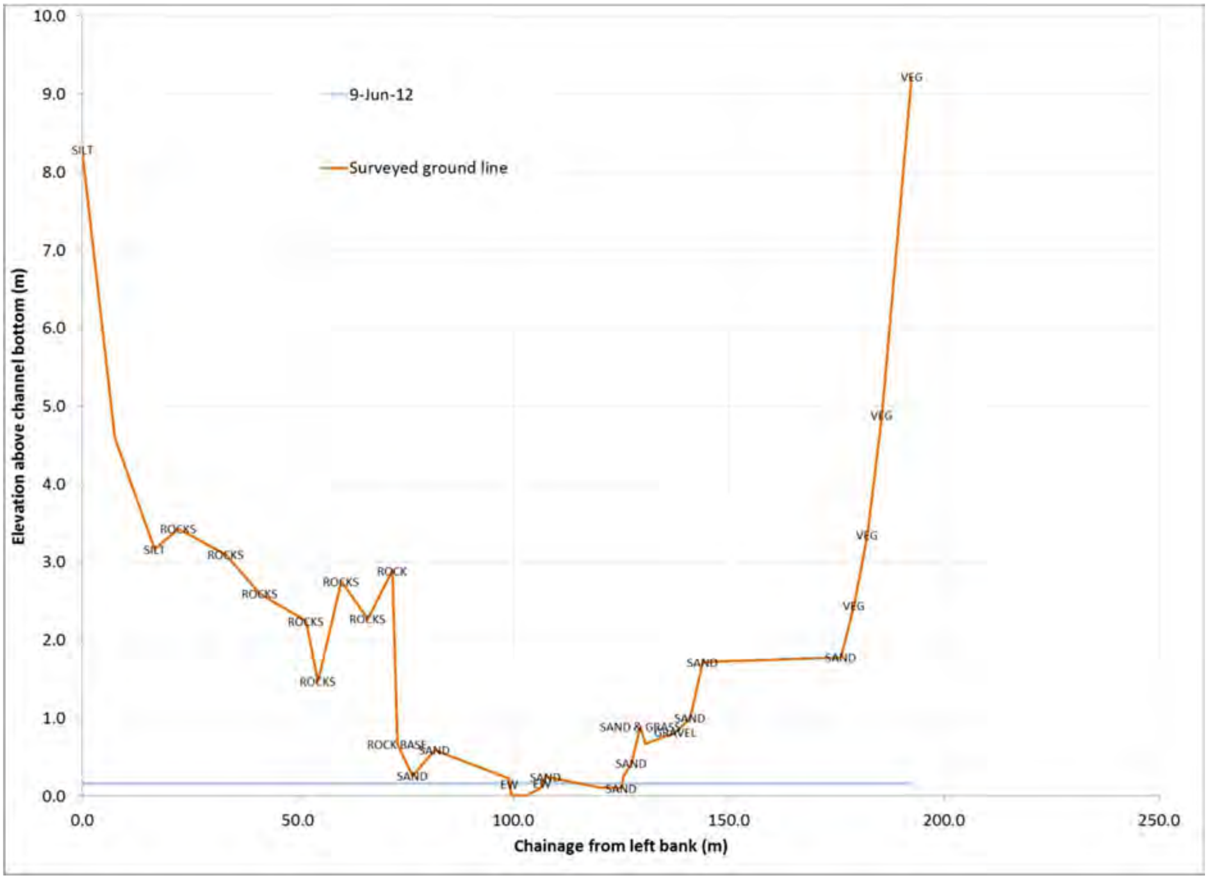

FIGURE 4.26: CROSS-SECTION SURVEYED FOR THE MALAPATI SITE SHOWING THE WATER LEVEL THAT WAS OBSERVED ON 9 JUNE 2012, EW = SURVEYED EDGE OF WATER

FIGURE 4.27: AERIAL VIEW OF SITE LMEWR03R WITH THE LOCATION OF THE SURVEYED CROSS SECTION AND THE DIRECTION OF FLOW ILLUSTRATED

FIGURE 4.28: SATELLITE VIEW OF THE MALAPATI CROSS-SECTION

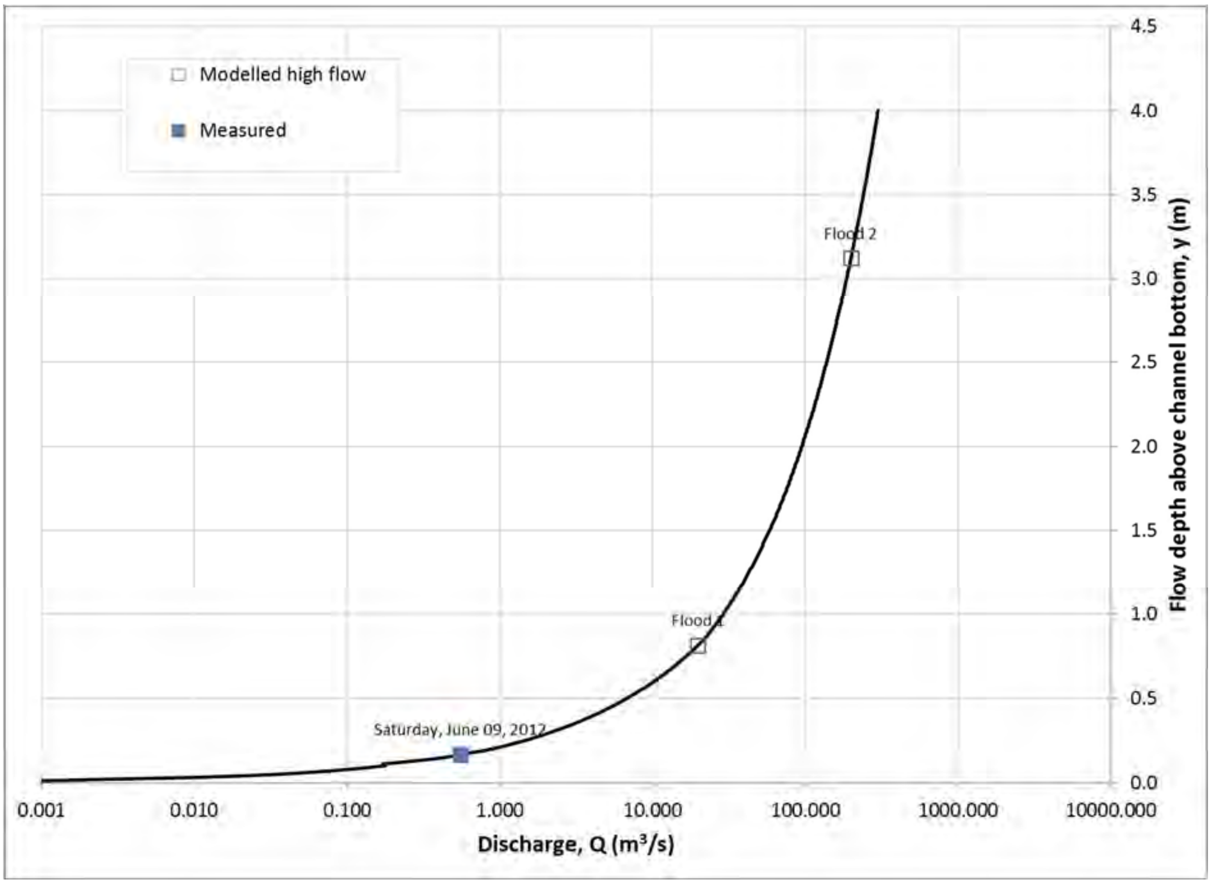

FIGURE 4.29: RATING CURVE DERIVED FOR MALAPATI

TABLE 4.6: OBSERVED AND MODELLED DATA USED TO DERIVE THE RATING CURVE

DATE	DEPTH (M)	MANNINGS N	ENERGY GRADIENT	DISCHARGE (M^3/S)	VELOCITY (M/S)	COMMENT
Zero flow	0.00	N/A	N/A	0.000	0.000	Modelled
Saturday, June 09, 2012	0.17	0.016	0.00152	0.560	0.598	Observed
Flood 1	0.81	0.019	0.00048	20.000	0.681	Modelled
Flood 2	3.12	0.019	0.00009	200.000	0.753	Modelled

TABLE 4.7: EQUATION TO THE RATING CURVE DERIVED FOR THE SITE (INTERCEPT AT $20M^3.S^{-1}$ AND 0.81 M)

Power Fit: $y = ax^b + c$		
COEFFICIENT DATA:	**LOWER PART**	**UPPER PART**
a =	0.214	0.112
b =	0.445	0.623
c =	0.000	0.087

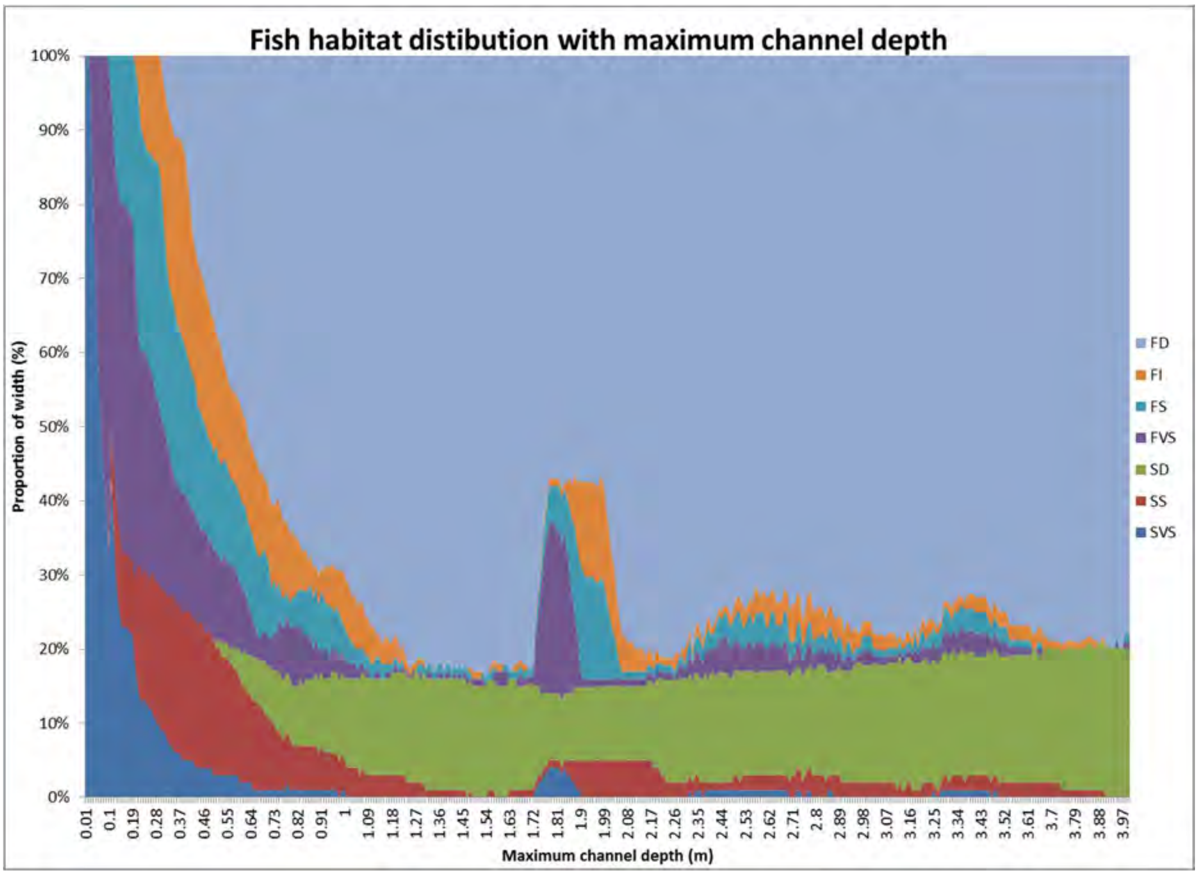

FIGURE 4.30: FISH HABITAT DISTRIBUTION VERSUS MAXIMUM DEPTH IN THE CHANNEL FOR MALAPATI

LmEWR04r on the Limpopo River at Pafuri

This site is located on the Limpopo River, 21 km downstream of the confluence with the Luvuvhu River and the eastern side of the Lebombo Ridge. It is located at an altitude of 183 masl and lies at the higher end of the Mozambican Lowland zone that forms the coastal plain. The reach has a wide (~600 m wide) sand dominated macro channel (Figure 4.31, 4.32, 4.33 and 4.34) with fig trees present on the floodplain. Some cultivation takes place on the floodplain, but grazing is the main land use and livestock drink directly from the river. Vegetated islands divide the macro channel into multiple active channels forming a braided pattern during low to moderate flows (Figure 4.30). The site appears relatively stable in plan layout from historical satellite imagery. The channels are sand dominated and shallow, even sections that appear to be pools. The right bank was undercut in areas with *Phragmites* reeds lining the channel.

Habitat diversity was relatively low in the shallow system. Some deeper water (up to 1 m deep) formed along undercut banks and root wads. Filamentous algal mats were common in habitats with lower flow velocities. Overgrazing and trampling are evident at the site, with poor vegetation cover, except for the large fig trees along the higher banks and floodplain.

The multiple channels made the hydraulic model less certain (Figure 4.33). The observed flow measured on the day of the survey was 0.669 m^3/s, corresponding to a maximum depth of 0.274 m on the cross-section (flow in three of the channels). The level of the water across the three channels (400 m width) was less than 15 cm, showing the hydraulic link between the channels due to the pervious sandy bed. The hydraulic model output predicted depth reasonable, but velocities were overestimated compared to the observed data (Table 4.8 and 4.9 and Figure 4.35). Flow velocity depth frequency distributions are shown in Figure 4.36.

FIGURE 4.31: AERIAL VIEW OF SITE LMEWR04 WITH THE LOCATION OF THE SURVEYED CROSS SECTION AND THE DIRECTION OF FLOW ILLUSTRATED

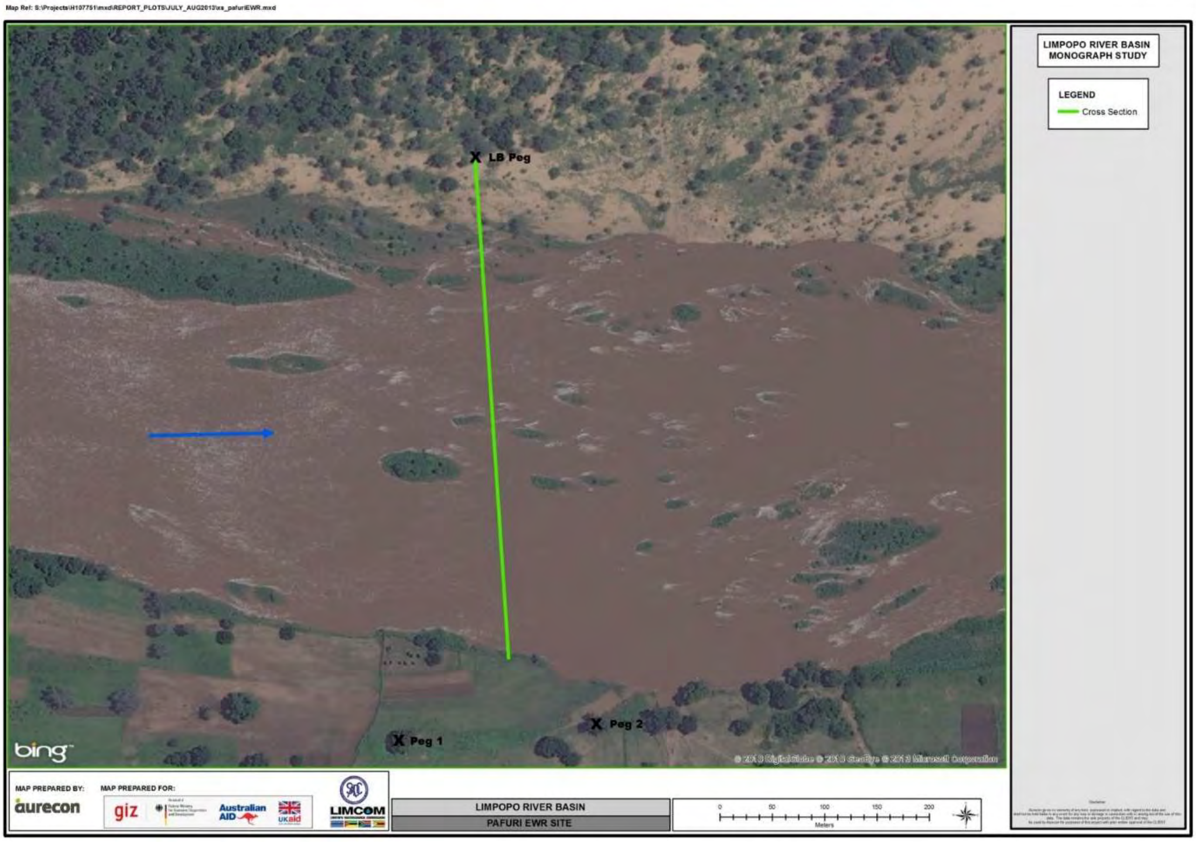

FIGURE 4.32: SATELLITE VIEW OF THE PAFURI CROSS-SECTION

FIGURE 4.33: VIEW FROM RIGHT BANK TOWARDS LEFT BANK

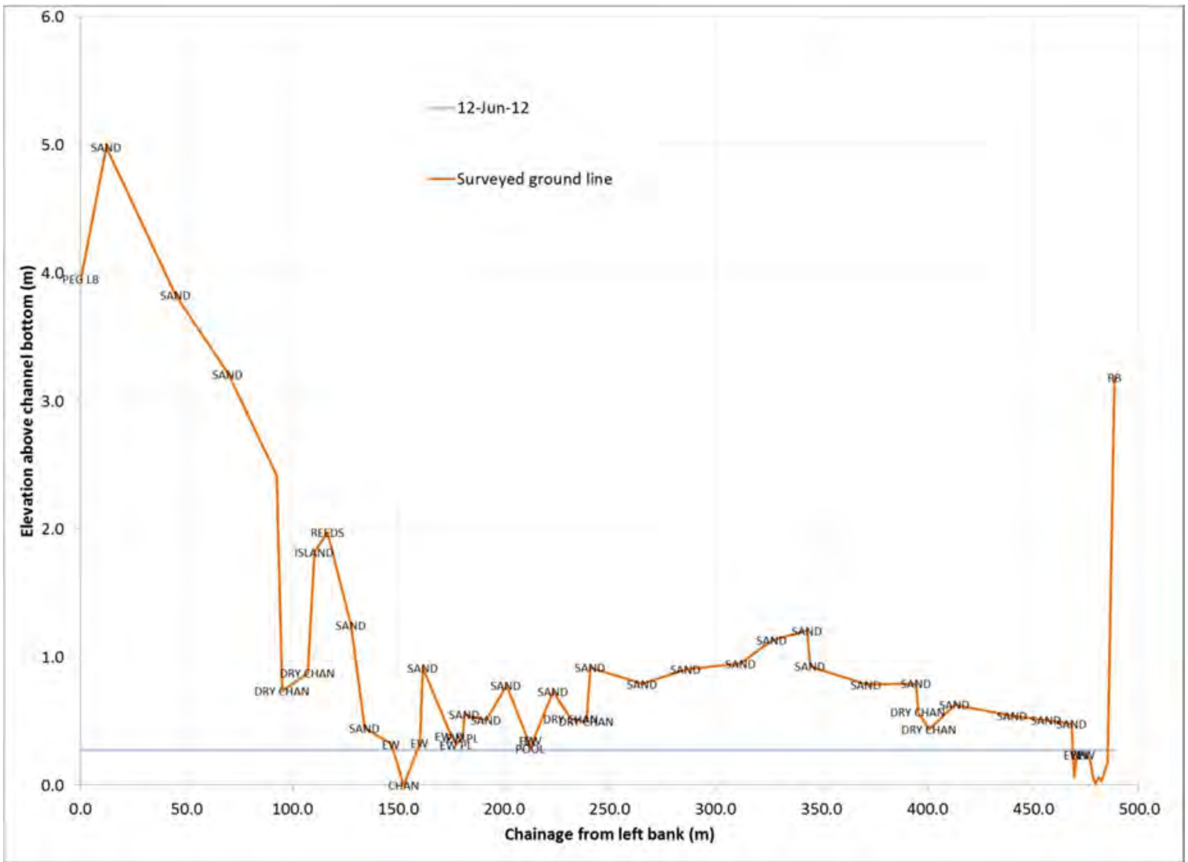

FIGURE 4.34 CROSS-SECTION SURVEYED FOR THE PAFURI SITE SHOWING THE WATER LEVEL THAT WAS OBSERVED ON 12 JUNE 2012, EW = SURVEYED EDGE OF WATER

TABLE 4.8: OBSERVED AND MODELLED DATA USED TO DERIVE THE RATING CURVE

DATE	DEPTH (M)	MANNINGS N	ENERGY GRADIENT	DISCHARGE (M3/S)	VELOCITY (M/S)	COMMENT
Zero flow	0.00	N/A	N/A	0.000	0.000	Modelled
Tuesday, June 12, 2012	0.27	0.027	0.00034	0.637	0.172	Observed
Flood 1	2.00	0.025	0.00086	681.499	1.367	Modelled
Flood 2	3.00	0.028	0.00086	1572.877	1.752	Modelled

TABLE 4.9: EQUATION TO THE RATING CURVE DERIVED FOR THE SITE (INTERCEPT AT 681.5 M3.S-1 AND 2M DEPTH)

Power Fit: $y = ax^b + c$		
COEFFICIENT DATA:	**LOWER PART**	**UPPER PART**
a =	0.308	0.054
b =	0.287	0.536
c =	0.000	0.231

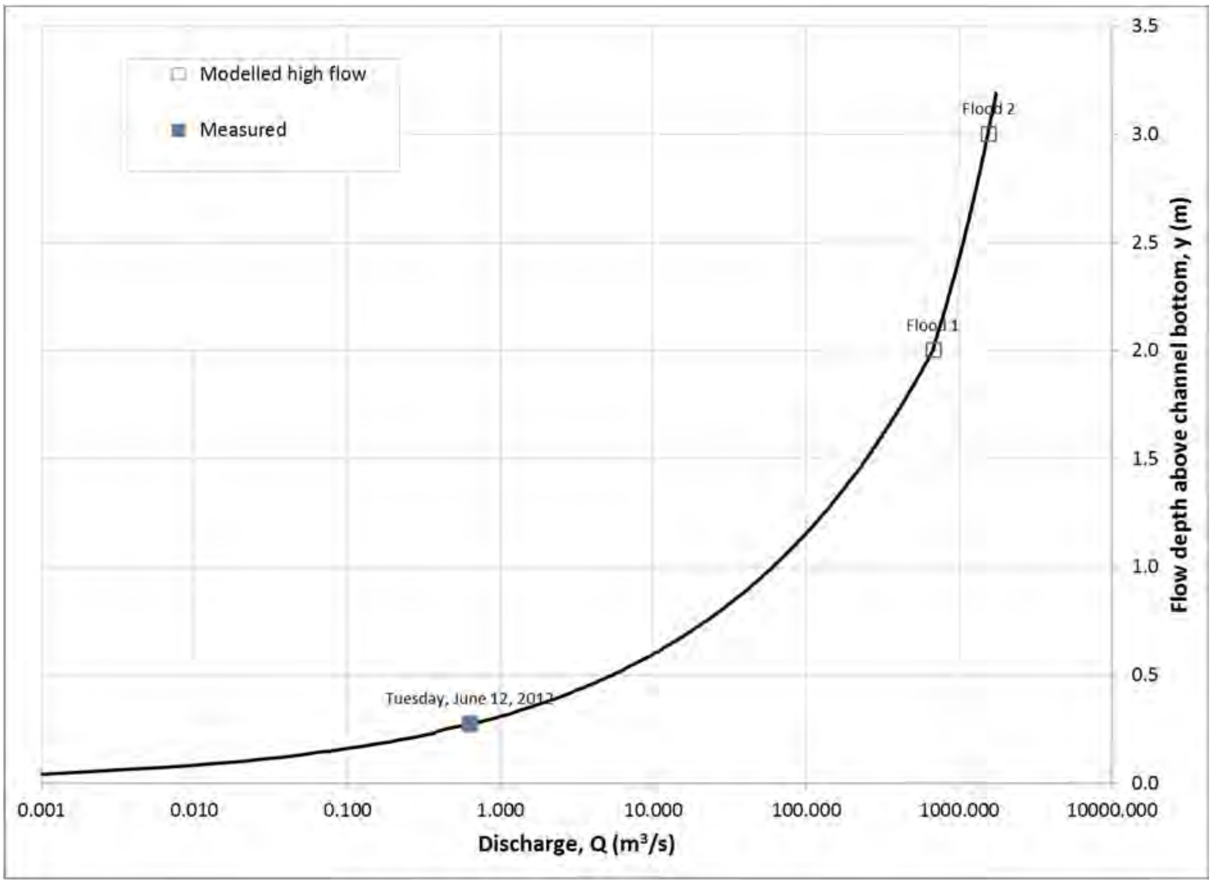

FIGURE 4.35: RATING CURVE DERIVED FOR PAFURI

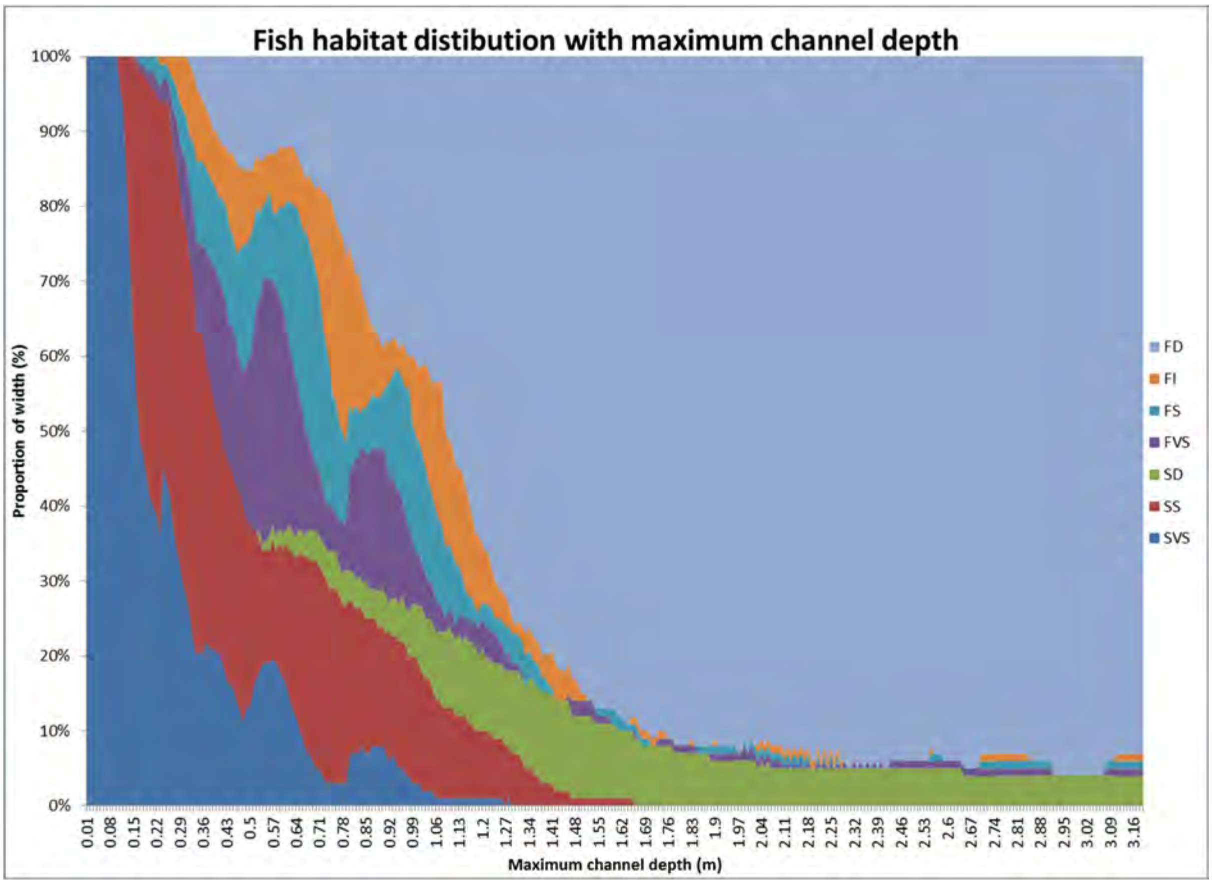

FIGURE 4.36: FISH HABITAT DISTRIBUTION VERSUS MAXIMUM DEPTH IN THE CHANNEL

LMEWR05R: LIMPOPO RIVER AT COMBOMUNE

Combomune lies at an elevation of 85 masl and is 125 km downstream of the confluence with the Nuanetsi River and upstream of the Elephantes confluence. It is in the middle of the coastal plain within a wide sandy floodplain (Figure 4.37). The macro channel is about 600 m wide and has a series of benches and sand bars (Figure 4.38, 4.39 and 4.40). The low flow channel is located along the left bank. The floodplain is extensively utilised for cultivation and grazing. Large Sycamore figs remain intact on the macro channel banks. Overgrazing and trampling are widespread resulting in poor vegetation cover. *Phragmites r*eeds line the banks causing some localised undercutting. Fish habitat was reasonable along this sand dominated reach with deeper water along the reed-lined banks providing deeper water and undercut banks.

The site is located on a slight bend with the low flow channel along the outer left of the channel. It is located 200 m upstream of the Combomune gauging station E33 and old pump station. The single transect was surveyed and linked to the Combomune gauging station E33 datum to allow to link to the existing flow rating for the gauge. The observed flow was 0.333 m^3/s, corresponding to a maximum depth of 0.175 m on the cross-section. Velocity depth predictions were reasonable, with depths being better than velocity frequencies (Table 4.10 and 4.11 and Figure 4.41). Observed velocities were slower than the modelled velocities at low flows as was observed. Flow velocity depth frequency distributions are shown in Figure 4.42.

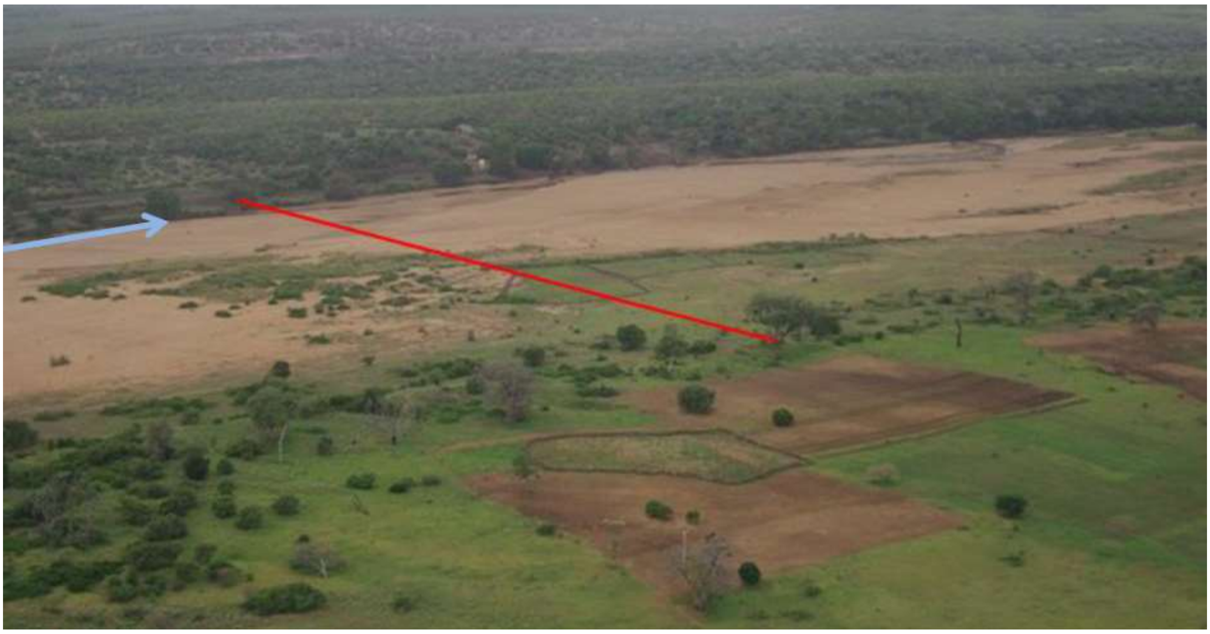

FIGURE 4.37: AERIAL VIEW OF SITE LMEWR05 WITH THE LOCATION OF THE SURVEYED CROSS SECTION AND THE DIRECTION OF FLOW ILLUSTRATED

FIGURE 4.38: SATELLITE VIEW OF THE COMBOMUNE CROSS-SECTION

FIGURE 4.39: VIEW FROM LEFT BANK TOWARDS RIGHT BANK

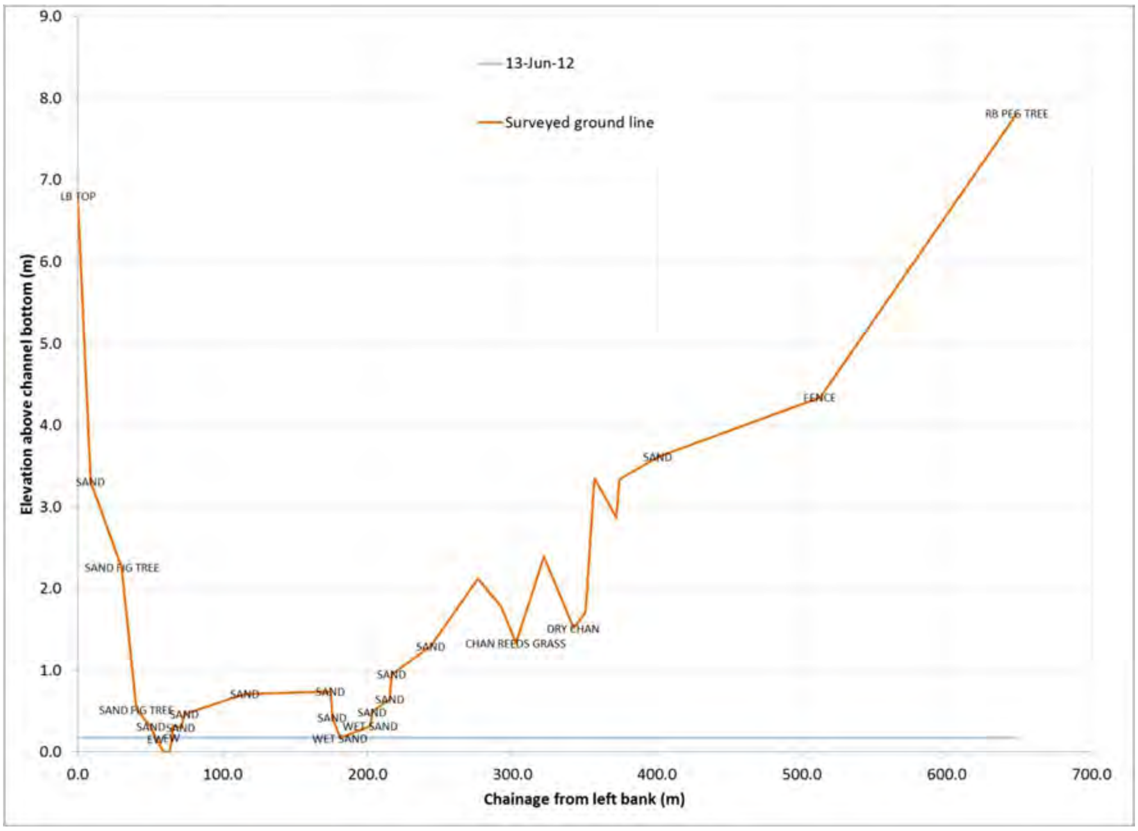

FIGURE 4.40: CROSS-SECTION SURVEYED FOR THE COMBOMUNE SITE SHOWING THE WATER LEVEL THAT WAS OBSERVED ON 13 JUNE 2012, EW = SURVEYED EDGE OF WATER

TABLE 4.10: OBSERVED AND MODELLED DATA USED TO DERIVE THE RATING CURVE

DATE	DEPTH (M)	MANNINGS N	ENERGY GRADIENT	DISCHARGE (M3/S)	VELOCITY (M/S)	COMMENT
Zero flow	0.00	N/A	N/A	0.000	0.000	Modelled
Wednesday, June 13, 2012	0.18	0.020	0.00046	0.333	0.245	Observed
Flood 1	2.00	0.023	0.00041	295.100	0.931	Modelled
Flood 2	5.00	0.019	0.00041	3329.632	2.166	Modelled

TABLE 4.11: EQUATION TO THE RATING CURVE DERIVED FOR THE SITE (INTERCEPT AT 295M³.S-1 AND 2 M DEPTH).

Power Fit: $y = ax^b + c$		
COEFFICIENT DATA:	LOWER PART	UPPER PART
a =	0.260	0.225
b =	0.359	0.381
c =	0.000	0.027

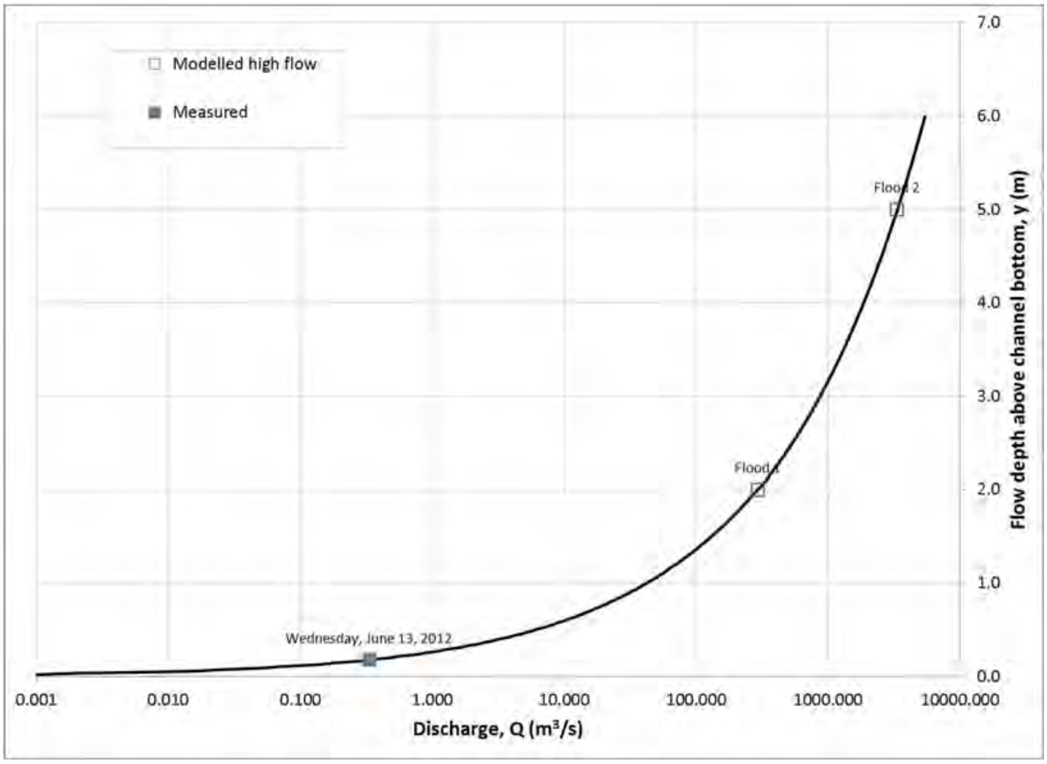

FIGURE 4.41: RATING CURVE DERIVED FOR COMBOMUNE

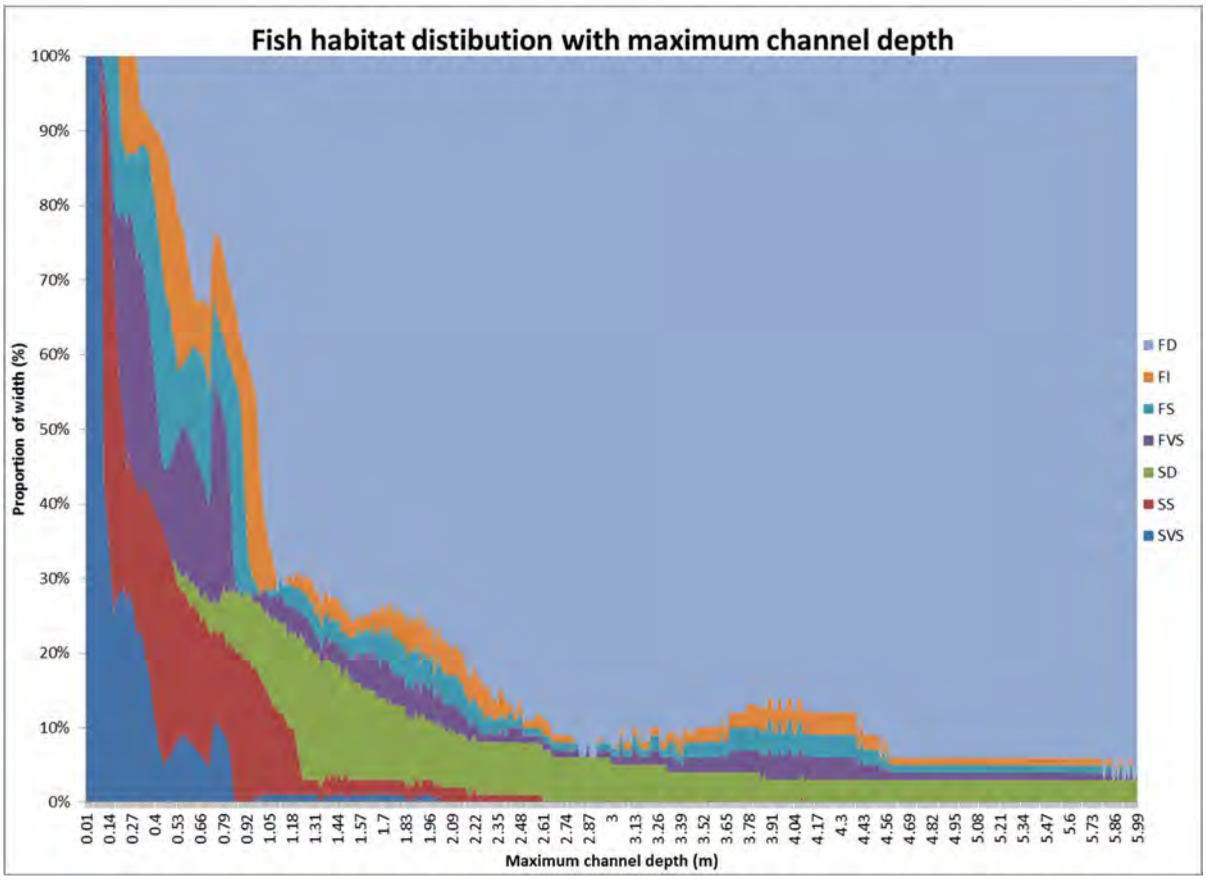

FIGURE 4.42: FISH HABITAT DISTRIBUTION VERSUS MAXIMUM DEPTH IN THE CHANNEL

LmEWR06r on the Shingwedzi River

The Shingwedzi River is one of the larger tributaries to the Elephantes River (a tributary to the Limpopo River). The site (and the Shingwedzi River catchment) is in the Kruger National Park at an elevation of 260 masl. It falls between the Lebombo Uplands and Lowveld ecoregions. The site is located 1 km downstream of the Kanniedood dam. The reach is bedrock dominated with reeds lining various pools and anastomosing channels (Figure 4.43). The macro channel was lined by large fig & jackal berry trees, and the active channel or lower riparian zone was dominated by *Phragmites mauritianus*, and sedges (*Cyperus textilis*). The reeds stabilise the sand banks/bars overlaying the bedrock. Riffle habitats are present along the narrow channels and connect the pools, which are maintained by the frequent movement of hippos and create deep slow flowing habitats. Undercut banks and overhanging reeds provide good fish habitat. Multiple channels are activated during higher flows. No cross section was surveyed for the site. The observed discharge of 0.003 m^3/s was measured at the site corresponding to a depth of 0.070 m in the small bedrock channel linking the pools.

FIGURE 4.43: AERIAL VIEW OF SITE LMEWR06R WITH THE LOCATION OF THE SURVEYED SITE AND THE DIRECTION OF FLOW ILLUSTRATED

LmEWR07r on the Limpopo River at Chokwe

This site is located on the Limpopo River at an elevation of 30 masl upstream of the estuarine environment. The site is downstream of the Elephantes River confluence on a wide floodplain. It is located just downstream of a bridge and located about 150 m upstream of the gauging station staff for Mozambique gauging station E35. The reach has a low gradient, wide sand dominated macro channel and wandering low flow channel (Figure 4.44, 4.45, 4.46 and 4.47). The macro channel is lined by Sycamore fig & Jackal berry trees, while the lower riparian zone is dominated by both species of *Phragmites* reeds. The floodplain has natural vegetation that is grazed by livestock. Sand bars are largely unvegetated, but small reed islands were present. Sand mining takes place from sand bars. Pools and backwaters provide deep slow flowing habitat. Shallow slow flowing habitats were common, but faster flowing deep and shallow habitats were rare. Reed lined undercut banks provided good fish habitat.

Hydraulically, the channel is relatively smooth with a sand bed and some vegetation on the banks. The observed flow was 18.782 m^3/s, corresponding to a maximum depth of 1.361 m on the cross-section. Predicted velocity-depth was reasonable, with velocities being overestimated by the hydraulic model (Figure 4.48 and Table 4.12 and 4.13). Flow velocity depth frequency distributions are shown in Figure 4.49.

FIGURE 4.44: AERIAL VIEW OF SITE LMEWR07R WITH THE LOCATION OF THE SURVEYED CROSS SECTION AND THE DIRECTION OF FLOW ILLUSTRATED

FIGURE 4.45 SATELLITE VIEW OF THE CHOKWE CROSS-SECTION

FIGURE 4.46 VIEW FROM CHANNEL TOWARDS LEFT AND RIGHT BANK

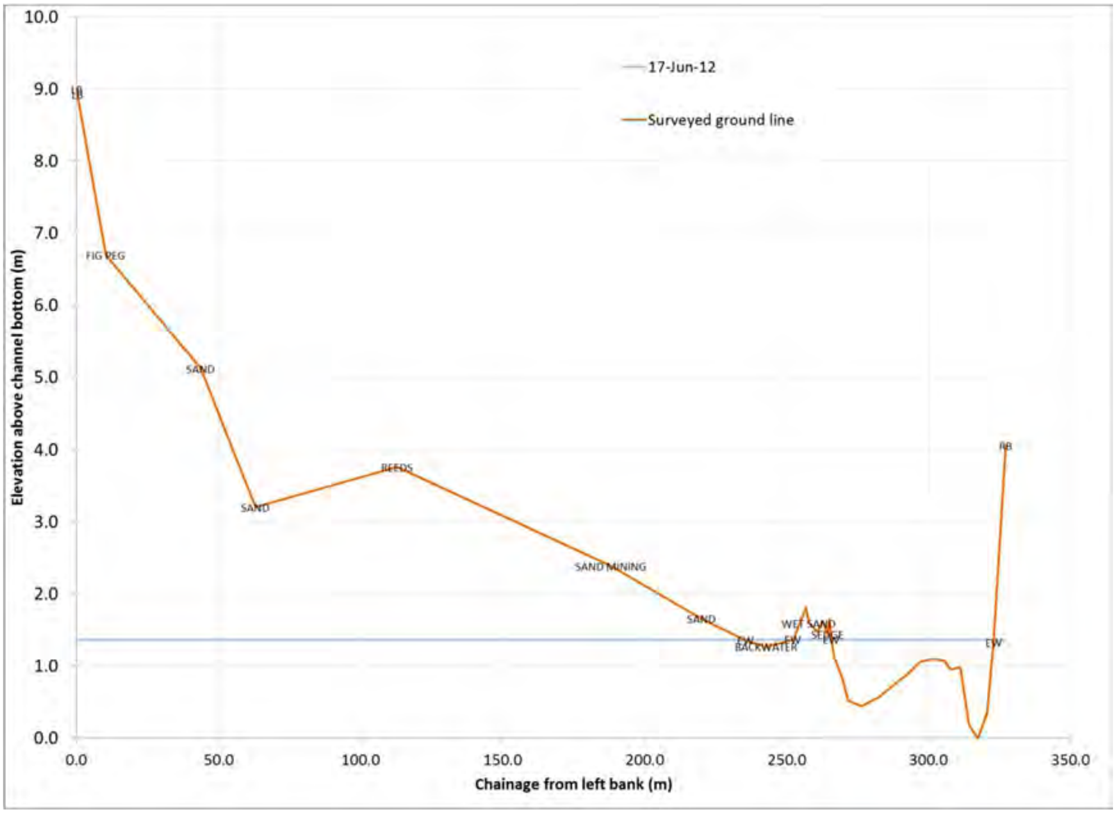

FIGURE 4.47: CROSS-SECTION SURVEYED FOR THE CHOKWE SITE SHOWING THE WATER LEVEL THAT WAS OBSERVED ON 17 JUNE 2012, EW = SURVEYED EDGE OF WATER

TABLE 4.12: OBSERVED AND MODELLED DATA USED TO DERIVE THE RATING CURVE

DATE	DEPTH (M)	MANNINGS N	ENERGY GRADIENT	DISCHARGE (M^3/S)	VELOCITY (M/S)	COMMENT
Zero flow	0.00	N/A	N/A	0.000	0.000	Modelled
Sunday, June 17, 2012	1.36	0.018	0.00021	18.782	0.509	Observed
Flood 1	2.00	0.014	0.00020	90.322	0.899	Modelled
Flood 2	4.00	0.024	0.00018	374.688	0.796	Modelled

TABLE 4.13: EQUATION TO THE RATING CURVE DERIVED FOR THE SITE (INTERCEPT AT 90 $M^3.S^{-1}$ AND 2 M DEPTH)

Power Fit: $y = ax^b + c$		
COEFFICIENT DATA:	LOWER PART	UPPER PART
a =	0.663	0.020
b =	0.245	0.837
c =	0.000	1.126

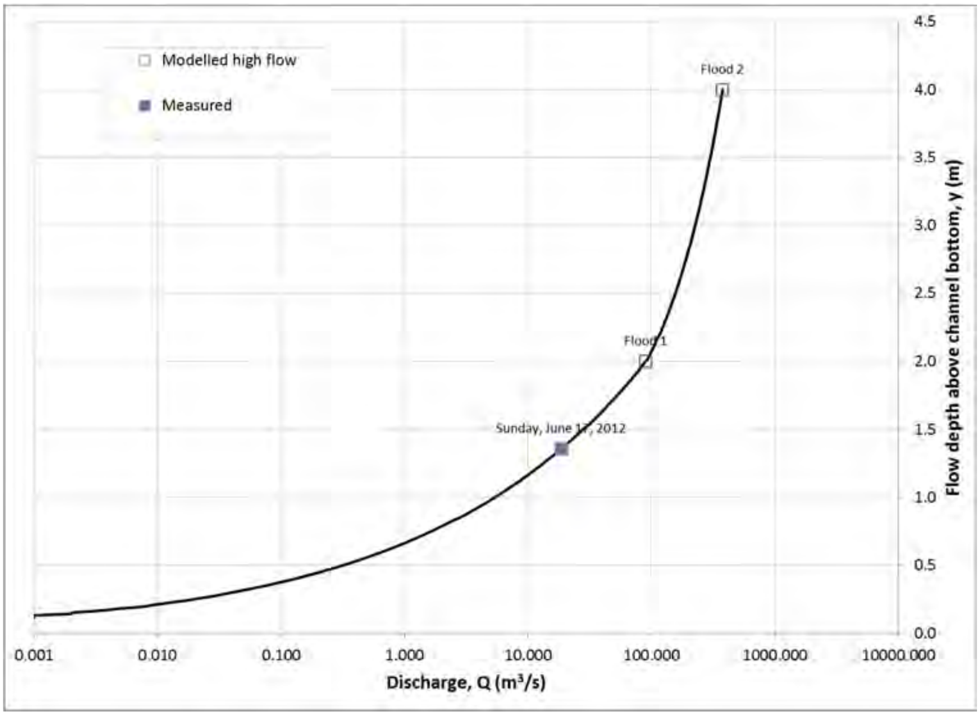

FIGURE 4.48: RATING CURVE DERIVED FOR THE CHOKWE SITE

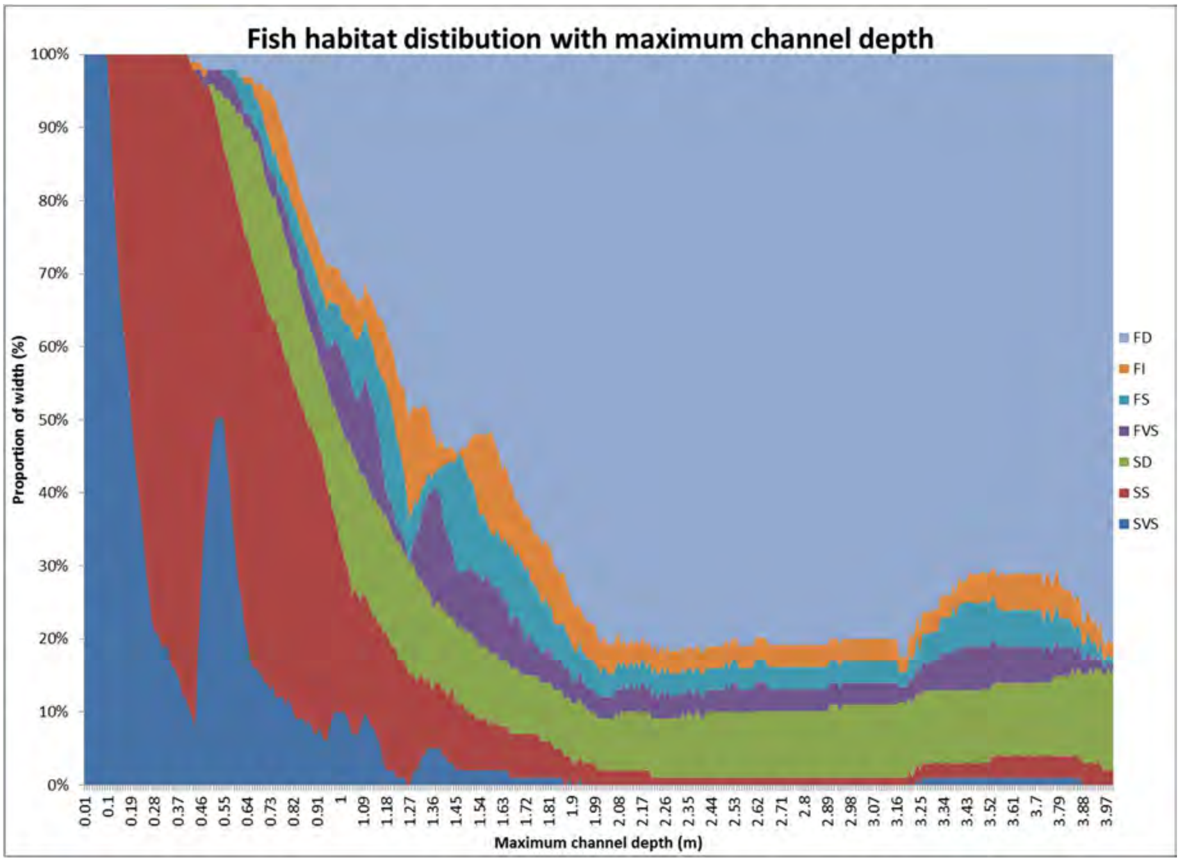

FIGURE 4.49: FISH HABITAT DISTRIBUTION VERSUS MAXIMUM DEPTH IN THE CHANNEL

LmEWR08r on the Changane River

The Changane River links large saline wetlands and water bodies in the Changane River catchment with the Limpopo River. The site is situated at 17 masl and the catchment drains the Mozambican coastal belt. The river is situated in a broad floodplain and has a low gradient channel (Figure 4.50).

The site was selected where a narrower channel was defined in an otherwise shallow wide wetland system (Figure 4.51 and 4.52). The floodplain has shrubs and grasses, and the channel is lined with reeds and sedges grow in the channel. The bed is composed of sand and mud. Livestock graze and trample the floodplain and wetlands. Slow shallow and slow deep habitats dominate this site.

The cross-section lies approximately 50 m downstream of the gauging staff for the Mozambique gauging station E452. The cross section was tied to the E452 datum. The observed flow was 0.003 m^3/s, corresponding to a maximum depth of 0.019 m on the cross-section (Figure 4.53 and Table 4.14 and 4.15). Flow velocity depth frequency distributions are shown in Figure 4.54.

FIGURE 4.50: AERIAL VIEW OF SITE LMEWR08

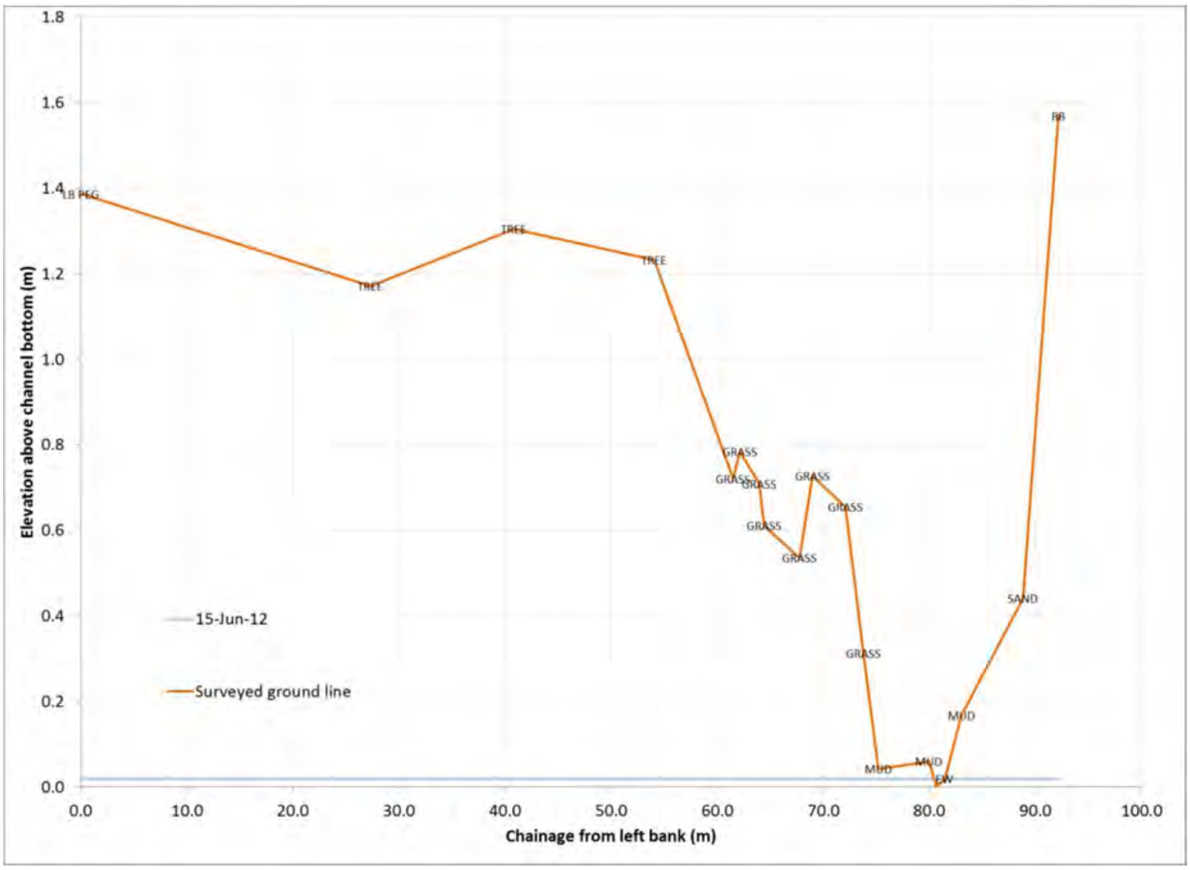

FIGURE 4.51: CROSS-SECTION SURVEYED FOR THE CHANGANE SITE SHOWING THE WATER LEVEL THAT WAS OBSERVED ON 15 JUNE 2012, EW = SURVEYED EDGE OF WATER

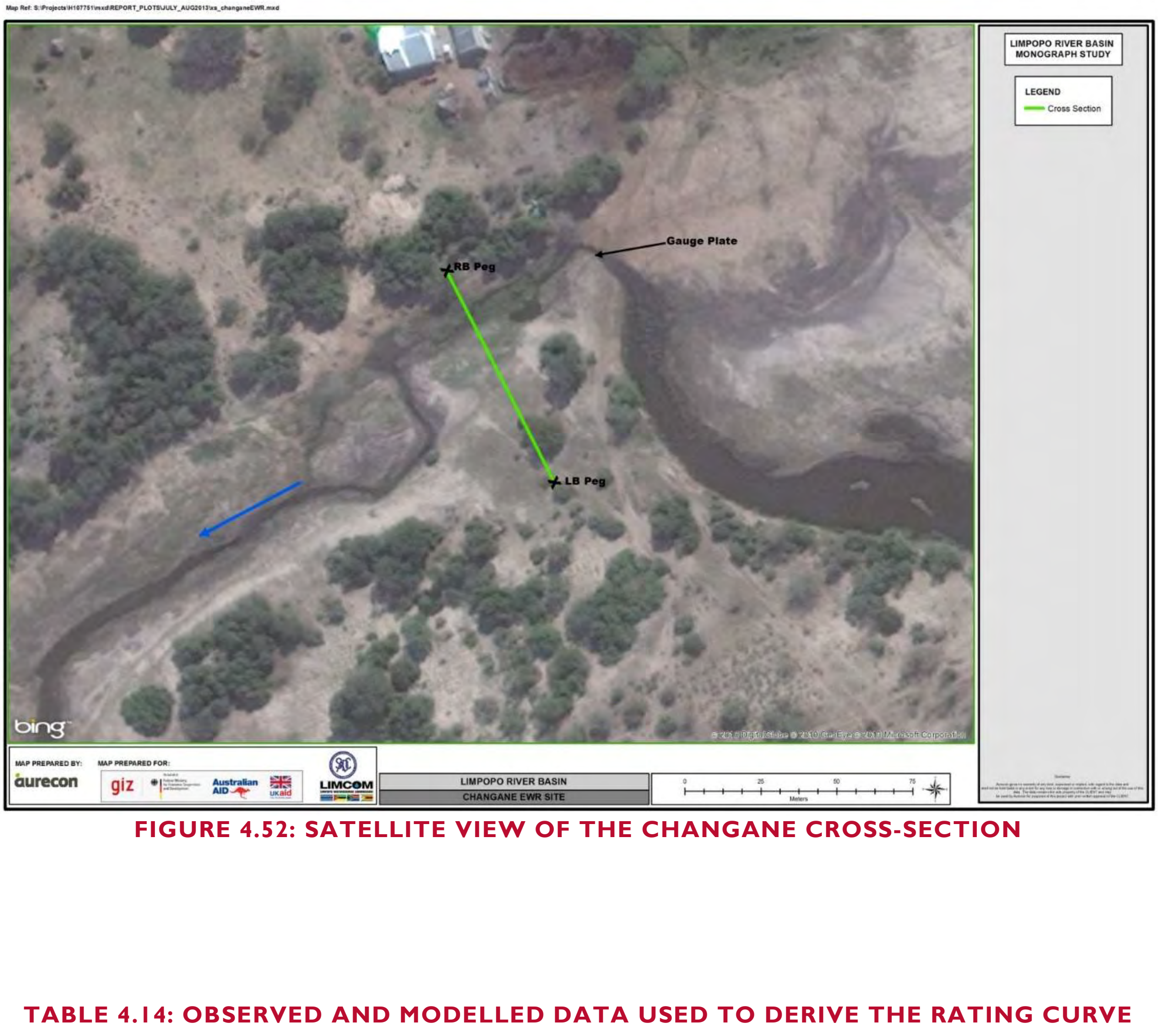

FIGURE 4.52: SATELLITE VIEW OF THE CHANGANE CROSS-SECTION

TABLE 4.14: OBSERVED AND MODELLED DATA USED TO DERIVE THE RATING CURVE

DATE	DEPTH (M)	MANNINGS N	ENERGY GRADIENT	DISCHARGE (M^3/S)	VELOCITY (M/S)	COMMENT
Zero flow	0.00	N/A	N/A	0.000	0.000	Modelled
Friday, June 15, 2012	0.02	0.009	0.00361	0.003	0.313	Observed
Flood 1	0.50	0.030	0.00185	3.476	0.671	Modelled
Flood 2	1.10	0.025	0.00021	8.929	0.415	Modelled

TABLE 4.15: EQUATION TO THE RATING CURVE DERIVED FOR THE SITE (INTERCEPT AT 3.5 $M^3.S^{-1}$ AND 0.5 M DEPTH)

Power Fit: $y = ax^b + c$		
COEFFICIENT DATA:	**LOWER PART**	**UPPER PART**
a =	0.281	0.166
b =	0.464	0.857
c =	0.000	0.018

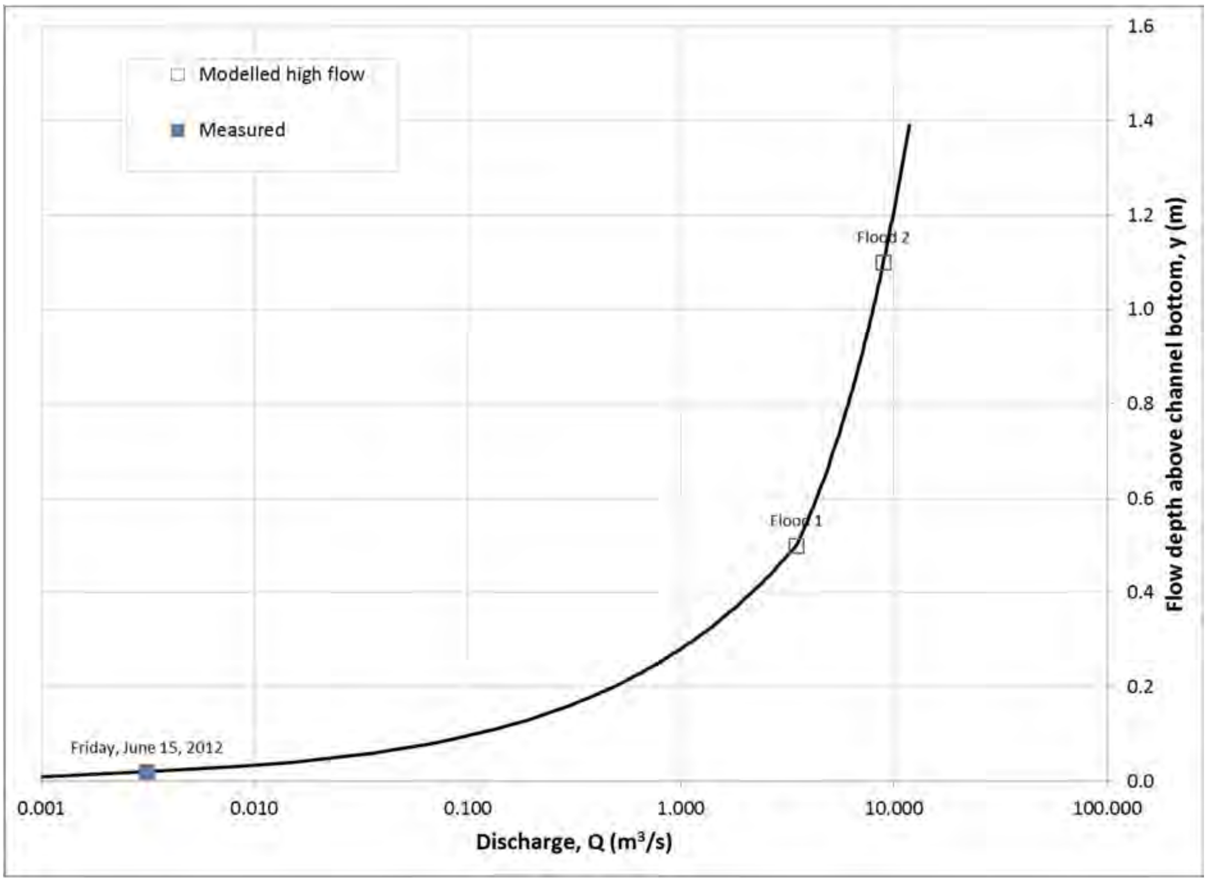

FIGURE 4.53: RATING CURVE DERIVED FOR THE CHANGANE SITE

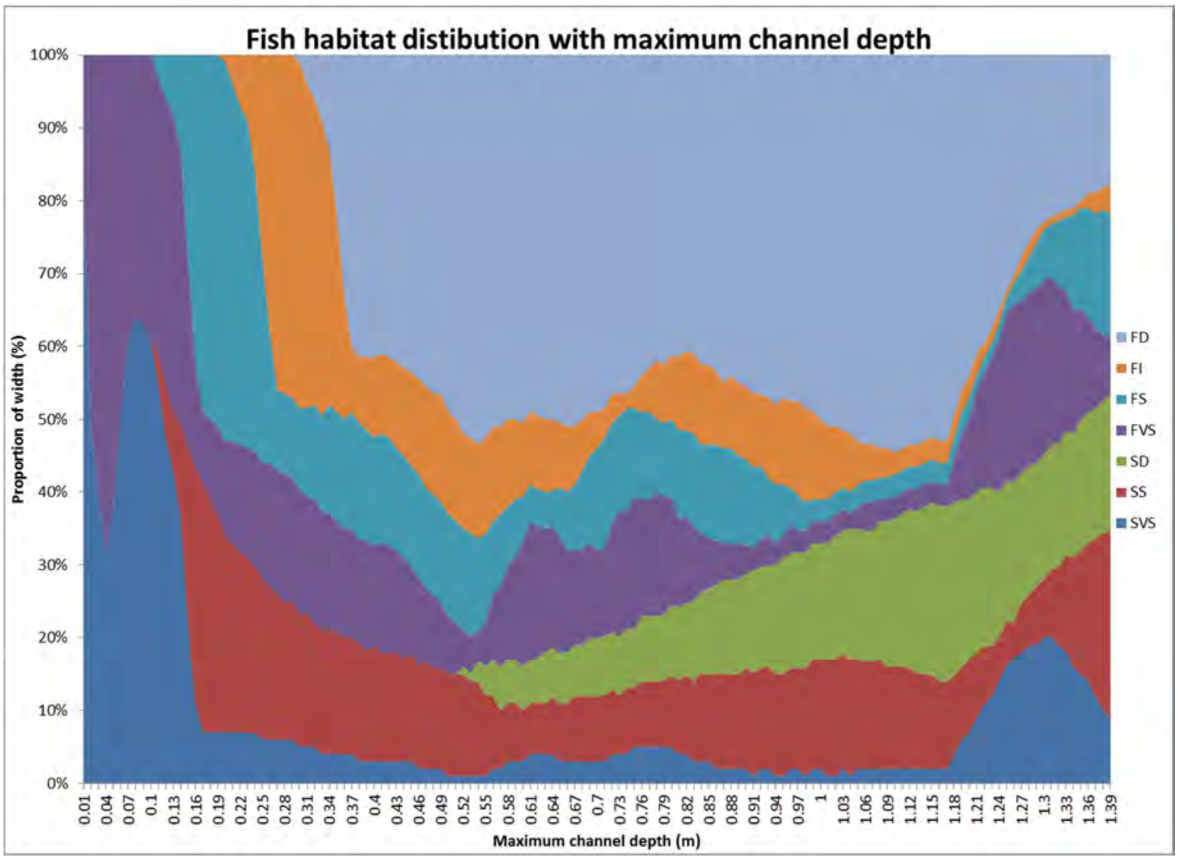

FIGURE 4.54: FISH HABITAT DISTRIBUTION VERSUS MAXIMUM DEPTH IN THE CHANNEL

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5 VEGETATION

5.1 INTRODUCTION

While the LIMCOM reports provide extensive and detailed coverage of past e-flow and biological specialist work, riparian and wetland vegetation is largely limited to the Limpopo estuary and surrounding floodplain environments. This report provides some general perspective on broader-scale vegetation within the Limpopo Basin and includes some detail of past and current specific e-flow sites.

5.2 BROAD-SCALE VEGETATION

The Limpopo River Basin essentially comprises 3 vegetation biomes, Savannah, Grassland, and Indian Ocean Coastal Belt. The WWF terrestrial ecoregions (Ohlson *et al.*, 2001), Limpopo Basin Level 1 ecoregions (Kleynhans reference), and Bioregions from Mucina & Rutherford (2006; 2012; 2018 update) were used for additional detail of terrestrial vegetation distribution within the catchment. These vegetation units, while broad, set the scene for components of the riparian floras, especially those associated with banks and less frequently inundated fluvial features, but do not adequately described the complete characteristics of riparian and wetland flora.

Terrestrial Ecoregions and Bioregions

A starting point to describe overall broad-scale vegetation in the Limpopo Basin was the WWF terrestrial ecoregions since this dataset is global and therefore covers the basin in its entirety. Descriptions of the ecoregions are summarized from the WWF (Ohlson *et al.*, 2001) and spatial data are shown in Figure 5.1. In addition, Level 1 Ecoregions were composed for the Limpopo Basin for this project by Kleynhans (2020, get ref; Figure 5.2), and Bioregions are shown for the South African portion of the Basin (Mucina & Rutherford, 2006; SANBI, 2012; 2018; Figure 5.3).

Drakensberg Montane Grasslands, Woodlands, and Forests

Montane grasslands and shrublands is a habitat type defined by the World Wildlife Fund and includes high altitude grasslands and shrublands around the world. The term "montane" in the name of the biome refers to "high altitude", rather than the ecological term, which denotes the region below the treeline.

The flora of the high alti-montane grasslands is mainly tussock grass, creeping plants, and small shrubs such as Erica's. These include the rare Spiral Aloe (*Aloe polyphylla*), which as its name suggests, has leaves with a spiral shape.

Meanwhile, the lower slopes are mainly grassland, but are also home to conifers such as *Podocarpus*. The grassland is of interest as it contains a great number of endemic plants. Grasses found here include oat grass *Monocymbium ceresiiforme, Diheteropogon filifolius, Sporobolus centrifugus*, *Harpochloa falx, Cymbopogon dieterlenii*, and *Eulalia villosa*.

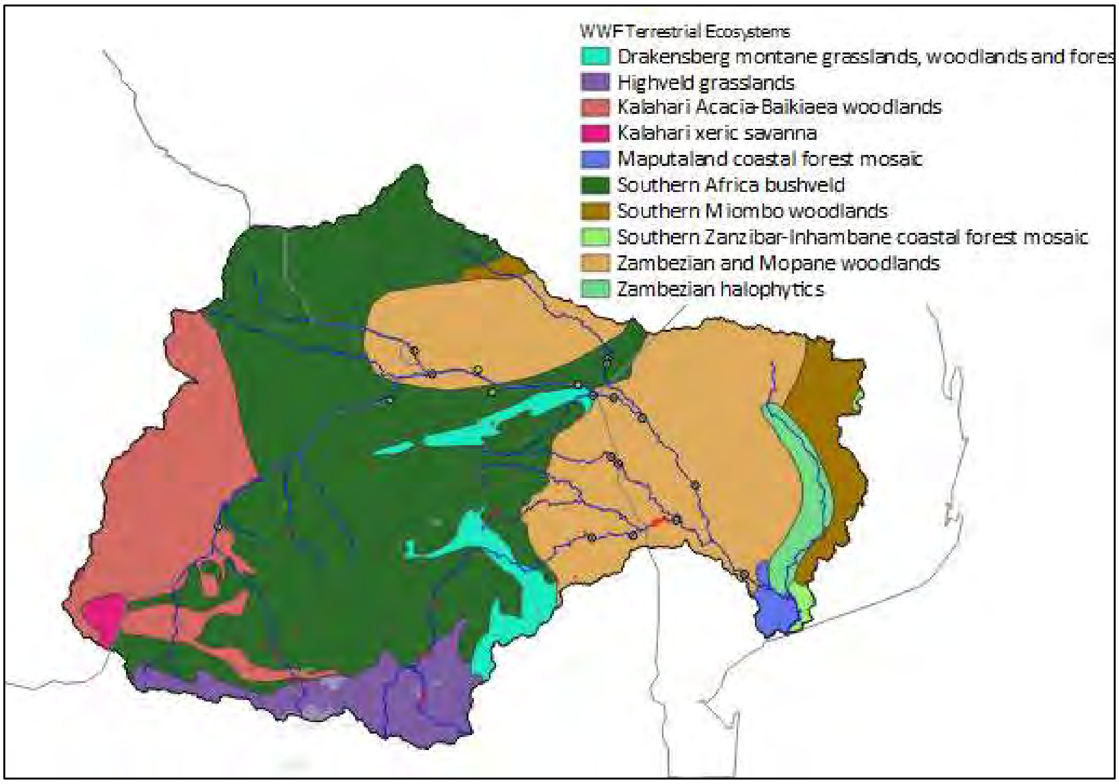

FIGURE 5.1. WWF TERRESTRIAL ECOREGIONS (OHLSON *ET AL.*, 2001; WWF)

Highveld Grasslands

The Highveld terrain is generally devoid of mountains, consisting of rolling plains, especially, sometimes interrupted by rocky ridges such as the Witwatersrand and the Magaliesberg. Naturally occurring vegetation in the Highveld consists of well-established grassland depending on the varying amounts of rainfall across the area: subtropical and temperate grassland, with true savannah not dominating the ecosystem until more tropical latitudes. The major grass species are *Hyparrhenia hirta* and *Sporobolus pyramidalis* and among these are other grasses and herbs. Trees and shrubs never thrived due to the frequent fires that occurred in the dry season and the heavy grazing (once by wild animals and now by livestock).

Kalahari Acacia-Baikiaea Woodlands

Large expanses of land in the tropics do not receive enough rainfall to support extensive tree cover. The tropical and subtropical grasslands, savannahs, and shrublands are characterized by rainfall levels between 90–150cm per year. Rainfall can be highly seasonal, with the entire year's rainfall sometimes occurring within a couple of weeks. African savannahs occur between forest or woodland regions and grassland regions. Flora includes acacia and baobab trees, grass, and low shrubs. *Acacia* trees lose their leaves in the dry season to conserve moisture, while the baobab stores water in its trunk for the dry season. Kalahari Acacia-Baikiaea woodland is an ecoregion located in Botswana, northern Namibia, South Africa, and Zimbabwe. The flora depends on the availability of water. The northern section to the west of the Okavango Delta and into Namibia has a moister climate and the *Baikiaea plurijuga* woodland with bush savannah is dominant. In the hardveld areas to the south, the climate becomes more arid and the plants are dominated by xerophytic acacias.

Kalahari Xeric Savannah

Ecoregions in this habitat type vary greatly for rainfall they receive, usually less than 250mm annually except in the margins. Generally, evaporation exceeds rainfall in these ecoregions. Temperature variability is also diverse in these lands. Many of these habitats are ephemeral in nature, reflecting the paucity and seasonality of available water. Woody-stemmed shrubs and plants characterize vegetation in these regions.

The Kalahari Desert is a large semi-arid sandy savannah in Southern Africa extending for 900,000 square kilometres, covering much of Botswana, parts of Namibia and regions of South Africa. Due to its low aridity, the Kalahari supports a variety of flora. The native flora includes acacia trees and many other herbs and grasses. Even where the Kalahari ""desert"" is dry enough to qualify as a desert in the sense of having low precipitation; it is not strictly speaking a desert because it has too dense a ground cover. Except on saltpans during the dry season, the vegetation cover can be dense, up to almost 100% in some limited areas.

In an area of about 600,000 km^2 in the south and west of the Kalahari, the vegetation is mainly xeric savannah. This area is the ecoregion identified by the WWF as Kalahari xeric savannah AT1309. Typical savannah grasses include *Schmidtia, Stipagrostis, Aristida,* and *Eragrostis*; these are interspersed with trees such as camelthorn (*Acacia erioloba*), grey camelthorn (Acacia haematoxylon), shepherd's tree (*Boscia albitrunca*), blackthorn (*Acacia mellifera*), and silver cluster-leaf (*Terminalia sericea*).

Maputaland Coastal Forest Mosaic

Tropical and subtropical moist forest is generally found in large, discontinuous patches centred on the equatorial belt and between the Tropics of Cancer and Capricorn. Forest composition is dominated by evergreen and semi-evergreen deciduous tree species. These trees number in the thousands and contribute to the highest levels of species diversity in any terrestrial major habitat type. In general, biodiversity is highest in the forest canopy. The canopy can be divided into five layers: overstory canopy with emergent crowns, a medium layer of canopy, lower canopy, shrub level, and finally understory. A perpetually warm, wet climate makes these environments more productive than any other terrestrial environment on Earth and promotes explosive plant growth.

Many forests are being cleared for farmland, while others are subject to large-scale commercial logging. The Maputaland coastal forest mosaic is a subtropical moist broadleaf forest ecoregion on the Indian Ocean coast of Southern Africa. It covers an area of 29,961 square kilometres in southern Mozambique, Swaziland, and the KwaZulu-Natal Province of South Africa. The ecoregion comprises a mosaic of many different plant communities, from the forest of the Lebombo Mountains through savannah, woodland, palm veld, grassland, sand dunes with patches of dense sand forest, and wetland habitats. The flora of the region includes several endemic species.

Southern Africa Bushveld

Covers proportionally the largest portion of the Basin. African savannahs occur between forest or woodland regions and grassland regions. Flora includes acacia and baobab trees, grass, and low shrubs. *Acacia* trees are deciduous to conserve moisture, while the baobab stores water in its trunk for the dry season. Many of these savannahs are in Africa. The Bushveld is a sub-tropical woodland ecoregion of Southern Africa. It encompasses most of Limpopo Province and a small part of the North West Province of South Africa, the Central and North-East Districts of Botswana and the Matabeleland South and part of the Matabeleland North provinces of Zimbabwe. As implied by the region's name, the Bushveld's well-grassed plains are dotted by dense clusters of trees and tall shrubs. The grasses found here are generally tall and turn brown or pale in winter, which is the dry season throughout most of Southern Africa. The undisturbed portions of this habitat, such as much of the Waterberg Biosphere, are home to many large mammal species including white rhino, black rhino, giraffe, blue wildebeest, kudu, impala and a variety of further antelope species and other game.

Southern Miombo Woodlands

The Southern miombo woodlands are a tropical grassland and woodland ecoregion extending across portions of Malawi, Mozambique, Zambia, and Zimbabwe. It is one of four miombo woodlands ecoregions that span the African continent south of the Congo forests and East African savannahs. The predominant vegetation is savannah and open-canopy woodland. The predominant trees are species of *Brachystegia* (aka miombo), *Julbernardia*, and *Isoberlinia*. Some eastward-facing mountains intercept winds from the Indian Ocean, and orographic rainfall sustain pockets of moist evergreen forest. These include the Moribane forest in Mozambique, and the Haroni and Rusitu reserves and Chirinda forest in Zimbabwe. The flora is similar to the coastal evergreen forests, and canopy trees include Newtonia buchananii, Celtis mildbraedii, and Khaya anthotheca.

Southern Zanzibar-Inhambane Coastal Forest Mosaic

Tropical and subtropical moist forest, also known as tropical moist forest, is a tropical and subtropical forest habitat type defined by the WWF. The Southern Zanzibar-Inhambane coastal forest mosaic, also known as the Southern Swahili coastal forests and woodlands, is a tropical moist broadleaf forest ecoregion of eastern Africa. It is a southern variation of Northern Zanzibar-Inhambane coastal forest mosaic. The ecoregion supports habitats of forest, savannah, and swamps. The southern portion of the ecoregion is not as well studied due to the 1977-1992 civil war in Mozambique.

Zambezi and Mopane Woodlands

Comprises a large portion of the Basin. The ecoregion is characterized by the mopane tree (*Colophospermum mopane*), and extends across portions of Botswana, Malawi, Mozambique, Namibia, South Africa, Swaziland, Zambia, and Zimbabwe, including the lower basins of the Zambezi and Limpopo rivers. The more humid Southern Zanzibar-Inhambane coastal forest mosaic and Maputaland coastal forest mosaic ecoregions lie between the Zambezian and mopane woodlands and the Indian Ocean. The Zambezian and mopane woodlands lie generally at a lower elevation, and has lower rainfall, than the neighbouring miombo woodlands ecoregions, which occupy the plateaus and escarpments above the river lowlands. It is bounded to the southwest by the Drakensberg Range and Southern African Bushveld and Drakensberg montane grassland, woodland, and forest ecoregions. To the west, it transitions to the drier Zambezian Baikiaea woodlands and Kalahari Acacia-Baikiaea woodlands on the Kalahari sands of the Southern African Plateau.

Zambezian Halophytics

Flooded grasslands and savannahs are a terrestrial habitat type of the WWF biogeographical system, consisting of large expanses or complexes of flooded grasslands. These areas support numerous plants and animals adapted to the unique hydrologic regimes and soil conditions. Large congregations of migratory and resident waterbirds may be found in these regions. However, the relative importance of these habitat types for these birds as well as more vagile taxa typically varies as the availability of water and productivity annually and seasonally shifts among complexes of smaller and larger wetlands throughout a region.

This habitat type is found on four of the continents on Earth. Some globally outstanding flooded savannahs and grasslands occur in the Everglades, Pantanal, Lake Chad flooded savannah, Zambezian flooded grasslands, and the Sudd. The Everglades are the world's largest rain-fed flooded grassland on a limestone substrate, and feature some 11,000 species of seed-bearing plants, 25 varieties of orchids, 300 bird species, and 150 fish species. The Pantanal, one of the largest continental wetlands on Earth, supports over 260 species of fish, 700 birds, 90 mammals, 160 reptiles, 45 amphibians, 1,000 butterflies, and 1,600 species of plants. The Makgadikgadi Pan, a saltpan situated in the middle of the dry savannah of north-eastern Botswana, and one of the largest salt flats in the world is an example of this ecoregion.

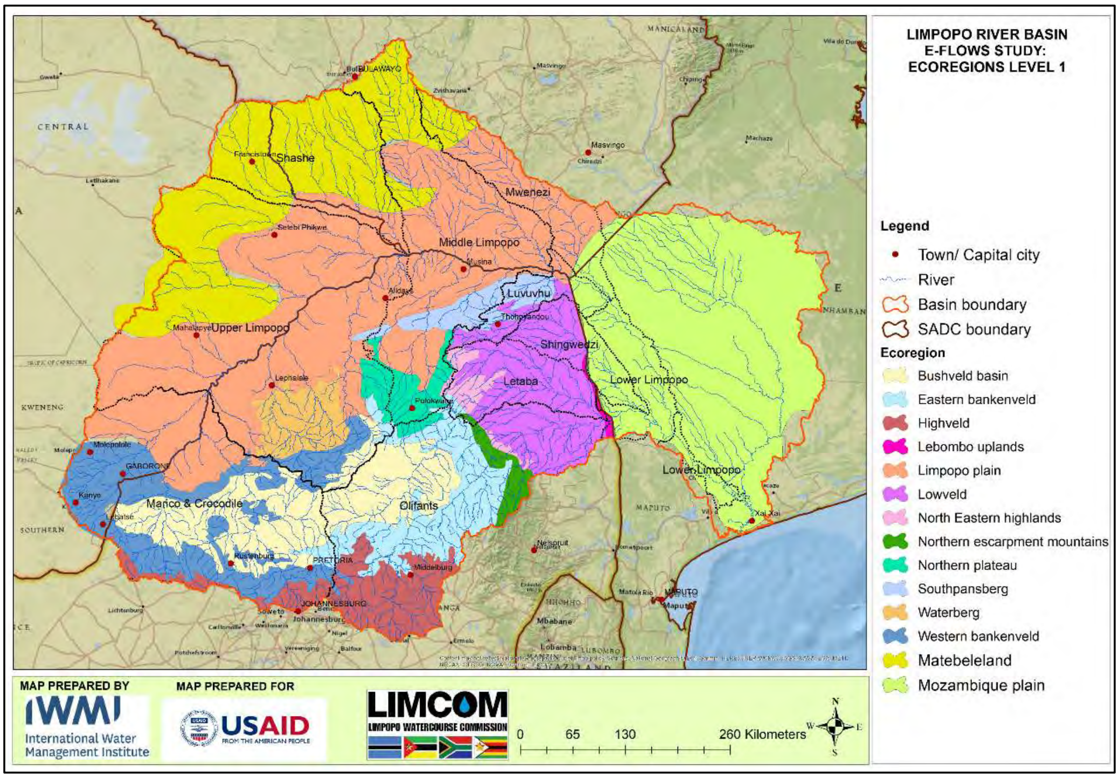

FIGURE 5.2. LEVEL 1 ECOREGIONS COMPOSED FOR THE LIMPOPO RIVER BASIN (KLEYNHANS, 2020 REF).

The vegetation Bioregions of the South African portion of the Limpopo Basin are shown in Figure 5.3 (SANBI, 2018). The Bioregion descriptions tie in well with both the Level 1 Ecoregions (Figure 5.2) and the WWF Terrestrial Ecoregions (Figure 5.1), but notable is Alluvial Vegetation, and more specifically Subtropical Alluvial Vegetation (Aza 7; Mucina & Rutherford, 2006). This unit comprises flat alluvial riverine terraces that support a complex of macrophytic vegetation, marginal reedbeds, extensive flooded grasslands, ephemeral herblands and riverine thickets. The vegetation of the Lowveld alluvia comprises a complex of subtropical riverine gallery forests, usually embedded within Savannah. Important taxa include Riparian Thickets (notably *Acacia karoo, Phoenix reclinata, Combretum erythrophyllum, Salix mucronata, Ziziphus mucronata* and *Philonoptera violaceae*), Reedbeds (Notably *Phragmites australis* and *P. mauritianus*), and flooded Grasslands (Notably sedges (*Cyperus* spp) and grasses such as *Echinochloa pyramidalis, Ischaemum afrum* and *Hermarthria altissima*).

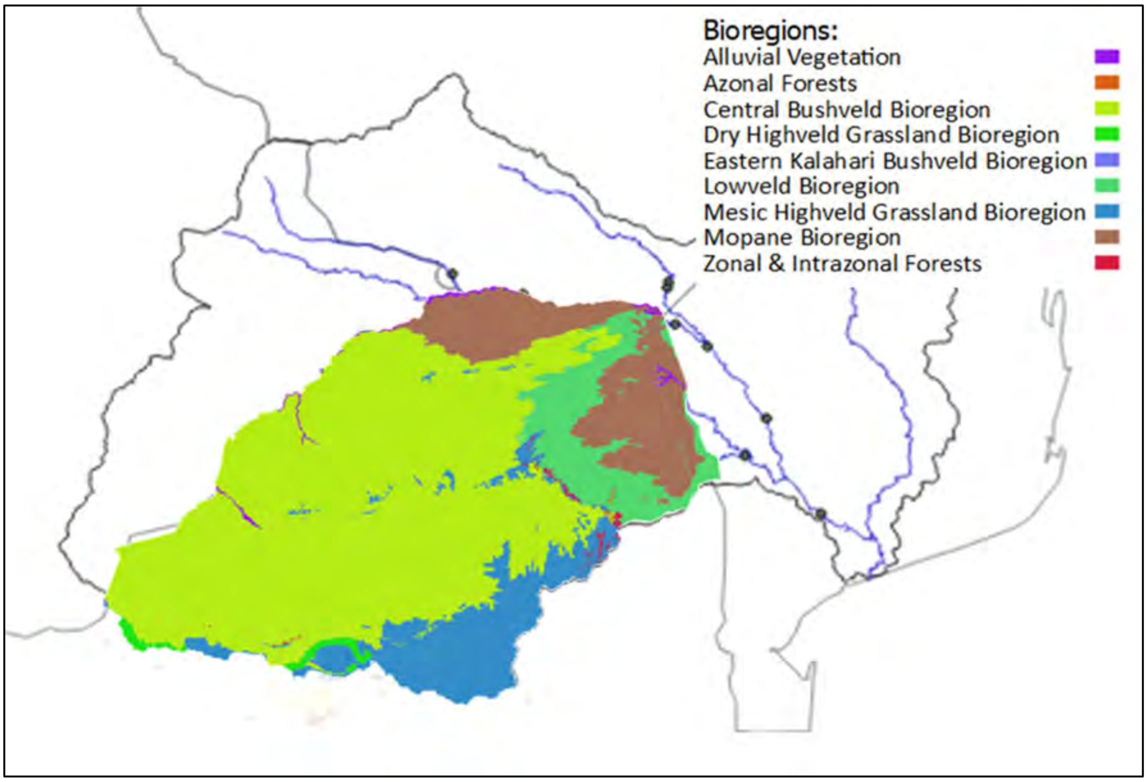

FIGURE 5.3. BIOREGIONS FOR THE SOUTH AFRICAN PORTION OF THE LIMPOPO BASIN (MUCINA & RUTHERFORD, 2006; SANBI 2012; 2018).

Wetlands

The South African National Freshwater Ecosystem Priority Areas Project (NFEPA) database was used to show the distribution of wetlands in the South African portion of the Limpopo Basin (Figure 5.4), while the Global Wetlands database was used to show wetlands along the Mozambique coastal area (Figure 5.5). The Global Wetlands Map was produced by the Sustainable Wetlands Adaptation and Mitigation Program (SWAMP), a collaborative effort between the Centre for International Forestry Research and the United States Forest Service, supported by the United States Agency for International Development (USAID) and the CGIAR Research Program on Forests, Trees and Agroforestry (FTA).

Wetlands are scattered throughout the basin with predominantly channelled valley bottom and seep wetlands in the highveld regions, floodplain wetlands in the lowveld regions (Figure 5.4), flooded grasslands with open water bodies within the Mozambique coastal belt area (Figure 5.5) and a well-defined and described estuary (Limpopo River Basin Monograph, 2013). High wetland density is particularly evident in the upper reaches of the Olifants River and wetlands of notable extent occur in the coastal plains area (Nel et al., 2011). The major impacts on riparian and wetland vegetation are removal and invasion by alien species (Bromilow, 2010), and removal is comprised mainly of mining, agriculture, and urbanization (Limpopo River Basin Monograph, 2013, WRC SOB reports).

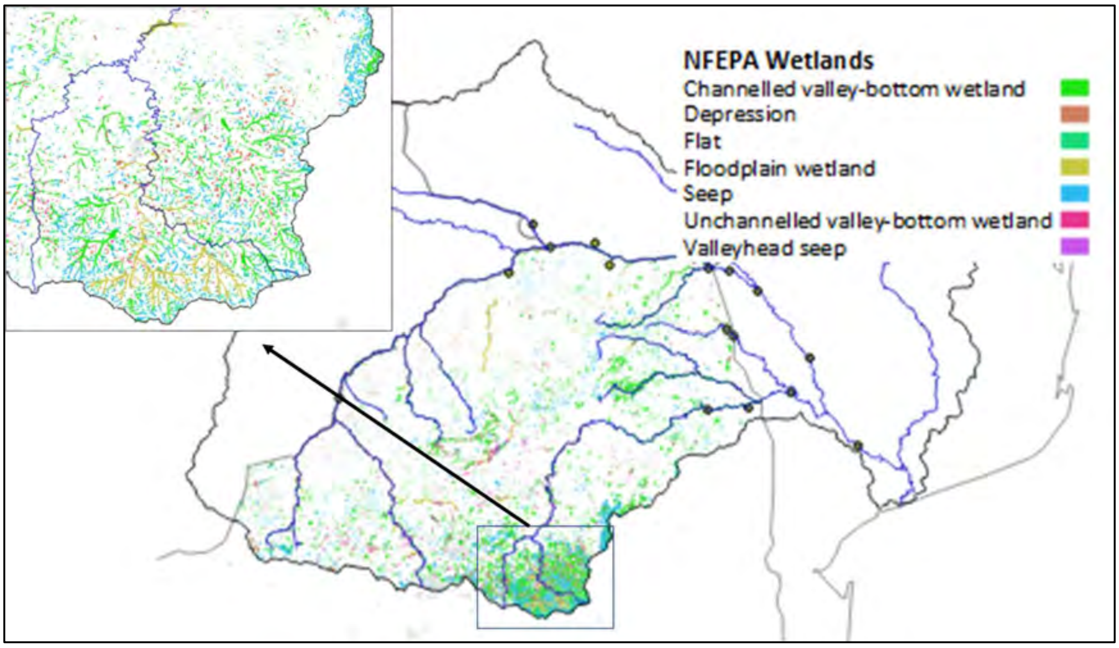

FIGURE 5.4. NFEPA WETLANDS (NEL *ET AL.*, 2011) IN THE SOUTH AFRICAN PORTION OF THE LIMPOPO BASIN. INSET SHOWS HIGH-DENSITY WETLAND AREA.

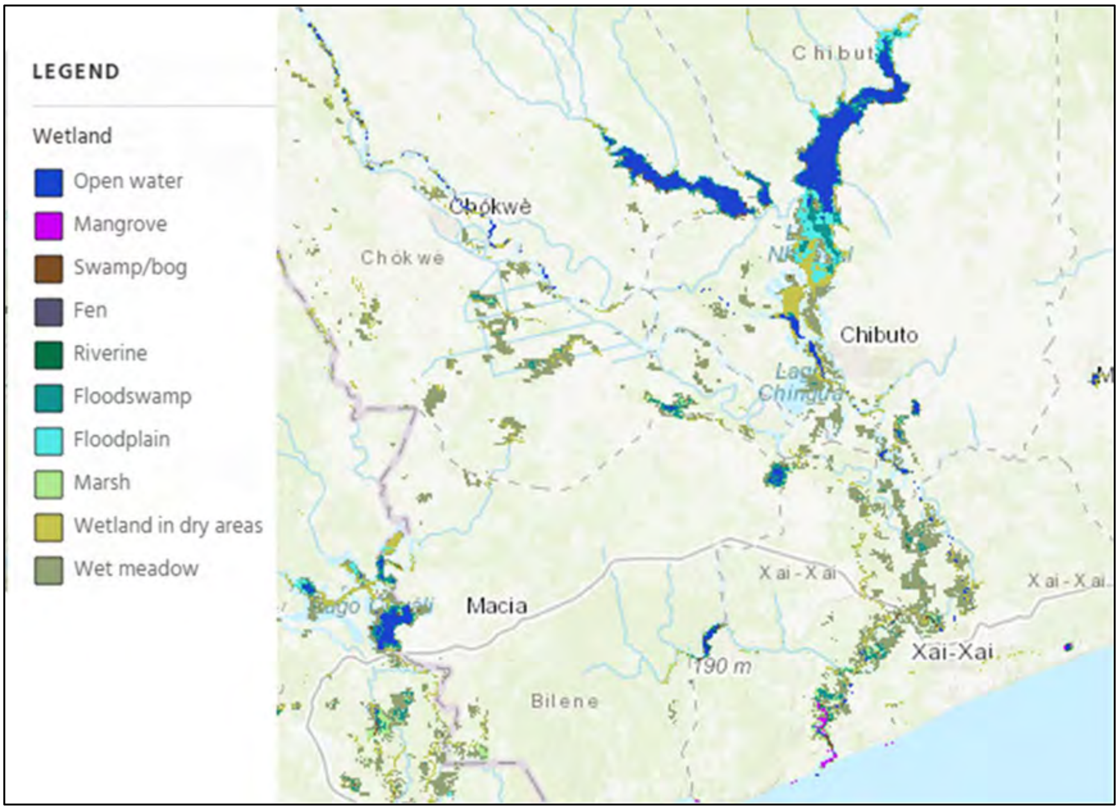

FIGURE 5.5. GLOBAL WETLANDS: THE MOZAMBIQUE COASTAL AND HALOPHYTIC ZONE

5.3 FINER-SCALE VEGETATION

This section provides more specific but general descriptions of riparian and wetland vegetation at current and past sites within the Limpopo Basin.

Main River Systems

Previous riparian and environmental work within the Basin include the Mokolo, Olifants, Elephantes and Wilge rivers. Below are summaries of vegetation descriptions or referrals to appendices of work done.

Olifants & Elephantes River

A single site on the lower Olifants and a single site on the Elephantes was assessed for riparian vegetation and e-flows in 2006 (Mackenzie). The report is included here for reference and interest (Appendix 3).

Wilge River

This was EWR site 4 of an e-flow assessment done in 2010 (Mackenzie, pers data). A description of the site vegetation as part of the VEGRAI level 4 assessment (Kleynhans *et al.,* 2007) is included in Appendix 4 for reference.

Mokolo River

An e-flow assessment was done in 2008 with 4 river sites and the Mokolo / Tambotie floodplain (confluence) as a 5th. The following is a brief description of the riparian / wetland vegetation (Mackenzie, pers data):

Mokolo Site 1:

The marginal zone was flooded at time of site visit and the following description was based on observation made by wading in relatively clear water. Vegetation structure, cover, abundance, and species composition was moderately altered. Zone dominated by hygrophytic grasses with a significant component of *Phragmites*. Woody component reduced from Reference with reduction in *Gomphostigma* and absence of *C.erythrophyllum*. Some 10% invasion by woody (*Eucalyptus and S. punicea*) and non-woody aliens. Reduced recruitment of *Combretum*. Impacts included woody veg removal, probable reduced flows (water abstraction), alien invasion, settlement, and extensive cultivation of upper zone and catchment.

Lower zone: Vegetation type, structure, cover, abundance, and composition somewhat altered by heavy grazing, tree cutting (*C. erythrophyllum* heavily targeted), invasion by *Eucalyptus* and alien weeds and probable reduced water quantity and quality. Upper zone and adjacent catchment extensively settled and mostly cultivated. Alien woody cover (*Eucalyptus and S. punicea*) recently reduced by clearing of large *Eucalyptus* trees. Lower zone currently dominated by hygrophytic grasses and sedges and to a lesser extent forbs.

Upper zone: Has been a serious to extreme change in vegetation type, structure, cover, abundance, and composition to what is expected. This degradation is the result of tree cutting (*C. erythrophyllum* heavily targeted), heavy grazing, cultivation of Upper zone, invasion by *Eucalyptus* and alien ruderal weeds and probable reduced water quantity and quality. Adjacent catchment extensively settled, cleared of indigenous woodland, and mostly cultivated.

Mokolo Site 2:

Marginal zone: Cobble and boulder dominated with exposed bedrock. Dominated by non-woody riparian vegetation, mainly *Phragmites mauritianus, Schoenoplectus corymbosus* and *Persicaria* species. Mostly inundated at the time of visit.

Lower zone: Cobble and boulder dominated with alluvial point bar and backwater depressions. Dominated by *Phragmites mauritianus* and *Miscanthus junceus*, with small woody component of *Combretum erythrophyllum* and the alien *Sesbania punicea.*

Upper zone: dominated by woody vegetation with typical woodland vegetation structure. Mostly consolidated alluvia dominated by *Combretum erythrophyllum, Acacia karoo* and *Panicum maximum.*

Mokolo Site 3:

Marginal zone flooded at time of site visit and following description based on observation made by wading in relatively clear water. Vegetation structure, cover, abundance, and species composition close to what is expected. Zone dominated by hygrophytic grasses such as *Ischaemum fasiculatum* and *Eragrostis inamoena,* and *Phragmites*. Only significant woody species is *Syzigium intermedium* which displays healthy population structure. Most of upstream catchment comprises untransformed woodland of Game Farms and large dams and cultivation absent, and hydrology therefore largely natural.

Lower zone flooded at time of site visit and following description based on observation made by wading in relatively clear water. Substrates are unconsolidated alluvial sands with 70% alluvial boulder cover. Vegetation structure, cover, abundance, and species composition close to what is expected. Dominant trees and shrubs are *Syzigium intermedium* and *Nuxia oppositifolia* though various other woody species are present. *Phragmites* and *Aristida cf. transvaalensis* common to dominant in herbaceous layer. Most of upstream catchment comprises untransformed woodland of Game Farms and large dams and cultivation absent, and hydrology therefore largely natural.

Upper zone steep, rocky, and dominated by terrestrial species with facultative riparian species (e.g. *Peltophorum* and *Terminalia*) present, but obligate riparian species absent. Substrate comprises transported (hillwash), non-hydric soils with high rock cover. Vegetation structure, cover, abundance, and species composition close to what is expected.

Mokolo Site 4:

Marginal zone dominated by a mixture of open sandy alluvia and reed beds (*Phragmites*) in an alluvial braided channel with backwater pools. *Cyperus* and *Persecaria* common

Lower zone: Predominantly alluvial and undulating. Macro-channel floor predominantly unconsolidated with a mix of opens sands, reeds (*Phragmites*) and woody species (*Syzygium* and *Nuxia* mainly)

Upper zone: Dominated by trees and shrubs with an understorey characteristic with savannah vegetation.

Floodplain:

This large (70 ha) floodplain wetland is situated directly above the confluence of the Tamboti River and the Mokolo River. The inundation and soil saturation cycles/regimes that are crucial to the functioning of this wetland ecosystem, are driven mostly by the flooding regimes of the Mokolo River, which cause back flooding in this wetland system, and to a lesser extent by the flooding regimes of the Tamboti River itself.

The vegetation of this floodplain wetland is dense seasonal marsh dominated by hydrophytic and hygrophytic grasses (Poaceae). Hydrophytic and hygrophytic sedges also contribute significantly to vegetation cover and species richness and may be locally dominant. As is typical of such wetlands, the vegetation displays clear lateral zonation of plant communities. This vegetation zonation is determined by variations in frequency and duration of inundation and soil saturation and accompanying anaerobic soil conditions.

The principal vegetation zones or bands are as follows (listed from the periphery of the wetland to the central zone):

- Tree Line, (*Acacia* species, *Combretum imbirbe*)
- Hygrophilous Grassland (transitional zone between terrestrial and wetland vegetation),
- Mixed Marsh vegetation (on temporary wetland soils),
- Seasonal *Oryza longistaminata* Marsh, and
- Marginal Vegetation (along non-perennial channel with perennial pools).

Tree line: This clearly defined zone demarcates the upper boundary of the floodplain and comprises woodland dominated by trees that are often pioneer species in disturbed terrestrial habitats but are also regarded as facultative hygrophytes. Common to dominant trees include *Acacia tortilis, Acacia nilotica, Acacia erioloba, Combretum imberbe* and *Combretum hereoense.*
Hygrophilous Grassland: This zone constitutes an ecotone (transitional habitat) and comprises a narrow band of grassland that is composed of terrestrial (mesophytic) grasses and grasses that are facultative hygrophytes. The soils of this zone never experience inundation or conditions of soil saturation but do experience seasonally or periodically elevated soil moisture level. Common to dominant species include *Setaria sphacelata* and *Themeda triandra*.

Temporary Mixed Marsh: This dense marsh vegetation occurs on temporary wetland soils that experience periodic inundation and/or soil saturation. Flooding is likely to be experienced only periodically and inundation is likely to be brief (few days at a time). Common to dominant species include *Cyperus* spp., *Eleocharis* spp., *Cynodon dactylon, Botriochloa bladhii, Setaria spacelata* and *Andropogon* sp.

Seasonal Oryza Marsh: This dense marsh vegetation is dominated by hydrophytic grasses, though sedges contribute significantly to species richness and cover, and may be locally dominant. Common to dominant grasses include *Oryza longistaminata,* Panicum cf. *schinzii* and *Paspalum distichum*. The sedges *Cyperus fastigiatus* and Schoenoplectus sp. are common to dominant in slight depression (mostly meander scars) where surface water accumulates. *Oryza longistaminata* forms conspicuous, almost mono-specific stands in the lower parts of this zone, in habitats that are frequently inundated for protracted periods (probably a period of 130 days or more at least every second year). Within South Africa, *Oryza* was previously known from only from Nylsvlei. The Tamboti wetland therefore represents only the second known locality for this species within South Africa and must be regarded as being of elevated conservation significance.

Marginal Vegetation: Includes the above with the addition of established reeds (*Phragmites australis*) along the edge of seasonal channels or pools.

Study Sites:

This section provides short general descriptions of riparian vegetation at the Olifants River sites that are part of this project.

Balule Weir (Olifants River)

The Balule site includes the section from Balule Weir to the bridge downstream of the weir (approximately 600m in length). The site is situated within the Kruger National Park, South Africa.

FIGURE 5.6. BALULE SITE, INDICATING LOCATION OF TRANSECT (RED) WITHIN THE SITE AND DOWNSTREAM BRIDGE (LOCATED AT: -24.05214, 31.72879).

As a general site description, 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*.

Mamba Weir (Olifants River)

The Mamba site is located approximately 500m upstream of Klaserie Camp and approximately 2,5km downstream of Mamba Weir within Kruger National Park, South Africa.

FIGURE 5.7. MAMBA SITE, DOWNSTREAM OF MAMBA WEIR AND UPSTREAM OF KLASERIE CAMP (LOCATED AT: -24.086236, 31.251118).

A general description of the vegetation and substrate at the site is as follows: 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 because of the 2000 and 2012 flood events.

Elephantes Sites

The extent of the site included 50m upstream and 50m downstream of the access road located at "-23.8759737, 32.2261606" within the Elephantes River, several kilometres downstream of Massingir Dam in Mozambique, Gaza.

FIGURE 5.8. ELEPHANTES SITE, MARKER INDICATING ACCESS ROAD AND SITE LOCATION. THE TRANSECT RAN PERPENDICULAR TO THE FLOW AND WAS APPROXIMATELY 400M IN LENGTH. THIS SATELLITE IMAGE WAS THE MOST RECENT IMAGE AVAILABLE (2004), THEREFORE DOES NOT REPRESENT THE CURRENT STATE OF THE VEGETATION.

The following is a general description of the state of the vegetation and substrate during the survey: the marginal zone was dominated by *Schoenoplectus brachyceras* and *Phragmites mauritianus* on alluvial soils with some cobbles. There was a single channel with a well-developed aquatic plant community, including *Potamogeton crispus, Ceratophyllum demersum, Spirogyra* sp. and *Azolla* sp.

Lower and upper zones were dominated by woody vegetation as well as clusters of *Phragmites mauritianus*. Dominant woody species included *Vachillia xanthophloea, Ficus sycomorus* and *Pluchea dioscoridis*. Distinct cohorts of *Ficus sycomorus* on defined benches were noteworthy, clearly indicating flood marks. There were distinct cobble bars present within the lower and upper zones with a large degree of open sandy areas. Additionally, it is important to note that there was a large degree of animal and human traffic at the site due to the nearby rural settlement.

5.4 PES & EI-ES:

The Present Ecological Sate (PES), Ecological Importance (EI), Ecological Sensitivity (ES) project was a landmark project commissioned by DWS to conduct a specialized desktop assessment of the water resources (rivers and wetlands) for South Africa in its entirety (DWS, 2014). The assessments included water quality, instream fauna, hydrology, impacts and riparian and wetland habitats. Figure 5.9 is an example of the Ecological category for the riparian and wetland components of the main Limpopo Catchment (Primary catchment A) and detail of riparian and wetland assessments are shown in Appendix 1 : Limpopo (primary catchment A), and Appendix 2 : Olifants (primary catchment B). Data that are directly available for this study include PES (riparian and ecostatus), EI (riparian and total), ES (riparian and total), species, especially riverine and wetland specialist, habitats and habitat state, and Impacts affecting each sub-quaternary.

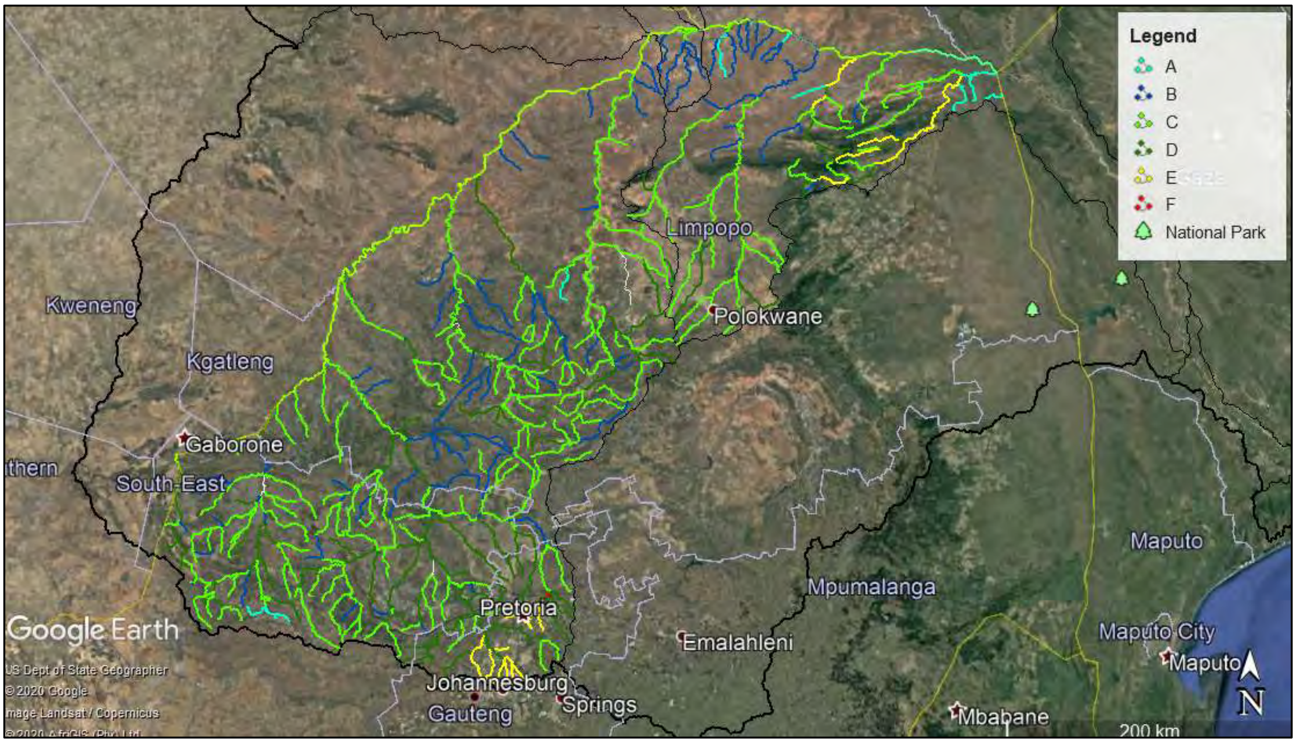

FIGURE 5.9. RIPARIAN PES (ECOLOGICAL CATEGORY) FOR THE LIMPOPO BASIN (PRIMARY CATCHMENT A).

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5.6 APPENDIX 1: RIPARIAN / WETLAND VEGETATION & PES-EI-ES FOR THE LIMPOPO

DATA PREPARATION FOR PRIMARY AND SECONDARY CATCHMENTS

SPECIES INFORMATION (PRE-ASSESSMENT)

List all wetland and riparian indicator species that have been recorded in the primary catchment. Enter distribution data (POSA database, 2009) of all indicator species into a GIS and overlay with secondary catchments (A1 to A9) to determine the species pool for both the primary as well as each secondary. Record data as follows:

- observed within the area of assessment
- collected herbarium material (POSA database, 2009) within the area of assessment
- assumed to be within area of assessment with high confidence based on current distribution

For each species in the pool, rate its significance as an indicator (this also signifies its sensitivity to flow/moisture changes). These data will be used when assessing the Ecological Sensitivity component. Ratings are as follows:

0. Facultative riparian species (probability of occurrence in the riparian to 0.75), can also be found in wetland temporary zone, floodplains, or upland
1. Preferential riparian species (probability of occurrence in the riparian zone is 0.76 to 0.9), can also be found in wetland temporary zone, floodplains, or upland
2. upper zone riparian obligate species (probability of occurrence in the riparian zone is > 0.9) / floodplain species / wetland obligate (temporary zone)
3. lower zone riparian obligate species (probability of occurrence in the riparian zone is >0.9) / wetland obligate (seasonal zone): (includes rheophyte, helophyte and hyperhydate life forms)
4. marginal zone riparian obligate species (probability of occurrence in the riparian zone is >0.9) / wetland obligate (permanent zone) :(includes rheophyte, hyperhydate and helophyte life forms)
5. aquatic: (includes epihydate, pleustophyte, vittate and sudd hydrophyte life forms)

For each species in the pool, record and flag the IUCN threat status (taxa listed as DD were not included in the assessment), level of endemism (if any) and protected status (National, provincial, regional etc). These data combined will be used to assess the Ecological Importance component.

ASSESSMENT OF SUB-QUATERNARIES (SQ)

ECOLOGICAL IMPORTANCE

All species in the species pool for each A secondary catchment are assessed for presence in the SQ (using then same GIS as set up before). Data are recorded as follows:

observed within the SQ

collected herbarium material (POSA database, 2009) within the SQ

neither observed nor collected, but likely to occur in the SQ based on 1) distribution data of the taxon as well as 2) habitat preference relative to habitat occurrence in the SQ (habitat types are assessed for presence using Google Earth ©, and listed as part of the information relating to the SQ [see Table 5.1 for a list of assessed habitats]).

Each presence score has an associated threat/protected status, which are summed to calculate the proportion of threatened/protected species relative to the total in the species pool e.g. there are 14 (4% of species pool) threatened/protected riparian/wetland indicators in the species pool for primary catchment A (Provided electronically). While this is interesting, it is not used for the assessment of the ecological importance; rather the number of threatened/protected riparian/wetland indicators in each secondary as indicated:

A1	A2	A3	A4	A5	A6	A7	A8	A9
2	8	6	4	5	7	8	9	9

Suppose the SQ being assessed contains 5 of a possible 9 species (this value is called the absolute taxon rarity) i.e. the proportion would be 0.56 (56% of possible threatened/protected species occur in the SQ; this value is called the relative taxon rarity). The relative taxon rarity is then converted to a rating between 0 and 5 (in increments of 0.5) according to the following rule:
=IF(H2=0,0,IF(H2<0.05,0.5,IF(H2<0.09,1,IF(H2<0.125,1.5,IF(H2<0.15,2,IF(H2<0.2,2.5,IF(H2<0.25,3, IF(H2<0.3,3.5,IF(H2<0.35,4,IF(H2<0.4,4.5,5))))))))));
where H2 = relative taxon rarity. In the example used of 5 threatened/protected species, the rating would be 5 (high).

The same procedure and rules are followed to calculate the absolute and relative taxon endemism, this time using endemic indicator species that occur in the SQ:

A1	A2	A3	A4	A5	A6	A7	A8	A9
1	13	8	9	6	10	11	8	9

The maximum of the threatened/protected and endemism ratings is assigned to the Ecological Importance component as its rating.

This EI rating is further modified by the following rule:
IF(D4="","",IF(D4<0.5,0,IF(D4<2.1,1,IF(D4<3.6,3,5))));
where D4 is either the threatened/protected or endemism rating, whichever is greater. The EI rating may be overridden if the vegetation unit in question is protected (e.g. covered under the forest act) and riparian.

ECOLOGICAL SENSITIVITY

Each species in the pool is rated for its significance as an indicator (this also signifies its sensitivity to flow). Ratings are as follows:

0. Facultative riparian species (probability of occurrence in the riparian zone is 0.26 to 0.75), can also be found in wetland temporary zone, floodplains, or upland
1. Preferential riparian species (probability of occurrence in the riparian zone is 0.76 to 0.9), can also be found in wetland temporary zone, floodplains, or upland
2. upper zone riparian obligate species (probability of occurrence in the riparian zone is > 0.9) / floodplain species / wetland obligate (temporary zone)
3. lower zone riparian obligate species (probability of occurrence in the riparian zone is >0.9) / wetland obligate (seasonal zone): (includes rheophyte, helophyte and hyperhydate life forms)
4. marginal zone riparian obligate species (probability of occurrence in the riparian zone is >0.9) / wetland obligate (permanent zone) :(includes rheophyte, hyperhydate and helophyte life forms)
5. aquatic: (includes epihydate, pleustophyte, vittate and sudd hydrophyte life forms)

Since all of the above communities are likely to be represented in the riparian zone of a particular SQ, the proportion of relative abundances of each flow sensitivity rating is used to calculate an overall rating for the sensitivity to flow of the riparian flora in the SQ. For each SQ species are grouped and counted (if present) as follows: No flow dependency (0) = species rated as 0 above; Low flow dependency (1; communities with a low sensitivity to water level or flow. Suitable level or flow will benefit taxa, but they do not have a crucial dependence on this.) = species rated as 1 and

2 above; Moderate flow dependency (3; communities with a moderate sensitivity. Appropriate water level or flow is beneficial during certain life-history stages to maintain viable populations.) = species rated as 3 above; High flow dependency (5; communities with a high sensitivity to water level or flow changes. Appropriate water level or flow is necessary during certain life-history stages to maintain viable populations.) = species rated as 4 and 5 above. The species counts are then used to determine a weighted mean of the ratings. This weighted rating is the overall rating for ES and represents the relative sensitivity to flow of the whole riparian zone.

Since the calculated ES rating can theoretically be any number between 0 and 5, it is further modified by the following rule: =IF(F4="","",IF(F4<0.5,0,IF(F4<2.1,1,IF(F4<3.6,3,5))));
where F4 is the weighted rating of sensitivity to flow.

PRESENT ECOLOGICAL STATE (PES)

Two components are rated to assess the PES, both from a desktop visual assessment using Google Earth © imagery:

Riparian/Wetland Habitat Continuity Modification: a visual assessment of modifications that indicate the potential that riparian/wetland **connectivity** (both lateral and longitudinal) may have been changed from the reference state. Modifications include physical fragmentation, e.g. inundation by weirs, dams; physical removal for farming, mining, etc, presence of roads, or urban areas. Ratings are essentially an 'average' overview of the situation along the length of the SQ i.e. some sections may be better or worse. Ratings are as follows:

0. None. Reference. No discernible impact or the modification is in such a way that it has no impact on habitat quality, diversity, size, and variability. Rating = 0
1. Small. The modification is limited to very few localities and the impact on habitat quality, diversity, size, and variability are also very small. Rating = 1
2. Moderate. The modifications are present at a small number of localities and the impact on habitat quality, diversity, size, and variability are also limited. Rating = 2
3. Large. The modification is generally present with a clearly detrimental impact on habitat quality, diversity, size, and variability. Large areas are, however, not influenced. Rating= 3
4. Serious. The modification is frequently present and the habitat quality, diversity, size, and variability in almost the whole of the defined area are affected. Only small areas are not influenced. Rating = 4
5. Critical. The modification is present overall with a high intensity. The habitat quality, diversity, size, and variability in almost the whole of the defined section are influenced detrimentally. Rating = 5

Riparian/Wetland Zone Modification: a visual assessment of modifications that indicate the potential that riparian/wetland zones may have been changed from the reference in terms of structure and composition that influence ecological functions and processes. Considerations include derived likelihoods that riparian/wetland zones may have changed in occurrence and structure due to flow modification and physical changes due to agriculture, mining, urbanization, inundation etc. The presence and impact of alien vegetation is also included where this is possible to discern or known. Ratings are essentially an 'average' overview of the situation along the length of the SQ i.e. some sections may be better or worse. Ratings are as follows:

0. None. Reference. No discernible impact or the modification is in such a way that it has no impact on habitat quality, diversity, size, and variability. Rating = 0
1. modification is limited to very few localities and the impact on habitat quality, diversity, size, and variability are also very small. Rating = 1

2. Moderate. The modifications are present at a small number of localities and the impact on habitat quality, diversity, size, and variability are also limited. Rating = 2
3. Large. The modification is generally present with a clearly detrimental impact on habitat quality, diversity, size, and variability. Large areas are, however, not influenced. Rating= 3
4. Serious. The modification is frequently present and the habitat quality, diversity, size, and variability in almost the whole of the defined area are affected. Only small areas are not influenced. Rating = 4
5. modification is present overall with a high intensity. The habitat quality, diversity, size, and variability in almost the whole of the defined section are influenced detrimentally. Rating = 5

TABLE 5.1 LIST OF HABITATS TO ASSESS FOR PRESENCE / ABSENCE FROM GOOGLE EARTH © IMAGERY.

Riparian / Wetland Habitat Types			Presence / absence (PES) (y/n)
Wetlands	Valley Bottom	River	
		Lake	
		Unchanneled Valley Bottom	
		Channelled Valley Bottom	
		Meandering Floodplain	
	Slopes	Seepage (isolated)	
		Seepage (connected)	
	Crest	Seepage (connected)	
		Pan	
Riparian	unconfined	grassed floodplain (without pools)	
		grassed floodplain (with pools / oxbows / marsh areas)	
		woodland floodplain	
	confined	kloof / ravine with mixed alluvial/bedrock influence	
		gorge (mainly bedrock features)	
		alluvial macro-channel bank (consolidated)	
		alluvial bars, terraces, levees (consolidated and unconsolidated)	
		exposed bedrock	
		cobble, boulder beds/bars	
		backwater pools or channels (permanent or seasonal)	
Cover characteristics		reed beds	
		sedge stands	
		woodland	
		grassed	
		aquatic	
		open substrates	

PRIMARY AND SECONDARY SPECIES POOLS FOR PRIMARY CATCHMENT A

Species Pool in A	**337**	100%	**A**	**Taxon Rarity (abs)**	2	8	6	4	5	7	8	9	9
Threatened / Protected	**14**	4%		**Taxon Rarity (rel)**	0.14	0.57	0.43	0.29	0.36	0.50	0.57	0.64	0.64
Endemic	**16**	5%		**Taxon Rarity (rating)**	2.0	5.0	5.0	3.5	4.5	5.0	5.0	5.0	5.0
Wetland Obligate	**143**	42%		**Taxon Endemism (abs)**	1	13	8	9	6	10	11	8	9
Obligate Riparian	**285**	85%		**Taxon Endemism (rel)**	0.06	0.81	0.50	0.56	0.38	0.63	0.69	0.50	0.56
Preferential Riparian	**41**	12%		**Taxon Endemism (rating)**	1.0	5.0	5.0	5.0	4.5	5.0	5.0	5.0	5.0
Facultative Riparian	**9**	3%		**1**	19	63	33	41	34	58	65	60	60
				3	10	67	15	35	27	55	55	34	44
				5	11	121	28	56	37	89	77	48	63
				ES rating	2.60	3.46	2.87	3.23	3.06	3.31	3.12	2.83	3.04

Threatened / Protected	**Endemic**	**Wetland Obligate**	**Species Pool in A**	**Relative Flow Sensitivity**	**Secondary Catchment**								
					A1	**A2**	**A3**	**A4**	**A5**	**A6**	**A7**	**A8**	**A9**
			337		**No taxa in secondary**								
					42	257	82	139	103	210	206	151	175
			Abildgaardia ovata (Burm.f.) Kral	3		2	2			2	2		
			Abutilon angulatum var. angulatum	1		2	2	2	2	2	2	2	2
Declining			***Acacia erioloba***	1	2	2	1	1	3	2	2		

		Acacia galpinii	1		2				2	2		
		Acacia gerrardii subsp. gerrardii var. gerrardii	1		2				2	2	2	2
		Acacia karoo	1	2	1	3	1	2	2	2	2	2
		Acacia robusta subsp. clavigera	1		2	2				2	2	2
		Acacia robusta subsp. robusta	1	2	1	2	1	2	2	2	2	2
		Acacia schweinfurthii var. schweinfurthii	2				1		2	2	2	2
		Acacia sieberiana var. woodii	1		1					2	3	2
		Acacia xanthophloea	2							2	2	2
		Agrostis lachnantha var. lachnantha	1		2	2	2		2	2	2	2
		*Alisma plantago-aquatica L.**	4		1							
		Amaranthus praetermissus	1		2				2	2	2	2
	y	*Andropogon appendiculatus*	3		2	2	2		2	2		
	y	*Andropogon eucomus*	3		2		2	2	2	2		
		Andropogon huillensis	1		2		2	2	2	2	2	2
		Anthocleista grandiflora	3				2			2	2	2
		Antidesma venosum	1							2	2	2
		Aponogeton desertorum Zeyh. ex A.Spreng.	5		2				2	2	2	
		Aponogeton junceus Lehm.	5		2		2		2			
		Aponogeton rehmannii Oliv.	5						2	2		
		Aponogeton stuhlmannii Engl.	5						2	2		
	y	*Aristida junciformis subsp. galpinii*	2		2							
	y	*Aristida junciformis subsp. junciformis*	3	2	2	2	2	2	2	2	2	2
	y	*Arundinella nepalensis*	3		2		2		2	2		
	y	*Azolla filiculoides Lam.**	3		1							
		Bacopa floribunda (R.Br.) Wettst.	3				2					
Declining / National		***Balanites maughamii subsp. maughamii***	1							2	2	2
		Balanites pedicellaris subsp. pedicellaris	2						2	2	2	2
	y	*Berula erecta*	3		1					2		2

			Bolbitis heudelotii (Bory ex Fée) Alston	3									2
			Bolboschoenus glaucus (Lam.) S.G.Sm.	3						2			2
National			***Breonadia salicina***	4								2	2
			Bridelia micrantha	2								2	2
			Bryum apiculatum Schwägr.	3		2						2	
			Bryum cellulare Hook.	3		2			2	2			
			Buddleja salviifolia	1		1	2	1		2	2	2	2
			Bulbostylis schoenoides (Kunth) C.B.Clarke	3		2							
		y	*Burnatia enneandra P.Micheli*	4									2
			Carex austro-africana (Kük.) Raymond	4		2				2	2		2
			Carex cognata Kunth	3		2		2		2			
			Carex glomerabilis Krecz.	3		2							
	y		*Cassinopsis ilicifolia*	1		2	2		2	2	2		2
			Celtis africana	1	2	2	2	2	3	2	2	2	2
		y	*Centella asiatica*	3		2		2	2	2	2		2
		y	*Ceratophyllum demersum L. var. demersum*	5		2		2		2			
			Chloris virgata	1	3	2	2	2	2	2	2	2	2
			Cladium mariscus (L.) Pohl subsp. jamaicense (Crantz) Kük.	4	2	2	2				2		
	y		*Combretum erythrophyllum*	3	2	1	2	1	2	1	2	2	2
National			***Combretum imberbe***	2	3	2	2	1	2	1	2	2	2
			Combretum microphyllum	1		2		1	2	1	2	2	2
			Commelina diffusa Burm.f. subsp. diffusa	3					2	2	2	2	2
			Commelina diffusa Burm.f. subsp. scandens (Welw. ex C.B.Clarke) Oberm.	4		2						2	2
			Commelina subulata Roth	3		2			2	2	2		2
			Cotula coronopifolia L.	4		2							
	SA		*Cotula nigellifolia (DC.) K.Bremer & Humphries var. nigellifolia*	0		2	2				2	2	2
			Courtoisina assimilis (Steud.) Maquet	3		2				2	2		

		Courtoisina cyperoides (Roxb.) Soják	3		2				2	2		
		Crassula natans Thunb. var. natans	4		2							
Declining	y	***Crinum bulbispermum (Burm.f.) Milne-Redh. & Schweick.***	3		1	2				2		
		Crinum lugardiae N.E.Br.	3	2	2		2		2	2	2	2
Declining		***Crinum macowanii***	0		2	2			2	2	2	2
		Crinum minimum	0			2	2	2	2	2	2	
VU		***Crinum moorei***	0		2							2
		Crinum paludosum I.Verd.	3		2	2			2			
		Croton megalobotrys	2		2		1	2	2	2	2	2
		Cullen tomentosum	1	3	2	2		2	2	2		
Declining		***Cyathea capensis var. capensis***	1								2	2
		Cyathea dregei	1		2		2		2	2	2	2
		Cyclosorus interruptus (Willd.) H.Itô	4		1						2	2
		Cyperus alopecuroides Rottb.	4						2			2
		Cyperus articulatus L.	4									2
	y	*Cyperus congestus Vahl*	4		2	2			2	2		
		Cyperus deciduus Boeck.	3		2				2			
	y	*Cyperus denudatus L.f. var. denudatus*	4		2		2	2	2	2	2	2
	y	*Cyperus difformis L.*	4	2	2	2		2	2	2		2
	y	*Cyperus digitatus Roxb. subsp. auricomus (Sieber ex Spreng.) Kük.*	4	2	2	2	2		2			
	y	*Cyperus dives Delile*	4							2	2	2
	y	*Cyperus eragrostis Lam.**	4		2				2			
		Cyperus fastigiatus Rottb.	3		2		2	2	2	2	2	2
		Cyperus fulgens C.B.Clarke var. contractus Kük.	3							2		
		Cyperus haematocephalus C.B.Clarke	3		2					2		
		Cyperus iria L.	3	2	2				2	2		
		Cyperus keniensis Kük.	3							2	2	2
		Cyperus laevigatus L.	3		2					2		2

			Cyperus latifolius Poir.	3		2		2				2	2
		y	*Cyperus longus L. var. longus*	4						2	2		
		y	*Cyperus longus L. var. tenuiflorus (Rottb.) Boeck.*	4	2		2			2	2	2	2
		y	*Cyperus marginatus Thunb.*	4		1							
		y	*Cyperus procerus Rottb.*	4		2				2			
			Cyperus rigidifolius Steud.	3		2							
		y	*Cyperus sexangularis Nees*	4		2	2		2	2	2	2	2
			Cyperus tenuispica Steud.	3				2					
			Dichanthium annulatum var. papillosum	2	2	2	2	2	3	2	2	2	2
			Diospyros lycioides subsp. guerkei	0		2	2	2	2	2	2		2
			Diospyros lycioides subsp. lycioides	0	2	1	2	1	2	2	2	2	
	SA		*Diospyros lycioides subsp. nitens*	0				2		2		2	
			Diospyros lycioides subsp. sericea	0				2	2	2	2	2	2
			Diospyros mespiliformis	2						2	2	2	2
			Dopatrium junceum (Roxb.) Buch.-Ham. ex Benth.	4						2	2		
			Drypetes gerrardii var. gerrardii	1						2	2	2	2
		y	*Echinochloa holubii*	3	3	2	2	2	2	2	2	3	2
NT			***Ectadium virgatum***	2								2	
		y	*Eleocharis acutangula (Roxb.) Schult.*	4		2		2	2	2			
		y	*Eleocharis atropurpurea (Retz.) C.Presl*	4		2		2	2	2	2		
		y	*Eleocharis dregeana Steud.*	4		2							
		y	*Eleocharis limosa (Schrad.) Schult.*	4		2		2		2	2		
		y	*Eleocharis variegata (Poir.) C.Presl*	4						2			
			Equisetum ramosissimum Desf. subsp. ramosissimum	3		2	2		2	2	2	2	2
			Equisetum ramosissimum subsp. debile	3		2							
	snA	y	*Eragrostis plana*	2		2	2	2	2	2	2		
		y	*Eragrostis planiculmis*	3		2				2			
			Eragrostis rotifer	3	3	2	2	2	3	2	2	2	2

	y	*Eriocaulon abyssinicum Hochst.*	3		2	2	2	2	2	2	2
	y	*Eriocaulon africanum Hochst.*	4							2	2
	y	*Eriocaulon maculatum Schinz*	4			2		2	2		2
	y	*Eriocaulon mutatum N.E.Br. var. angustisepalum (H.E.Hess) S.M.Phillips*	4		2						
	y	*Eriocaulon sonderianum Körn.*	4		2		2	2			
	y	*Eriocaulon transvaalicum N.E.Br. subsp. transvaalicum*	4		2		2	2			
snA		*Erythrina caffra*	1		2						
		Euclea divinorum	1					2	2	2	2
		Faidherbia albida	3			1	2	2	2	2	2
		Ficus capreifolia	2							2	2
		Ficus sur	1			2	2	1	2	2	2
		Ficus sycomorus subsp. sycomorus	3					1	2	2	2
	y	*Fimbristylis bisumbellata (Forssk.) Bubani*	3								2
	y	*Fimbristylis complanata (Retz.) Link*	3		2	2		2	2		
	y	*Fimbristylis ferruginea (L.) Vahl*	3		2			2	2		2
	y	*Fimbristylis squarrosa (Poir.) Vahl*	3					2		2	2
	y	*Fissidens ovatus Brid.*	4		2	2		2	2	2	2
	y	*Fissidens palmifolius (P.Beauv.) Broth.*	4		2						
	y	*Floscopa glomerata (Willd. ex Schult. & J.H.Schult.) Hassk.*	4		2	2	2	2	2	2	2
	y	*Fuirena bullifera J.Raynal & Roessler*	3								2
	y	*Fuirena ciliaris (L.) Roxb.*	3					2			
	y	*Fuirena coerulescens Steud.*	3	2	2						
	y	*Fuirena leptostachya Oliv. forma leptostachya*	3		2						
	y	*Fuirena leptostachya Oliv. forma nudiflora Lye*	3			2					
	y	*Fuirena pachyrrhiza Ridl.*	3						2		

		y	*Fuirena pubescens (Poir.) Kunth var. pubescens*	3		2		2	2	2	2	2	2
		y	*Fuirena stricta Steud. var. stricta*	4		2				2	2	2	2
		y	*Gomphocarpus fruticosus subsp. fruticosus*	3	2	1	2	1	2	2	2	2	2
			Gomphostigma virgatum	4		1	2	2	2	2	2	2	
	y		*Grewia caffra*	2		2				2	2		2
Declining		y	***Gunnera perpensa L.***	3		2			2	2	2	2	2
		y	*Hemarthria altissima*	3		2		2	2	2	2		2
			Hesperantha coccinea	3		1					2		
		y	*Heteranthera callifolia Rchb. ex Kunth*	4		2				2	2		
		y	*Hydrocotyle sibthorpioides Lam.*	4							2	2	2
		y	*Hydrocotyle verticillata Thunb.*	3		1					2		
			Hypolepis sparsisora (Schrad.) Kuhn	3		2				2	2	2	2
Declining			***Ilex mitis var mitis***	1		1	2	2	2	2	2	2	2
			Imperata cylindrica	2		1	2			2	2	2	2
		y	*Ischaemum fasciculatum*	4		1		1	2	2	2	2	2
			Isolepis cernua (Vahl) Roem. & Schult. var. cernua	1		2							
			Isolepis costata Hochst. ex A.Rich.	2		2		2		2	2	2	2
		y	*Isolepis fluitans (L.) R.Br. var. fluitans*	4		2	2	2	2	2	2	2	2
			Isolepis inyangensis Muasya & Goetgh.	3						2	2	2	2
			Isolepis sepulcralis Steud.	1		2					2	2	2
			Isolepis setacea (L.) R.Br.	1		2					2	2	
		y	*Juncus dregeanus Kunth subsp. dregeanus*	3		2		2	2	2	2		
		y	*Juncus effusus L.*	4		1		2	2	2			
		y	*Juncus exsertus Buchenau*	4		2	2			2	2	2	2
		y	*Juncus lomatophyllus Spreng.*	4		2				2	2	2	2
		y	*Juncus oxycarpus E.Mey. ex Kunth*	4	3	2	3	2	2	2	2	2	2
		y	*Juncus punctorius L.f.*	4		2				2	2		
		y	*Juncus rigidus Desf.*	4		2	2			2	2	2	2

	SA	?	*Kniphofia coralligemma*	?				2		2	2	2	2
		y	*Kniphofia multiflora*	3							2	2	2
		y	*Kniphofia porphyrantha*	2		2							
		?	*Kniphofia splendida*	?							2	2	2
NT	SA	y	***Kniphofia typhoides***	3		2	2						
			Kohautia cynanchica	1	3	2	2	2	2	2	2	2	2
			Kyllinga alata Nees	3		2		2		2			
			Kyllinga erecta Schumach. var. erecta	3		2		2	2	2	2		2
			Kyllinga melanosperma Nees	3		2		2		2	2	2	2
			Kyllinga pulchella Kunth	3		2							
			Kyllingiella microcephala (Steud.) R.W.Haines & Lye	3		2							
			Lagarosiphon cordofanus Casp.	5							2		
			Lagarosiphon major (Ridl.) Moss ex Wager	5		2							
			Lagarosiphon muscoides Harv.	5		2		2		2	2	2	
		y	*Leersia hexandra*	4		1		1	2	2	3	2	2
			Lemna aequinoctialis Welw.	5		2					2	2	2
			Lemna gibba L.	5		2				2			
			Lemna minor L.	5		2							
	y		*Leucosidea sericea*	2		1					2	2	2
		y	*Limnophyton obtusifolium (L.) Miq.*	5							2		
		y	*Limosella africana Glück var. africana*	5		2				2			
		y	*Limosella longiflora Kuntze*	5		2							
		y	*Limosella maior Diels*	5		2		2		2	2	2	2
			Lipocarpha chinensis (Osbeck) Kern	4		2		2	2	2		2	2
			Lipocarpha micrantha (Vahl) G.C.Tucker	3		2							
			Lipocarpha nana (A.Rich.) Cherm.	3		2		2	2	2		2	2
			Lipocarpha rehmannii (Ridl.) Goetgh.	3		2		2		2	2		
		y	*Ludwigia adscendens (L.) Hara subsp. diffusa (Forssk.) P.H.Raven*	4		2		2	2	2			2

	y	*Ludwigia octovalvis (Jacq.) P.H.Raven*	4		2		1	3	2	2	2	2
	y	*Ludwigia palustris (L.) Elliott*	4		2		2		2			
		Lycium cinereum	1	2	2	2	3	2	2	2	2	
		Marsilea aegyptiaca Willd.	4		2							
		Marsilea coromandelina Willd.	4							2		
		Marsilea ephippiocarpa Alston	4		2					2		2
		Marsilea macrocarpa C.Presl	4	2	2		2		2	2		
		Marsilea villifolia Bremek. & Oberm. ex Alston & Schelpe	4						2			
		Melianthus comosus	2		2							
	y	*Mentha aquatica*	2		2	2				2	2	2
		Mimulus gracilis R.Br.	4		2	2		2	2	2		2
		Mimusops zeyheri	3	2	2	2	1	2	2	2	2	2
SnA	y	*Miscanthus junceus*	3		2	2	1	2	2	2	2	2
		Morella serrata	2		2	2	2	2	2			
		*Myriophyllum aquaticum (Vell.) Verdc.**	4		2		2	2				
	y	*Najas graminea Delile var. graminea*	4		2							
	y	*Nasturtium officinale**	4		1				2	2		
	y	*Neptunia oleracea Lour.*	4		2							2
	y	*Nesaea crassicaulis (Guill. & Perr.) Koehne*	4						2			2
		Nuxia oppositifolia	2				1	2	2	3	2	2
	y	*Nymphaea lotus L.*	5		2		2					
	y	*Nymphaea nouchali Burm.f. var. caerulea (Savigny) Verdc.*	5		2	2	2	2	2	2	2	2
	y	*Nymphaea nouchali Burm.f. var. zanzibariensis (Casp.) Verdc.*	5		2	2	2		2	2		2
		Nymphoides indica (L.) Kuntze subsp. occidentalis A.Raynal	5		1		1		2			
		Nymphoides thunbergiana (Griseb.) Kuntze	5		2		2	2	2		2	2

		Olea europaea subsp. africana	1	2	1	2	1	2	2	2	2	2
VU	y	***Oryza longistaminata A.Chev. & Roehr.***	4				1		2			
	y	*Ottelia ulvifolia (Planch.) Walp.*	5		2		2		2	2		
		Panicum schinzii	1		2		2	2	2	2		
	y	*Paspalum dilatatum**	2		1	2	2		2	2	2	2
	y	*Paspalum distichum*	4		1		2		2	2		2
	y	*Paspalum urvillei**	2		2				2	2	2	2
	y	*Pennisetum macrourum*	3		2					2	2	2
		Pennisetum sphacelatum	1		2							
	y	*Pennisetum thunbergii*	3		2							
	y	*Persicaria attenuata (R.Br.) Soják subsp. africana K.L.Wilson*	4	3	2	2	2	2	2	2	2	2
	y	*Persicaria decipiens (R.Br.) K.L.Wilson*	4		1	2	1	2	1	2	2	2
	y	*Persicaria lapathifolia (L.) Gray**	4	3	1	2	1	2	1	2	2	2
	y	*Persicaria limbata (Meisn.) H.Hara**	4		2		2		2			2
	y	*Persicaria meisneriana (Cham. & Schltdl.) M.Gómez*	4		2		2	2	2	2	2	2
	y	*Persicaria senegalensis (Meisn.) Soják forma albotomentosa (R.A.Graham) K.L.Wilson*	4		2				2			2
	y	*Persicaria senegalensis (Meisn.) Soják forma senegalensis*	4		1		1		2			2
	y	*Persicaria serrulata*	4		1					2	2	
National		***Philenoptera violacea***	2					2	1	2	2	2
		Phoenix reclinata	2					2	1	3	2	2
	y	*Phragmites australis*	4	3	1	2	1	2	1	2	2	2
	y	*Phragmites mauritianus*	4		1	2	1	2	1	2	2	2
		Phyllanthus reticulatus var. reticulatus	2						2	2	2	2
	y	*Pistia stratiotes L.*	5		2							2
		Platycarpha carlinoides	1						2			

	Pontederia cordata L. var. ovalis Solms	4		2							
y	*Potamogeton crispus L.*	5		2							
y	*Potamogeton octandrus Poir.*	5		2		2	2	2	2		
y	*Potamogeton pectinatus L.*	5		2							
y	*Potamogeton pusillus L.*	5		2	2				2		
y	*Potamogeton schweinfurthii A.Benn.*	5		2							
y	*Potamogeton trichoides Cham. & Schltdl.*	5		2							
	Pteris buchananii Baker ex Sim	3		2	2						
	Pycreus betschuanus (Boeck.) C.B.Clarke	3	2		2			2	2		
	Pycreus chrysanthus (Boeck.) C.B.Clarke	3						2	2		
	Pycreus flavescens (L.) P.Beauv. ex Rchb.	2		2		2	2	2			
	Pycreus macranthus (Boeck.) C.B.Clarke	2		2		2		2			
	Pycreus macrostachyos (Lam.) J.Raynal	3					2	2	2		
y	*Pycreus mundii Nees*	4		2				2	2	2	2
	Pycreus muricatus (Kük.) Napper	3									2
	Pycreus niger (Ruíz & Pav.) Cufod. subsp. elegantulus (Steud.) Lye	3							2		2
y	*Pycreus nitidus (Lam.) J.Raynal*	4		2		2		2	2	2	2
	Pycreus pelophilus (Ridl.) C.B.Clarke	3				2	2	2	2	2	2
	Pycreus polystachyos (Rottb.) P.Beauv. var. polystachyos	2		2		2			2	2	2
	Pycreus pumilus (L.) Domin	3		2		2		2	2	2	
	Pycreus rehmannianus C.B.Clarke	3					2	2			
	Pycreus unioloides (R.Br.) Urb.	4		2		2					
	Ranunculus baurii	2		2							
y	*Ranunculus meyeri Harv.*	4		2							
y	*Ranunculus multifidus**	2	3	2	2	2		2	2	2	2
	Rauvolfia caffra	2		2					2	2	2
	Rhynchospora brownii Roem. & Schult.	3		2				2	2	2	2
	Riccia stricta (Lindenb.) Perold	4		2		2	2	2	2	2	2
y	*Rotala capensis (Harv.) A.Fern. & Diniz*	4						2	2		

	y	*Rotala filiformis (Bellardi) Hiern*	4		2					2		
	y	*Rotala mexicana Cham. & Schltdl.*	4		2							
	y	*Rotala tenella (Guill. & Perr.) Hiern*	4		2			2	2	2		
		Rumex lanceolatus	2		2	2				2		
		Salix mucronata subsp. capensis	4		2							
		Salix mucronata subsp. woodii	4		1	2	2		2	2	2	2
y		*Salsola aphylla*	1				2					
		*Salvinia molesta D.S.Mitch.**	5		2							
	y	*Samolus valerandi L.*	4		2	2				2	2	2
		Scadoxus puniceus	1	2	2	2			2	2	2	2
SA	y	*Schoenoplectus brachyceras (Hochst. ex A.Rich.) Lye*	4		1	2			2	2	2	2
	y	*Schoenoplectus corymbosus (Roth ex Roem. & Schult.) J.Raynal*	4		2	2	2		2			
	y	*Schoenoplectus decipiens (Nees) J.Raynal*	4		2							
	y	*Schoenoplectus erectus (Poir.) Palla ex J.Raynal*	4				2			2		
	y	*Schoenoplectus leucanthus (Boeck.) J.Raynal*	4		2							
	y	*Schoenoplectus muricinux (C.B.Clarke) J.Raynal*	4	2	2	2	2		2	2		
	y	*Schoenoplectus muriculatus (Kük.) Browning*	4		2				2	2		
SA	y	*Schoenoplectus paludicola (Kunth) J.Raynal*	4		2		2					
	y	*Schoenoplectus pulchellus (Kunth) J.Raynal*	4		2							
	y	*Schoenoplectus senegalensis (Hochst. ex Steud.) Palla ex J.Raynal*	4				2		2	2		
	y	*Schoenoplectus tabernaemontani (C.C.Gmel.) Palla**	4		2							
y		*Schotia brachypetala*	2		1		1	2	2	2	2	2

		Scirpus ficinioides Kunth	3		2		2					
		Scleria aterrima (Ridl.) Napper	3						2			
		Scleria dieterlenii Turrill	3		2							
		Scleria distans Poir.	2		2							
		Scleria dregeana Kunth	2		2				2			
		Scleria melanomphala Kunth	3								2	2
		Scleria woodii C.B.Clarke	3		2				2			
y		*Searsia dentata*	1		2	2	2	2	2	2		
		Searsia gerrardii	3		2							
		Searsia lancea	1	2	1	2	1	2	2	2	2	2
		Searsia pyroides var pyroides	2	2	1	2	1	2	1	2	2	2
		Setaria incrassata	2	3	2	2	2	2	2	2	2	2
		Setaria sphacelata var. sericea	3		1			2	2	2	2	2
	y	*Spirodela punctata (G.Mey.) C.H.Thomps.*	5		2							
		Spirostachys africana	2	2	1	2	1	2	1	2	2	2
		Sporobolus fimbriatus	2	3	2	2	2		2	2		2
		Sporobolus ioclados	2		2	2	2	3	2	2	2	2
		Syngonanthus wahlbergii (Wikstr. ex Körn.) Ruhland var. wahlbergii	4		2		2	2	2			
		Syzygium cordatum subsp. cordatum	4		2		1	2	1	2	2	2
		Syzygium guineense subsp. guineense	4			2	1	2	2	2	2	2
		Syzygium intermedium	3				2				2	
		Terminalia sericea	0	2	1	2	1	2	1	2	2	2
		Thelypteris confluens (Thunb.) C.V.Morton	3		2		2	2	3	2	2	2
		Trema orientalis	2		2				2	2	2	2
		Trichilia emetica subsp. emetica	2								2	2
	y	*Typha capensis (Rohrb.) N.E.Br.*	4	2	1	2			2	2		2
		Utricularia arenaria A.DC.	4		2			2	2			
	y	*Utricularia stellaris*	5		2				2	2		
		Utricularia subulata L.	4		2						2	2
	y	*Veronica anagallis-aquatica L.*	4		2	2			2	2		2

	Wolffia arrhiza (L.) Horkel ex Wimm.	5		2							
	Wolffia globosa (Roxb.) Hartog & Plas	5		2							
	Xanthocercis zambesiaca	1				1	2	1	2	2	2
y	*Xyris capensis Thunb.*	4		2		2	2	2	2	2	2
y	*Xyris congensis Büttner*	4		2		2	2	2	2	2	2
y	*Xyris gerrardii N.E.Br.*	4		2		2	2	2	2		
y	*Xyris obscura N.E.Br.*	4		2							
y	*Xyris rehmannii L.A.Nilsson*	4							2	2	2
y	*Zannichellia palustris L.*	4		2					2		
y	*Zantedeschia aethiopica*	4								2	2
	Ziziphus mucronata subsp. mucronata	1	2	1	2	1	2	1	2	2	2

5.7 APPENDIX 2: RIPARIAN / WETLAND VEGETATION & PES-EI-ES FOR THE OLIFANTS

DATA PREPARATION FOR PRIMARY CATCHMENT

TERMS AND DEFINITIONS

The following terms are borrowed from SANBI and used to describe ecological sensitivity ratings in the spreadsheet comments:

Life Form	Definitions of life forms
Epihydate:	a plant with leaves and/or stems floating on the surface of the water but not rising above the water, roots penetrating the substrate.
Helophyte:	a plant typical of marshy or lake-edge environments, in which the perennating organ lies in soil or mud below the water level, but the aerial shoots protrude above the water
Hydrophyte:	a plant that is morphologically and/or physiologically adapted to grow in water or very wet environments.
Hyperhydate:	an emergent plant, with leaves and/or stems emerging well beyond the water surface, roots penetrating the substrate.
Pleustophyte:	a plant that is free-floating on the water surface, not attached to or penetrating the substrate, with some photosynthetic parts in contact with air
Rheophyte:	a flood-resistant plant that is confined to the beds of swift-flowing streams or rivers and to adjacent floodplains.
Sudd hydrophyte:	an aquatic plant that grows rooted in sudd (an impenetrable mass of floating vegetable matter).
Vittate:	pertaining to submerged plants, rooted in substrate, leaves arranged along elongated stem.

SPECIES INFORMATION (PRE-ASSESSMENT)

List all wetland and riparian indicator species that have been recorded in the primary catchment. Enter distribution data (POSA database, 2009) of all indicator species into a GIS and overlay with B primary to determine the species pool (Species pool and riparian characteristics for B primary are outlined in Table 5.1). Record data as follows:

observed within the area of assessment

collected herbarium material (POSA database, 2009) within the area of assessment

For each species in the pool, rate its significance as an indicator (this also signifies its sensitivity to flow/moisture changes). These data will be used when assessing the Ecological Sensitivity component. Ratings are as follows:

0. Facultative riparian species (probability of occurrence in the riparian to 0.75), can also be found in wetland temporary zone, floodplains, or upland
1. Preferential riparian species (probability of occurrence in the riparian zone is 0.76 to 0.9), can also be found in wetland temporary zone, floodplains, or upland
2. upper zone riparian obligate species (probability of occurrence in the riparian zone is > 0.9) / floodplain species / wetland obligate (temporary zone)
3. lower zone riparian obligate species (probability of occurrence in the riparian zone is >0.9) / wetland obligate (seasonal

zone): (includes rheophyte, helophyte and hyperhydate life forms)

4. marginal zone riparian obligate species (probability of occurrence in the riparian zone is >0.9) / wetland obligate (permanent zone) :(includes rheophyte, hyperhydate and helophyte life forms)
5. aquatic: (includes epihydate, pleustophyte, vittate and sudd hydrophyte life forms)

For each species in the pool, record and flag the IUCN threat status (taxa listed as DD were **not** included in the assessment), level of endemism (if any) and protected status (National, provincial, regional etc). These data combined will be used to assess the Ecological Importance component.

ASSESSMENT OF SUB-QUATERNARIES (SQ)

ECOLOGICAL IMPORTANCE

All species in the species pool for the B primary catchment are assessed for presence in the SQ (using then same GIS as set up before). Data are recorded as follows:

observed within the SQ

collected herbarium material (POSA database, 2009) within the SQ

neither observed nor collected, but likely to occur in the SQ based on 1) distribution data of the taxon as well as 2) habitat preference relative to habitat occurrence in the SQ (habitat types are assessed for presence using Google Earth ©, and listed as part of the information relating to the SQ [see Table 5.1 for a list of assessed habitats]).

Each presence score has an associated threat/protected status, which are summed to calculate the proportion of threatened/protected species relative to the total in the species pool e.g. there are 19 threatened/protected riparian/wetland indicators in the species pool for primary catchment B (Provided electronically). Suppose the SQ being assessed contains 5 of those species (this value is called the absolute taxon rarity) i.e. the proportion would be 0.21 (21% of possible threatened/protected species occur in the SQ; this value is called the relative taxon rarity). The relative taxon rarity is then converted to a rating between 0 and 5 (in increments of 0.5) according to the following rule:

=IF(H2=0,0,IF(H2<0.05,0.5,IF(H2<0.09,1,IF(H2<0.125,1.5,IF(H2<0.15,2,IF(H2<0.2,2.5, IF(H2<0.25,3,IF(H2<0.3,3.5,IF(H2<0.35,4,IF(H2<0.4,4.5,5))))))))));

where H2 = relative taxon rarity. In the example used of 5 threatened/protected species, the rating would be 3 (moderate).

The same procedure and rules are followed to calculate the absolute and relative taxon endemism, this time using endemic indicator species that occur in the SQ.

The maximum of the threatened/protected and endemism ratings is assigned to the Ecological Importance component as its rating.

This EI rating is further modified by the following rule:

IF(D4="","",IF(D4<0.5,0,IF(D4<2.1,1,IF(D4<3.6,3,5))));

where D4 is either the threatened/protected or endemism rating, whichever is greater. The EI rating may be overridden if the vegetation unit in question is protected (e.g. covered under the forest act) and riparian.

ECOLOGICAL SENSITIVITY

Each species in the pool is rated for its significance as an indicator (this also signifies its sensitivity to flow). Ratings are as follows:

0. Facultative riparian species (probability of occurrence in the riparian zone is 0.26 to 0.75), can also be found in wetland temporary zone, floodplains, or upland
1. Preferential riparian species (probability of occurrence in the riparian zone is 0.76 to 0.9), can also be found in wetland temporary zone, floodplains, or upland
2. upper zone riparian obligate species (probability of occurrence in the riparian zone is > 0.9) / floodplain species / wetland obligate (temporary zone)
3. lower zone riparian obligate species (probability of occurrence in the riparian zone is >0.9) / wetland obligate (seasonal zone): (includes rheophyte, helophyte and hyperhydate life forms)
4. marginal zone riparian obligate species (probability of occurrence in the riparian zone is >0.9) / wetland obligate (permanent zone) :(includes rheophyte, hyperhydate and helophyte life forms)
5. aquatic: (includes epihydate, pleustophyte, vittate and sudd hydrophyte life forms)

Since all of the above communities are likely to be represented in the riparian zone of a particular SQ, the proportion of relative abundances of each flow sensitivity rating is used to calculate an overall rating for the sensitivity to flow of the riparian flora in the SQ. For each SQ species are grouped and counted (if present) as follows: No flow dependency (0) = species rated as 0 above; Low flow dependency (1; communities with a low sensitivity to water level or flow. Suitable level or flow will benefit taxa, but they do not have a crucial dependence on this.) = species rated as 1 and 2 above; Moderate flow dependency (3; communities with a moderate sensitivity. Appropriate water level or flow is beneficial during certain life-history stages to maintain viable populations.) = species rated as 3 above; High flow dependency (5; communities with a high sensitivity to water level or flow changes. Appropriate water level or flow is necessary during certain life-history stages to maintain viable populations.) = species rated as 4 and 5 above. The species counts are then used to determine a weighted mean of the ratings. This weighted rating is the overall rating for ES and represents the relative sensitivity to flow of the whole riparian zone.

Since the calculated ES rating can theoretically be any number between 0 and 5, it is further modified by the following rule: =IF(F4="","",IF(F4<0.5,0,IF(F4<2.1,1,IF(F4<3.6,3,5))));
where F4 is the weighted rating of sensitivity to flow.

PRESENT ECOLOGICAL STATE (PES)

Two components are rated to assess the PES, both from a desktop visual assessment using Google Earth © imagery:

Riparian/Wetland Habitat Continuity Modification: a visual assessment of modifications that indicate the potential that riparian/wetland **connectivity** (both lateral and longitudinal) may have been changed from the reference state. Modifications include physical fragmentation, e.g. inundation by weirs, dams; physical removal for farming, mining, etc, presence of roads, or urban areas. Ratings are essentially an 'average' overview of the situation along the length of the SQ i.e. some sections may be better or worse. Ratings are as follows:

0. None. Reference. No discernible impact or the modification is in such a way that it has no impact on habitat quality, diversity, size, and variability. Rating = 0
1. Small. The modification is limited to very few localities and the impact on habitat quality, diversity, size, and variability are also very small. Rating = 1
2. Moderate. The modifications are present at a small number of localities and the impact on habitat quality, diversity, size, and variability are also limited. Rating = 2
3. Large. The modification is generally present with a clearly detrimental impact on habitat quality, diversity, size, and variability. Large areas are, however, not influenced. Rating= 3
4. Serious. The modification is frequently present and the habitat quality, diversity, size, and variability in almost the whole of the defined area are affected. Only small areas are not influenced. Rating = 4
5. Critical. The modification is present overall with a high intensity. The habitat quality, diversity, size, and variability in almost the whole of the defined section are influenced detrimentally. Rating = 5

Riparian/Wetland Zone Modification: a visual assessment of modifications that indicate the potential that riparian/wetland zones may have been changed from the reference in terms of structure and composition that influence ecological functions and processes. Considerations include derived likelihoods that riparian/wetland zones may have changed in occurrence and structure due to flow modification and physical changes due to agriculture, mining, urbanization, inundation etc. The presence and impact of alien vegetation is also included where this is possible to discern or known. Ratings are essentially an 'average' overview of the situation along the length of the SQ i.e. some sections may be better or worse.

Ratings are as follows:

0. None. Reference. No discernible impact or the modification is in such a way that it has no impact on habitat quality, diversity, size, and variability. Rating = 0
1. modification is limited to very few localities and the impact on habitat quality, diversity, size, and variability are also very small. Rating = 1
2. Moderate. The modifications are present at a small number of localities and the impact on habitat quality, diversity, size, and variability are also limited. Rating = 2

3. Large. The modification is generally present with a clearly detrimental impact on habitat quality, diversity, size, and variability. Large areas are, however, not influenced. Rating= 3
4. Serious. The modification is frequently present and the habitat quality, diversity, size, and variability in almost the whole of the defined area are affected. Only small areas are not influenced. Rating = 4
5. modification is present overall with a high intensity. The habitat quality, diversity, size, and variability in almost the whole of the defined section are influenced detrimentally. Rating = 5

LIST OF HABITATS TO ASSESS FOR PRESENCE / ABSENCE FROM GOOGLE EARTH © IMAGERY.

Riparian / Wetland Habitat Types			Status (Y, N, Y (assumed), Y (artificial), Common, Dominant)
Wetlands	Valley Bottom	River	
		Lake	
		Unchanneled Valley Bottom	
		Channelled Valley Bottom	
		Meandering Floodplain	
	Slopes	Seepage (isolated)	
		Seepage (connected)	
		Depression	
	Crest	Seepage (connected)	
		Pan	
Riparian	unconfined	grassed floodplain (without pools)	
		grassed floodplain (with pools / oxbows / marsh areas)	
		Sodic site	
		woodland floodplain	
		Seasonal / Ephemeral drainage line	
	confined	kloof / ravine with mixed alluvial/bedrock influence	
		gorge (mainly bedrock features)	
		alluvial macro-channel bank (consolidated)	
		alluvial bars, terraces, levees (consolidated and unconsolidated)	
		braided / mid-channel bars	
		Incised alluvial channel	
		exposed bedrock	

Riparian / Wetland Habitat Types			Status (Y, N, Y (assumed), Y (artificial), Common, Dominant)
		Riffles: cobble / boulder beds/bars	
		Bedrock / mixed anastomosing	
		In-channel pools, deep slow water (not dams / weirs)	
		backwater pools or channels (permanent or seasonal)	
Vegetation characteristics		Non-woody	
	Non-woody	Reeds / Reedbeds	
		Sedges / Sedge stands	
		Typha stands (bullrushes)	
		grass / grassland	
		aquatic	
	Woody	Woody	
		Shrub	
		woodland	
		forest	
		thicket	
		Terrestrial woody	
		Woody rheophytes	
		Marginal / Seasonal zone woody riparian obligates	
		Bank zone woody riparian	
		Perennial alien woody species	
	open substrates	open substrates	

PRELIMINARY LIST OF SPECIES AND CALCULATION OF RATINGS IN PRIMARY CATCHMENT B

Species Pool in B	**380**	100 %	**B**	**Taxon Rarity (abs)**
Threatened /Protected	**17**	4%		**Taxon Rarity (rel)**
Endemic	**24**	6%		**Taxon Rarity (rating)**
Wetland Obligate	**118**	31 %		**Taxon Endemism (abs)**
Obligate Riparian	**182**	48 %		**Taxon Endemism (rel)**
Preferential Riparian	**35**	9%		**Taxon Endemism (rating)**
Facultative Riparian	**8**	2%		**1**
				3
				5
				ES rating

Threatened /Protected	**Endemic**	**B Status**	**Wetland Obligate**	**Species Pool in B** **380**	**Relative Flow Sensitivity**
		2		*Abildgaardia ovata (Burm.f.) Kral*	3
		2		*Abutilon angulatum var. angulatum*	1
Declining/National		1		***Acacia erioloba***	1
		1		*Acacia galpinii*	1
		2		*Acacia gerrardii subsp. gerrardii var. gerrardii*	1
		1		*Acacia karoo*	1
		2		*Acacia robusta subsp. clavigera*	1
		1		*Acacia robusta subsp. robusta*	1
		1		*Acacia schweinfurthii var. schweinfurthii*	2
		2		*Acacia sieberiana var. woodii*	1
		1		*Acacia xanthophloea*	2
		2		*Agrostis lachnantha var. lachnantha*	1
		2		*Amaranthus praetermissus*	1
		2		*Ampelopteris prolifera (Retz.) Copel.*	3
		2	y	*Andropogon appendiculatus*	3
		2	y	*Andropogon eucomus*	3
		2		*Andropogon huillensis*	1
		2		*Antidesma venosum*	1
		2	y	*Aponogeton junceus Lehm.*	5
	SA	2	y	*Aponogeton natalensis Oliv.*	5
		2	y	*Aponogeton rehmannii Oliv.*	5
		2	y	*Aponogeton stuhlmannii Engl.*	5
		2	y	*Aristida junciformis subsp. galpinii*	2
		1	y	*Aristida junciformis subsp. junciformis*	3
		2	y	*Arundinella nepalensis*	3

		1	y	*Azolla filiculoides Lam.**	3
Declining/National		2		***Balanites maughamii subsp. maughamii***	1
		1	y	*Berula erecta*	3
		2	y	*Bolboschoenus glaucus (Lam.) S.G.Sm.*	4
		2	y	*Brasenia schreberi J.F.Gmel.*	5
National		1		***Breonadia salicina***	3
		1		*Bridelia micrantha*	2
		2		*Bryum cellulare Hook.*	3
		1		*Buddleja salviifolia*	1
		2		*Bulbostylis schoenoides (Kunth) C.B.Clarke*	3
		2	y	*Burnatia enneandra P.Micheli*	4
		2	y	*Carex austro-africana (Kük.) Raymond*	4
		2		*Carex cognata Kunth*	3
		2		*Carex glomerabilis Krecz.*	3
	SA	2		*Carex mossii Nelmes*	4
		2		*Carpha capitellata (Nees) Boeck.*	3
	y	2		*Cassinopsis ilicifolia*	1
		1		*Celtis africana*	1
		1	y	*Centella asiatica*	3
		1	y	*Ceratophyllum demersum L. var. demersum*	5
		2		*Chloris virgata*	1
		2	y	*Cladium mariscus (L.) Pohl subsp. jamaicense (Crantz) Kük.*	4
	y	1		*Combretum erythrophyllum*	3
National		1		***Combretum imberbe***	2
		2		*Combretum microphyllum*	1
		2	y	*Commelina diffusa Burm.f. subsp. diffusa*	3
		2	y	*Commelina diffusa Burm.f. subsp. scandens (Welw. ex C.B.Clarke) Oberm.*	4
		2		*Commelina subulata Roth*	3
		2	y	*Cotula coronopifolia L.*	4
	SA	2		*Cotula nigellifolia (DC.) K.Bremer & Humphries var. nigellifolia*	0
		2		*Courtoisina assimilis (Steud.) Maquet*	3
		2		*Courtoisina cyperoides (Roxb.) Soják*	3
		2	y	*Crassula natans Thunb. var. natans*	4
Declining/Provincial		1	y	***Crinum bulbispermum (Burm.f.) Milne-Redh. & Schweick.***	3
		2	y	*Crinum lugardiae N.E.Br.*	3
Declining/Provincial		2		***Crinum macowanii***	0
		2		*Crinum minimum*	0
		2	y	*Crinum paludosum I.Verd.*	3
		1		*Croton megalobotrys*	2
		2		*Cullen tomentosum*	1
Declining/Regional		2		***Cyathea capensis var. capensis***	1
		2		*Cyathea dregei*	1
		1		*Cyclosorus interruptus (Willd.) H.Itô*	4
		2	y	*Cyperus alopecuroides Rottb.*	4
		2	y	*Cyperus articulatus L.*	4
		1	y	*Cyperus congestus Vahl*	4

		2	y	*Cyperus deciduus Boeck.*	3
		2	y	*Cyperus denudatus L.f. var. denudatus*	4
		2	y	*Cyperus difformis L.*	4
		1	y	*Cyperus dives Delile*	4
	SA	2	y	*Cyperus elephantinus (C.B.Clarke) Kük.*	4
		2	y	*Cyperus fastigiatus Rottb.*	3
		2	y	*Cyperus iria L.*	3
		2	y	*Cyperus keniensis Kük.*	3
		2	y	*Cyperus laevigatus L.*	3
		2	y	*Cyperus latifolius Poir.*	3
		2	y	*Cyperus longus L. var. longus*	4
		2	y	*Cyperus longus L. var. tenuiflorus (Rottb.) Boeck.*	4
		2	y	*Cyperus maculatus Boeck.*	3
		1	y	*Cyperus marginatus Thunb.*	4
		2	y	*Cyperus papyrus L.*	4
		2	y	*Cyperus procerus Rottb.*	4
		2	y	*Cyperus rigidifolius Steud.*	3
		1	y	*Cyperus sexangularis Nees*	4
		2	y	*Cyperus tenuispica Steud.*	3
		2		*Dichanthium annulatum var. papillosum*	2
		2		*Diospyros lycioides subsp. guerkei*	0
		2		*Diospyros lycioides subsp. lycioides*	0
	SA	2		*Diospyros lycioides subsp. nitens*	0
		2		*Diospyros lycioides subsp. sericea*	0
		1		*Diospyros mespiliformis*	2
		2	y	*Eleocharis acutangula (Roxb.) Schult.*	4
		2	y	*Eleocharis atropurpurea (Retz.) C.Presl*	4
		2	y	*Eleocharis dregeana Steud.*	4
		2	y	*Eleocharis limosa (Schrad.) Schult.*	4
		1		*Equisetum ramosissimum Desf. subsp. ramosissimum*	3
	SnA	2	y	*Eragrostis plana*	2
		2		*Eragrostis planiculmis*	3
		2		*Eragrostis rotifer*	3
		2	y	*Eriocaulon abyssinicum Hochst.*	3
		2	y	*Eriocaulon africanum Hochst.*	4
	SA	2	y	*Eriocaulon dregei Hochst.*	4
				Eriocaulon hydrophilum Markötter	
				Eriocaulon maculatum Schinz	
				Eriocaulon mutatum N.E.Br. var. angustisepalum (H.E.Hess) S.M.Phillips	
				Eriocaulon sonderianum Körn.	
				Eriocaulon transvaalicum N.E.Br. subsp. tofieldifolium (Schinz) S.M.Phillips	
			y	*Eriocaulon transvaalicum N.E.Br. subsp. transvaalicum*	
	y	2		*Erythrina caffra*	1
CR	SA	2		***Euclea dewinteri***	1
		1		*Euclea divinorum*	1
		1		*Faidherbia albida*	3
		1		*Ficus capreifolia*	2

		2		*Ficus sur*	1
		1		*Ficus sycomorus subsp. sycomorus*	3
				Fimbristylis bisumbellata (Forssk.) Bubani	
				Fimbristylis complanata (Retz.) Link	
				Fimbristylis dichotoma (L.) Vahl subsp. dichotoma	
				Fimbristylis ferruginea (L.) Vahl	
				Fimbristylis squarrosa (Poir.) Vahl	
	SA	2		*Fissidens fasciculatus Hornsch.*	4
				Fissidens ovatus Brid.	
				Fissidens palmifolius (P.Beauv.) Broth.	
				Floscopa glomerata (Willd. ex Schult. & J.H.Schult.) Hassk.	
				Fuirena bullifera J.Raynal & Roessler	
				Fuirena ciliaris (L.) Roxb.	
				Fuirena coerulescens Steud.	
				Fuirena hirsuta (P.J.Bergius) P.L.Forbes	
				Fuirena leptostachya Oliv. forma leptostachya	
				Fuirena leptostachya Oliv. forma nudiflora Lye	
				Fuirena obcordata P.L.Forbes	
				Fuirena pachyrrhiza Ridl.	
				Fuirena pubescens (Poir.) Kunth var. pubescens	
				Fuirena stricta Steud. var. stricta	
		1	y	*Gomphocarpus fruticosus subsp. fruticosus*	3
		1		*Gomphostigma virgatum*	4
	y	1		*Grewia caffra*	2
Declining/Provincial		2	y	***Gunnera perpensa L.***	3
		2	y	*Hemarthria altissima*	3
				Heteranthera callifolia Rchb. ex Kunth	
				Histiopteris incisa (Thunb.) J.Sm.	
	SA	2	y	*Hydrocotyle schlechteri H.Wolff*	3
				Hydrocotyle sibthorpioides Lam.	
		2	y	*Hydrocotyle verticillata Thunb.*	3
				Hypolepis sparsisora (Schrad.) Kuhn	
Declining		2		***Ilex mitis var mitis***	1
		1		*Imperata cylindrica*	2
		2	y	*Ischaemum fasciculatum*	4
Rare				***Isoetes schweinfurthii A.Braun ex Baker***	3
NT				***Isoetes transvaalensis Jermy & Schelpe***	3
NT				***Isoetes welwitschii A.Braun***	3
				Isolepis cernua (Vahl) Roem. & Schult. var. cernua	
				Isolepis costata Hochst. ex A.Rich.	
				Isolepis fluitans (L.) R.Br. var. fluitans	
				Isolepis inyangensis Muasya & Goetgh.	
				Isolepis natans (Thunb.) A.Dietr.	
				Isolepis sepulcralis Steud.	
				Isolepis setacea (L.) R.Br.	
				Juncus dregeanus Kunth subsp. dregeanus	

		2	y	*Juncus effusus L.*	4
		2	y	*Juncus exsertus Buchenau*	4
		1	y	*Juncus lomatophyllus Spreng.*	4
		2	y	*Juncus oxycarpus E.Mey. ex Kunth*	4
		2	y	*Juncus punctorius L.f.*	4
		2	y	*Juncus rigidus Desf.*	4
	SA	2	?	*Kniphofia coralligemma*	?
	SA	2	y	*Kniphofia fluviatilis*	3
		2	y	*Kniphofia linearfolia*	3
		2	y	*Kniphofia multiflora*	3
		2	y	*Kniphofia porphyrantha*	2
		2	?	*Kniphofia splendida*	?
NT	SA	2	y	***Kniphofia typhoides***	3
		2		*Kohautia cynanchica*	1
		1		*Kraussia floribunda*	2
				Kyllinga alata Nees	
				Kyllinga erecta Schumach. var. erecta	
				Kyllinga melanosperma Nees	
				Kyllinga pauciflora Ridl.	
				Kyllinga pulchella Kunth	
				Kyllingiella microcephala (Steud.) R.W.Haines & Lye	
				Lagarosiphon cordofanus Casp.	
				Lagarosiphon major (Ridl.) Moss ex Wager	
				Lagarosiphon muscoides Harv.	
				Lagarosiphon verticillifolius Oberm.	
		2	y	*Leersia hexandra*	3
				Lemna aequinoctialis Welw.	
				Lemna gibba L.	
				Lemna minor L.	
				Leptodictyum riparium (Hedw.) Warnst.	
	y	1		*Leucosidea sericea*	2
				Limnophila indica (L.) Druce	
				Limnophyton obtusifolium (L.) Miq.	
				Limosella africana Glück var. africana	
				Limosella grandiflora Benth.	
				Limosella longiflora Kuntze	
				Limosella maior Diels	
				Lipocarpha chinensis (Osbeck) Kern	
				Lipocarpha micrantha (Vahl) G.C.Tucker	
				Lipocarpha nana (A.Rich.) Cherm.	
				Lipocarpha rehmannii (Ridl.) Goetgh.	
		2	y	*Ludwigia adscendens (L.) Hara subsp. diffusa (Forssk.) P.H.Raven*	4
		2	y	*Ludwigia octovalvis (Jacq.) P.H.Raven*	4
		2	y	*Ludwigia palustris (L.) Elliott*	4
				Ludwigia polycarpaea Short & R.Peter ex Torr. & A.Gray	4
		2		*Lycium cinereum*	
				Marsilea aegyptiaca Willd.	
				Marsilea apposita Launert	
				Marsilea burchellii (Kunze) A.Braun	

				Marsilea capensis A.Braun	
				Marsilea coromandelina Willd.	
				Marsilea ephippiocarpa Alston	
VU		2	y	***Marsilea farinosa Launert subsp. arrecta J.E.Burrows***	4
				Marsilea farinosa Launert subsp. farinosa	
				Marsilea macrocarpa C.Presl	
				Marsilea villifolia Bremek. & Oberm. ex Alston & Schelpe	
				Melianthus comosus	2
		2	y	*Mentha aquatica*	2
				Mimulus gracilis R.Br.	
		2		*Mimusops obovata*	1
		1		*Mimusops zeyheri*	2
	SnA	1	y	*Miscanthus junceus*	3
				Monochoria africana (Solms) N.E.Br.	
		2		*Morella serrata*	2
				Myriophyllum aquaticum (Vell.) Verdc.	
				Myriophyllum spicatum L.	
				Najas graminea Delile var. graminea	
		1		*Nasturtium officinale**	4
				Neptunia oleracea Lour.	
				Nesaea crassicaulis (Guill. & Perr.) Koehne	
		1		*Nuxia oppositifolia*	2
				Nymphaea lotus L.	
				Nymphaea mexicana Zucc.	
				Nymphaea nouchali Burm.f. var. caerulea (Savigny) Verdc.	
				Nymphaea nouchali Burm.f. var. zanzibariensis (Casp.) Verdc.	
				Nymphoides indica (L.) Kuntze subsp. occidentalis A.Raynal	
				Nymphoides thunbergiana (Griseb.) Kuntze	
		2		*Olea europaea subsp. africana*	1
VU		2	y	***Oryza longistaminata A.Chev. & Roehr.***	4
				Ottelia exserta (Ridl.) Dandy	
				Ottelia ulvifolia (Planch.) Walp.	
		2	y	*Panicum schinzii*	1
		2	y	*Paspalum dilatatum**	2
		1	y	*Paspalum distichum*	4
		2	y	*Paspalum urvillei**	2
		2		*Pennisetum macrourum*	3
		2	y	*Pennisetum sphacelatum*	1
		2	y	*Pennisetum thunbergii*	3
		2	y	*Persicaria amphibia (L.) Gray**	4
		2	y	*Persicaria attenuata (R.Br.) Soják subsp. africana K.L.Wilson*	4
		2	y	*Persicaria decipiens (R.Br.) K.L.Wilson*	4
		2	y	*Persicaria lapathifolia (L.) Gray**	4
		2	y	*Persicaria limbata (Meisn.) H.Hara**	4
		2	y	*Persicaria meisneriana (Cham. & Schltdl.) M.Gómez*	4

		2	y	*Persicaria senegalensis (Meisn.) Soják forma albotomentosa (R.A.Graham) K.L.Wilson*	4
		2	y	*Persicaria senegalensis (Meisn.) Soják forma senegalensis*	4
		2		*Persicaria serrulata*	4
National		1		***Philenoptera violacea***	2
		2	y	*Phoenix reclinata*	2
		1		*Phragmites australis*	4
		1		*Phragmites mauritianus*	4
		1		*Phyllanthus reticulatus var. reticulatus*	2
	SA	2	y	*Pimpinella hydrophila H.Wolff*	4
				Pistia stratiotes L.	
				Platyhypnidium macowanianum (Paris) M.Fleisch.	
				Pontederia cordata L. var. ovalis Solms	
				Potamogeton crispus L.	5
			y	*Potamogeton octandrus Poir.*	5
		2		*Potamogeton pectinatus L.*	5
			y	*Potamogeton pusillus L.*	5
		2		*Potamogeton schweinfurthii A.Benn.*	5
				Potamogeton trichoides Cham. & Schltdl.	5
				Pteris buchananii Baker ex Sim	
				Pycreus betschuanus (Boeck.) C.B.Clarke	
				Pycreus chrysanthus (Boeck.) C.B.Clarke	
				Pycreus cooperi C.B.Clarke	
				Pycreus flavescens (L.) P.Beauv. ex Rchb.	
				Pycreus intactus (Vahl) J.Raynal	
				Pycreus macranthus (Boeck.) C.B.Clarke	
				Pycreus macrostachyos (Lam.) J.Raynal	
				Pycreus mundii Nees	
				Pycreus muricatus (Kük.) Napper	
				Pycreus niger (Ruíz & Pav.) Cufod. subsp. elegantulus (Steud.) Lye	
				Pycreus nigricans (Steud.) C.B.Clarke	
				Pycreus nitidus (Lam.) J.Raynal	
				Pycreus pelophilus (Ridl.) C.B.Clarke	
				Pycreus permutatus (Boeck.) Napper	
				Pycreus polystachyos (Rottb.) P.Beauv. var. polystachyos	
				Pycreus pumilus (L.) Domin	
				Pycreus rehmannianus C.B.Clarke	
				Pycreus unioloides (R.Br.) Urb.	
		2	y	*Ranunculus baurii*	2
		2	y	*Ranunculus meyeri Harv.*	4
		2		*Ranunculus multifidus**	2
				Ranunculus rionii Lagger	
		2		*Rauvolfia caffra*	2
				Rhynchospora brownii Roem. & Schult.	
			y	*Riccia stricta (Lindenb.) Perold*	
				Rotala capensis (Harv.) A.Fern. & Diniz	
				Rotala filiformis (Bellardi) Hiern	
				Rotala mexicana Cham. & Schltdl.	

			Rotala tenella (Guill. & Perr.) Hiern	
	2		*Rumex lanceolatus*	2
	2		*Salix fragilis var fragilis**	3
			Salix mucronata subsp. capensis	3
	1		*Salix mucronata subsp. woodii*	3
			Salvinia molesta D.S.Mitch.	
			Samolus valerandi L.	
		y	*Schoenoplectus articulatus (L.) Palla*	4
SA	2	y	*Schoenoplectus brachyceras (Hochst. ex A.Rich.) Lye*	4
SA			*Schoenoplectus brachyceras (Hochst. ex A.Rich.) Lye x S. decipiens (Nees) Raynal*	4
	2	y	*Schoenoplectus corymbosus (Roth ex Roem. & Schult.) J.Raynal*	4
	2	y	*Schoenoplectus decipiens (Nees) J.Raynal*	4
		y	*Schoenoplectus erectus (Poir.) Palla ex J.Raynal*	4
	2	y	*Schoenoplectus leucanthus (Boeck.) J.Raynal*	4
	2	y	*Schoenoplectus muricinux (C.B.Clarke) J.Raynal*	4
	2	y	*Schoenoplectus muriculatus (Kük.) Browning*	4
	2	y	*Schoenoplectus pulchellus (Kunth) J.Raynal*	4
	2	y	*Schoenoplectus scirpoides (Schrad.) Browning*	4
	2	y	*Schoenoplectus senegalensis (Hochst. ex Steud.) Palla ex J.Raynal*	4
	2	y	*Schoenoplectus tabernaemontani (C.C.Gmel.) Palla**	4
			Schoenus nigricans L.	
y	1		*Schotia brachypetala*	2
			Scirpus ficinioides Kunth	
			Scleria aterrima (Ridl.) Napper	
			Scleria dieterlenii Turrill	
			Scleria distans Poir.	
			Scleria dregeana Kunth	
			Scleria foliosa Hochst. ex A.Rich.	
			Scleria melanomphala Kunth	
			Scleria rehmannii C.B.Clarke	
			Scleria welwitschii C.B.Clarke	
			Scleria woodii C.B.Clarke	
y	2		*Searsia dentata*	1
	1		*Searsia gerrardii*	3
	2		*Searsia lancea*	1
	2		*Setaria incrassata*	2
	1		*Setaria sphacelata var. sericea*	3
			Sphaerothylax algiformis Bisch. ex C.Krauss	
			Sphagnum capense Hornsch.	
			Sphagnum fimbriatum Wilson	
			Sphagnum strictum Sull. subsp. pappeanum (Müll.Hal.) A.Eddy	
			Sphagnum truncatum Hornsch.	
			Spirodela punctata (G.Mey.) C.H.Thomps.	
	1		*Spirostachys africana*	2
	2		*Sporobolus fimbriatus*	2

		Syngonanthus wahlbergii (Wikstr. ex Körn.) Ruhland var. wahlbergii	
1		*Syzygium cordatum subsp. cordatum*	3
1		*Syzygium guineense subsp. guineense*	3
2		*Syzygium intermedium*	3
1		*Terminalia sericea*	0
		Tetraria cuspidata (Rottb.) C.B.Clarke var. cuspidata	
		Thelypteris confluens (Thunb.) C.V.Morton	
		Torenia thouarsii (Cham. & Schltdl.) Kuntze	
2		*Trema orientalis*	2
1		*Trichilia emetica subsp. emetica*	2
		Tristicha trifaria (Bory ex Willd.) Spreng. subsp. trifaria	
1	y	*Typha capensis (Rohrb.) N.E.Br.*	4
		Utricularia arenaria A.DC.	
		Utricularia scandens Benj.	
2	y	*Utricularia stellaris*	3
		Utricularia subulata L.	
		Veronica anagallis-aquatica L.	
		Vittia pachyloma (Mont.) Ochyra	
		Wolffia arrhiza (L.) Horkel ex Wimm.	
		Wolffia globosa (Roxb.) Hartog & Plas	
1		*Xanthocercis zambesiaca*	1
		Xyris anceps Lam. var. anceps	
		Xyris capensis Thunb.	
		Xyris congensis Büttner	
		Xyris gerrardii N.E.Br.	
		Xyris obscura N.E.Br.	
		Xyris rehmannii L.A.Nilsson	
		Xyris rubella Malme	
		Zannichellia palustris L.	
1		*Ziziphus mucronata subsp. mucronata*	1

5.8 APPENDIX 3: RESERVE DETERMINATION OF THE ELEFANTES AND LOWER LIMPOPO RIVERS, MOZAMBIQUE: RIPARIAN VEGETATION

P D Naidoo and Associates
By:
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1. VEGRAI LEVEL 4 ASSESSMENT FOR ELEFANTES EWR 1

PES: C (62.0%) WITH AVERAGE CONFIDENCE OF 2.2

FIGURE 1A. AERIAL VIEW OF PART OF THE SECTION AT EWR 1 ON THE ELEFANTES RIVER.

Elefantes EWR site 1 occurs in zone 3 as outlined in the geomorphological stream zone classification report (Rountree, 2006). The section below Massingir dam is characterised by extensive sandy alluvial deposits in and adjacent to the active channel (Figure 5 in that report). The active channel largely flows within a restrictive "macro-channel", within which the active channel meanders and braids. This morphological pattern has been well documented in the reaches upstream in South Africa (van Niekerk et al, 1995, Rountree et al., 2001). See Fig.1 a and b for aerial view and photographs respectively.

The floodplain at this site is over 2000m wide and is characterised by extensive riparian forests (see Appendix 1 for species). It is also characterised by a flat depositional environment with many of the features being dependent on water table connectivity with the active channel (see wetland scoping report by Marneweck, 2005). The groundwater aquifer can be up to 15km wide and known to have high quality water yield (draft Groundwater Report, Elefants Reserve Study). These aquifers are recharged during periods of high river flow and then discharge into the river again once the stage drops. There is thus a seasonal switch between influent and effluent river processes (see the draft geomorphological stream zone classification report by Rountree, 2006). The woody component of riparian forests will depend on ground water levels and movement for survival, while floods and rainfall patterns will be important for recruitment and the early stages of seedling and sapling establishment.

FIGURE 1B. PHOTOGRAPHS OF THE SECTION AT EWR 1 ON THE ELEFANTES RIVER.

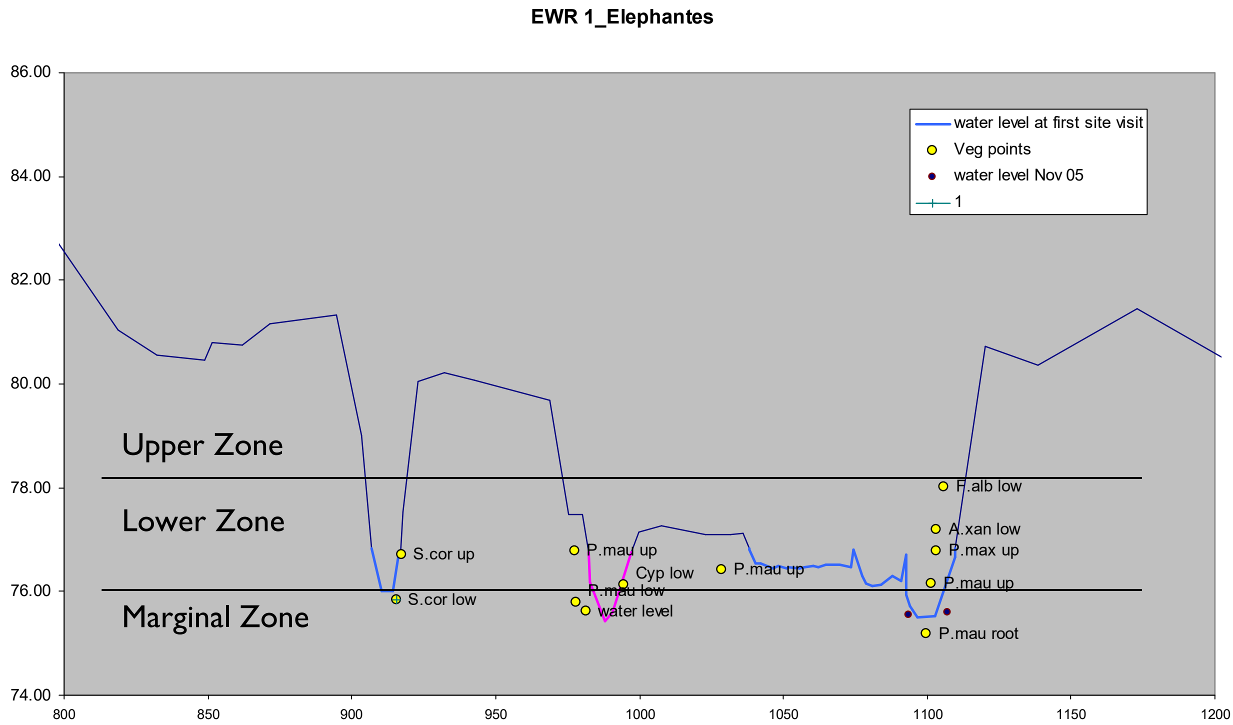

FIGURE 2. ZONE DELINEATION AND LOW FLOW SPECIES PLACEMENT AT EWR 1 ON ELEFANTES. LOW = LOWER LIMIT; UP = UPPER LIMIT; S.COR = *SCHOENOPLECTUS CORYMBOSUS*; P.MAU = *PHRAGMITES MAURITIANUS*; CYP = *CYPERUS SPP*; A.XAN = *ACACIA XANTHOPHLOEA*; F.ALB = *FAIDHERBIA ALBIDA*.

1.1. MARGINAL ZONE

IMPACTS

Impacts in the marginal zone are mainly from reduced flows (Table 5.2), which have resulted in reduced aerial cover and abundance of non-woody vegetation. Vegetation removal, mainly from reed cutting and herbivory by livestock, was also prevalent, but with low intensity and not very extensive. In terms of exotic invasion, some *Eichornia crassipes* was present in backwaters, but with localised occurrence.

TABLE 5.2 IMPACT ASSESSMENT IN MARGINAL ZONE AT ELEFANTES EWR 1.

	IMPACT RATINGS		
IMPACTS	INTENSITY	EXTENT	CONFIDENCE
REMOVAL	1.0	2.0	2.0
EXOTIC INVASION	2.0	1.0	3.0
WATER QUANTITY	2.0	5.0	2.0
WATER QUALITY	0.5	4.0	1.0
AVERAGE			2.0

RESPONSE

The woody component for the marginal zone (see Fig. 2 for delineation) was turned off in VEGRAI assessment since this zone is vegetated by non-woody species (*P. mauritianus, S. corymbosus, Cyperus sp*). Non-woody cover and abundance were moderately reduced from what was expected in reference conditions, mainly from reduced flows and vegetation removal (Table 5.3). Similarly, species composition had changed moderately as more *S. corymbosus* and less *P. mauritianus* was expected in and around backwaters and other permanently or nearly permanently wetted areas.

TABLE 5.3. RIPARIAN VEGETATION RESPONSE IN MARGINAL ZONE AT ELEFANTES EWR 1.

		RESPONSE METRIC RATINGS		
VEGETATION COMPONENTS	RESPONSE METRIC	CONSIDER? (Y/N)	RATING	CONFIDENCE
WOODY	COVER	N		
	ABUNDANCE	N		
	POPULATION STRUCTURE	N	0.0	
	VERTICAL STRUCTURE	Y	2.0	
	RECRUITMENT	N	0.0	
	SPECIES COMPOSITION	N	0.0	
			2.0	0.0
NON-WOODY	COVER	Y	2.0	3.0
	ABUNDANCE	Y	2.0	3.0
	SPECIES COMPOSITION	Y	2.0	3.0
			2.0	3.0

RANKING

Since the woody component was not prevalent in the marginal zone, it was switched off for the marginal zone and did not contribute in the weighting (Table 5.4). Marginal zone contribution to the overall EC was therefore from the non-woody vegetation component only.

TABLE 5.4. RANKING OF VEGETATION COMPONENTS IN THE MARGINAL ZONE AT ELEFANTS EWR1.

VEGETATION COMPONENTS	CONSIDER? (Y/N)	RANK	WEIGHT	RATING	WEIGHTED RATING	MEAN CONFIDENCE
WOODY	N	2.0	0.0	2.0		0.0
NON-WOODY	Y	1.0	100.0	2.0	2.00	3.0
					2.00	1.5
CHANGE (%) IN VEGETATION COMPONENTS:OVERALL CHANGE IN LATERAL ZONE CONDITION			**40.0**			

LOWER ZONE

IMPACTS

Impacts in the lower zone are also mainly from vegetation removal and reduced flows (Table 5.5). The lack of woody juveniles was due to high levels of herbivory from livestock. Woody vegetation had also been removed for both fuel and to clear areas for subsistence agriculture. The effect of reduced flows is less in this zone than in the marginal zone, but will have an impact on groundwater movement and recharge, which is an important dynamic on this system for vegetation survival through the dry season and reproductive capacity in the wet season.

TABLE 5.5. IMPACT ASSESSMENT IN LOWER ZONE AT ELEFANTES EWR 1.

	IMPACT RATINGS		
IMPACTS	INTENSITY	EXTENT	CONFIDENCE
REMOVAL	3.0	3.0	3.0
EXOTIC INVASION	0.0	0.0	3.0
WATER QUANTITY	1.0	3.0	2.0
WATER QUALITY	0.0	0.0	4.0
AVERAGE			3.0

RESPONSE

The lower zone (see Fig 2 for delineation) was characterised by *P. mauritianus, A. xanthophloea* and *F. albida*. Cover and abundance for both woody and non-woody vegetation was moderately reduced from reference due to vegetation removal and herbivory from livestock (Table 5.6). Non-woody species composition was not assessed and was near natural for woody species. Recruitment of woody vegetation was prevalent, but reduced by browsing of seedlings and saplings. This, in turn, affected population structure (see VEGRAI model for data & curves) in that the lack of juveniles changed population curves.

TABLE 5.6. RIPARIAN VEGETATION RESPONSE IN LOWER ZONE AT ELEFANTES EWR 1.

		RESPONSE METRIC RATINGS		
VEGETATION COMPONENTS	RESPONSE METRIC	CONSIDER? (Y/N)	RATING	CONFIDENCE
WOODY	COVER	Y	2.0	4.0
	ABUNDANCE	Y	2.0	3.0
	POPULATION STRUCTURE	Y	2.0	2.0
	VERTICAL STRUCTURE	Y	2.0	
	RECRUITMENT	Y	1.3	2.0
	SPECIES COMPOSITION	Y	0.8	3.0
			1.7	2.3
NON-WOODY	COVER	Y	2.0	3.0
	ABUNDANCE	Y	2.0	3.0
	SPECIES COMPOSITION	N		
			2.0	3.0

RANKING

Woody vegetation was ranked highest in the lower zone due to its role in bank stabilization and shading of shallow flows (thermal implications for instream fauna), but non-woody vegetation (mainly *P. mauritianus*) was also weighted high since it provides marginal vegetation cover at low flow and spawning habitat to instream fauna at higher flows (Table 5.7).

TABLE 5.7. RANKING OF VEGETATION COMPONENTS IN THE LOWER ZONE AT ELEFANTS EWR1.

VEGETATION COMPONENTS	CONSIDER? (Y/N)	RANK	WEIGHT	RATING	WEIGHTED RATING	MEAN CONFIDENCE
WOODY	Y	1.0	100.0	1.7	1.69	2.3
NON-WOODY	Y	2.0	80.0	2.0	1.60	3.0
					3.29	2.7
CHANGE (%) IN VEGETATION COMPONENTS:OVERALL CHANGE IN LATERAL ZONE CONDITION			**36.5**			

UPPER ZONE

IMPACTS

Impacts in the upper zone, again, (see Fig. 2 for delineation) are mainly from vegetation removal due to the chopping of wood and extensive browsing from livestock (Table 5.8). A single exotic occurred (see Appendix I for species) and no clear impacts due to flow quantity and quality were discernible. Vegetation in the upper zone is more likely to be dependent on lateral ground water movement and rainfall rather than channel flow.

TABLE 5.8. IMPACT ASSESSMENT IN UPPER ZONE AT ELEFANTES EWR 1.

	IMPACT RATINGS		
IMPACTS	INTENSITY	EXTENT	CONFIDENCE
REMOVAL	3.0	4.0	3.0
EXOTIC INVASION	0.5	1.0	2.0
WATER QUANTITY	0.0	0.0	2.0
WATER QUALITY	0.0	0.0	2.0
AVERAGE			2.3

RESPONSE

The upper zone is characterised mainly by extensive shrub/tree woodlands with *Acacia sp* thickets in places. Shrubs include *G. senegalensis, G. flavescence* and *P. reticulates* while trees include *F. albida, A. xanthophloae, L. capasa, D. mespiliformis, F. sycomorus* and *S. birea*. As in the lower zone, woody and non-woody cover and abundance were lower than expected due to removal and browsing (Table 5.9). Browsing also reduced recruitment, which skewed population structure curves (see population structure & recruitment in VEGRAI assessment). Species composition changed moderately due to selective harvesting of wood, especially *Acacia* species, which, because of their thorns are used as fences and to protect young crops.

TABLE 5.9. RIPARIAN VEGETATION RESPONSE IN UPPER ZONE AT ELEFANTES EWR 1.

		RESPONSE METRIC RATINGS		
VEGETATION COMPONENTS	RESPONSE METRIC	CONSIDER? (Y/N)	RATING	CONFIDENCE
WOODY	COVER	Y	2.0	4.0
	ABUNDANCE	Y	2.0	3.0
	POPULATION STRUCTURE	Y	1.7	2.0
	VERTICAL STRUCTURE	Y	2.0	
	RECRUITMENT	Y	1.7	2.0
	SPECIES COMPOSITION	Y	1.3	2.0
			1.8	2.2
NON-WOODY	COVER	Y	2.0	4.0
	ABUNDANCE	Y	2.0	3.0
	SPECIES COMPOSITION	N		
			2.0	3.5

RANKING

Woody vegetation was ranked highest in the upper zone due to its dominance and its potential to reduce flow via its utilization of ground water (Table 5.10).

TABLE 5.10. RANKING OF VEGETATION COMPONENTS IN THE UPPER ZONE AT ELEFANTS EWR1.

VEGETATION COMPONENTS	CONSIDER? (Y/N)	RANK	WEIGHT	RATING	WEIGHTED RATING	MEAN CONFIDENCE
WOODY	Y	1.0	100.0	1.8	1.78	2.2
NON-WOODY	Y	2.0	60.0	2.0	1.20	3.5
					2.98	2.8
CHANGE (%) IN VEGETATION COMPONENTS:OVERALL CHANGE IN LATERAL ZONE CONDITION			**37.3**			

RIPARIAN ZONE ECOLOGICAL CATEGORY

For the calculation of the EC for the riparian zone the marginal and lower zones were weighted highest due to their contribution to instream fauna habitat and bank stabilization, and the upper zone much lower (Table 5.11). The resultant EC for the Elefantes at EWR 1 is a C (62%) with and average confidence of 2.2. Confidence is low to medium due to time constraints for site visits.

TABLE 5.11. RIPARIAN ZONE EC CALCULATION FOR ELEFANTES EWR 1.

LEVEL 4 ASSESSMENT					
RIPARIAN VEGETATION EC METRIC GROUP	CALCULATED RATING	WEIGHTED RATING	CONFIDENCE	RANK	WEIGHT
MARGINAL	60.0	24.0	1.5	1.0	100.0
LOWER ZONE	63.9	23.0	2.8	2.0	90.0
UPPER ZONE	62.7	15.0	2.8	3.0	60.0
	3.0				250.0
LEVEL 4 VEGRAI (%)				62.0	
VEGRAI EC				**C**	
				C	
AVERAGE CONFIDENCE				2.2	

RECOMMENDED EC FOR ELEFANTES EWR 1

An improvement in the VEGRAI EC for Elefantes EWR 1 from 62.0% to 71.6%, the class remaining a C (Table 5.12), is possible for woody and non-woody cover and abundance in the marginal and lower zones. This improvement is expected if low flows are increased and zero flows eliminated, and is due to increased growth and vigour under conditions that have less water stress. The assumption is made that seasonality of flow remains unchanged. *Schoenoplectus corymbosus* and *Phragmites mauritianus* will be the main species to respond in the marginal zone, while *P.mauritianus, Acacia xanthophloea, Faidherbia albida* and shrub species are likely to respond in the lower zone.

TABLE 5.12. RECOMMENDED RIPARIAN ZONE EC FOR ELEFANTES AT EWR1.

LEVEL 4 ASSESSMENT					
RIPARIAN VEGETATION EC METRIC GROUP	CALCULATED RATING	WEIGHTED RATING	CONFIDENCE	RANK	WEIGHT
MARGINAL	73.3	29.3	1.5	1.0	100.0
LOWER ZONE	75.6	27.2	2.8	2.0	90.0
UPPER ZONE	62.7	15.0	2.8	3.0	60.0
	3.0				250.0
LEVEL 4 VEGRAI (%)				**71.6**	
VEGRAI EC				**C**	
				C	
AVERAGE CONFIDENCE				2.2	

INCISED CHANNEL SCENARIO:

In the event that the channel incises because of reduced sediments loads from Massingir dam and possibly increased low flows, riparian vegetation response is likely to be as follows: Marginal zone species (*P.mauritianus, S. corymbosus, Cyperus sp*) distribution will migrate downwards and follow the channel. Lower and upper zone species will become more water stressed depending on the rate of subsidence of the water table. Wetland species associated with wetlands, pans and backwaters will become water stressed or will die since these habitats are likely to dry out. Woody riparian vegetation recruitment in lower and upper zones will likely continue to take cues from rainfall and flood events, but establishment of juveniles and sub-adults is likely to be less successful as water table levels drop. This will result in reduced cover and abundance of riparian vegetation in these zones and altered population structure to most deep-rooted species. Depending on the rate at which the water table drops, existing woody vegetation mortality may increase, but even if survival takes place, reproductive output is likely to be reduced.

HIGH FLOW REQUIREMENTS AT EWR1 (ELEFANTES)

Although woody riparian vegetation in the lower and upper riparian zone is likely to depend on ground water availability for its survival at this site, high flows are required to recharge ground water, mobilise and replenish nutrients and sediments and provide microsites for recruitment and regeneration. Increased growth and vigour of vegetation at high flows also results in years where reproductive output can be markedly improved in the same or subsequent years. Suggested high flows at EWR 1 for Elefantes are outlined in Table 5.13 and shown in Fig. 3. These flows are important in terms of their frequency rather than their actual discharge. The values for average discharge listed in Table 5.13 are approximate and confidence for their estimation is low.

TABLE 5.13. FLOODS REQUIRED FOR RIPARIAN VEGETATION AT EWR 1 (ELEFANTES). SEE FIG. 3 FOR STAGE LEVELS.

Approximate return period of flow	AVE Q	APPROX. FLOW DEPTH
Class 2 flood 2 floods per annum in summer or late summer for a duration of 3 days or more to inundate lower level reed beds (*P. mauritianus*)	37	1.25
Class 3 flood 2 floods per annum in summer or late summer for a duration of 2 days or more to inundate *A. xanthophloea* at lower limit and facilitate regeneration	75	1.7
Class 4 flood Annual flood to occur in late summer to activate lower level of tree line (*F. albida*) and to inundate higher level reed beds (*P. mauritianus*). Facilitates regeneration episodes for *F. albida*	160	2.5
Class 5 flood every 2/3 years to inundate marginal zone *P.mauritianus* reed beds, activate seasonal channels & bars which support *A. xanthoploea,* and maintain *P.mauritianus* low density, high elevation reed beds	220	4.5
Class 6 flood every 5 years to activate ephemeral channels & bars for *A. xanthoploea F.albida, D. mespiliformis* and shrubs, and to activate greater floodplain	450	5.9
Class 7 flood every 10 years for activation of more xeric tree and shrub species (*S. birea),*these are the species with infrequent recruitment patterns, critical for species with punctuated recruitment and distinct cohorts.	640	7.0

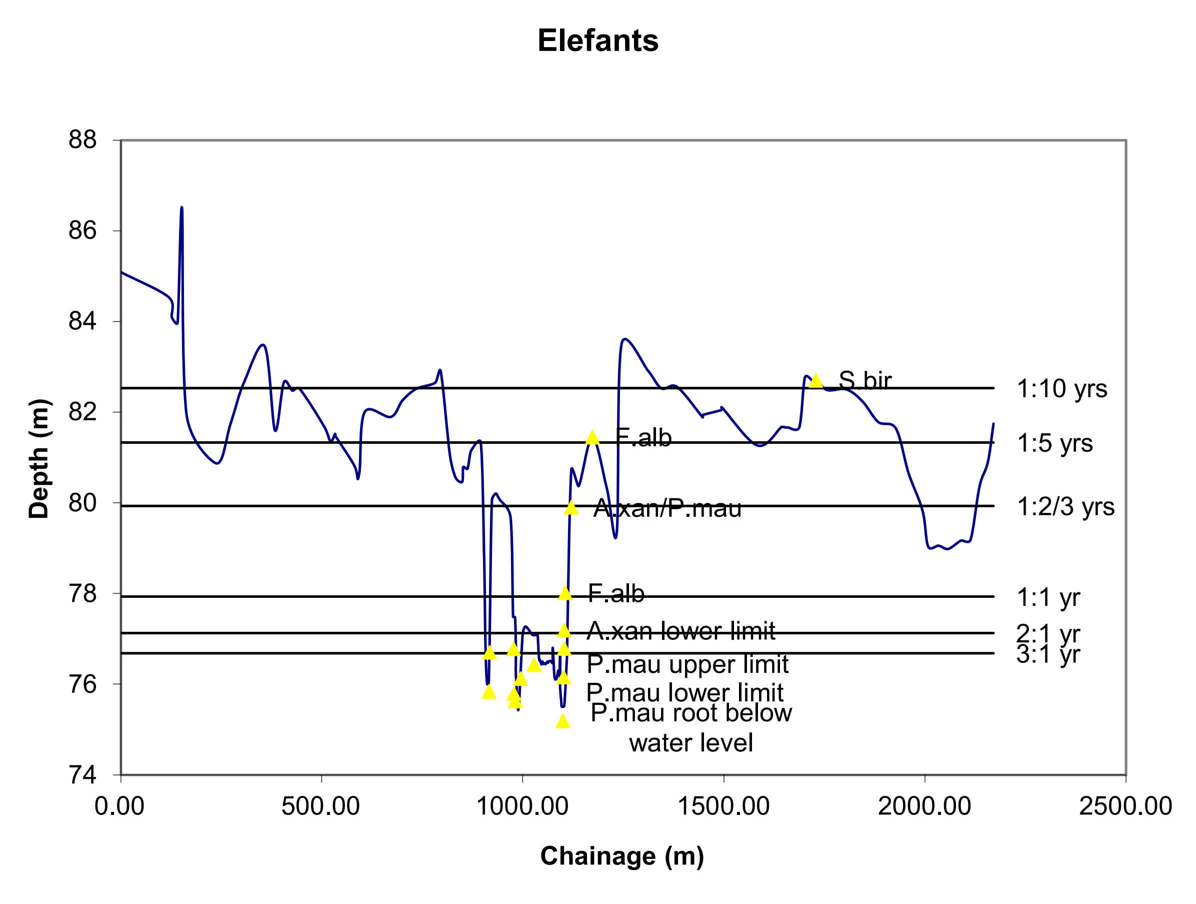

FIGURE 3. FLOODS REQUIRED FOR RIPARIAN VEGETATION AT EWR 1 (ELEFANTES). A.XAN = *ACACIA XANTHOPHLOEA*, P.MAU = *PHRAGMITES MAURITIANUS*, F.ALB = *FAIDHERBIA ALBIDA*, S.BIR = *SCLEROCARYA BIRREA*.

VEGRAI LEVEL 4 ASSESSMENT FOR LIMPOPO EWR 2

PES: C/D (60.4%) WITH AVERAGE CONFIDENCE OF 2.2

Limpopo EWR site 2 occurs in zone 4 upstream of Chokwe as outlined in the geomorphological stream zone classification report (Rountree, 2006). The river here is again characterised by extensive exposed sedimentary units (Figure 6 in that report). Although there is an extensive floodplain several kilometres wide (EWR 2 is 3600m wide), there is little evidence of meandering or ox-bow lake formation in this zone, suggesting that the position of the active channel is stable (Figs 5a and b). This zone is thus morphologically similar to Zone 3, but the extensive floodplain forests are no longer prevalent, due to a likely combination of lower rainfall and more extensive deforestation in the region. Additionally, the sediment load in the channel will have increased due to the influence of the Limpopo River system.

FIGURE 4A. AERIAL VIEW OF PART OF THE SECTION AT EWR 2 ON THE LIMPOPO RIVER.

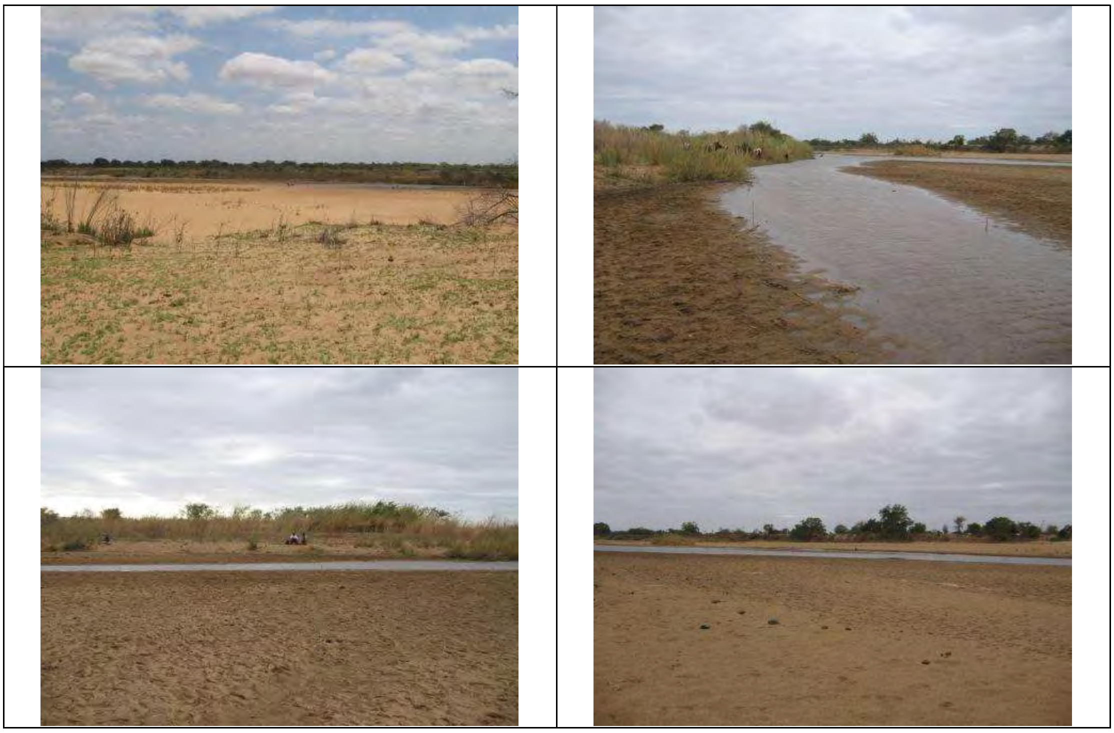

FIGURE 4B. PHOTOGRAPHS OF THE SECTION AT EWR 2 ON THE LIMPOPO RIVER.

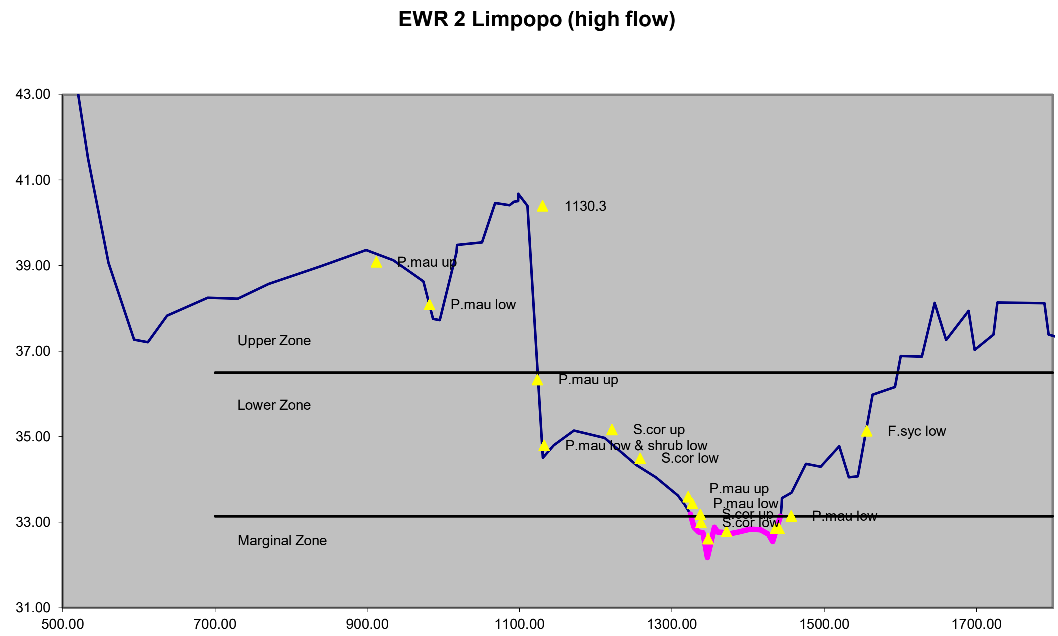

FIGURE 5. ZONE DELINEATION AND VEGETATION PLACEMENT FOR EWR 2 ON LIMPOPO. SPECIES ABBREVIATIONS ARE AS IN FIGURE 1.

MARGINAL ZONE

IMPACTS

Impacts in the marginal zone are mainly from vegetation removal and reduced flows (Table 5.14), which have resulted in reduced aerial cover and abundance of non-woody vegetation. Vegetation removal is mainly from reed cutting and trampling and herbivory from livestock.

TABLE 5.14. IMPACT ASSESSMENT IN MARGINAL ZONE AT LIMPOPO EWR 2.

	IMPACT RATINGS		
IMPACTS	INTENSITY	EXTENT	CONFIDENCE
REMOVAL	2.0	4.0	3.0
EXOTIC INVASION	0.0	0.0	2.0
WATER QUANTITY	1.0	4.0	2.0
WATER QUALITY	0.0	0.0	2.0
AVERAGE			2.3

RESPONSE

The woody component for the marginal zone (see Fig. 5 for delineation) was turned off in VEGRAI assessment since this zone is vegetated predominantly by non-woody species (*P. mauritianus, S. corymbosus, Cyperus sp*). Non-woody cover and abundance were moderately reduced from what was expected in reference conditions, mainly from reduced flows and vegetation removal (Table 5.15). Similarly, species composition had changed moderately as more *S. corymbosus* and less *P. mauritianus* was expected in and around backwaters and other permanently or nearly permanently wetted areas.

TABLE 5.15. RIPARIAN VEGETATION RESPONSE IN MARGINAL ZONE AT LIMPOPO EWR 2.

VEGETATION COMPONENTS	RESPONSE METRIC	RESPONSE METRIC RATINGS		
		CONSIDER? (Y/N)	RATING	CONFIDENCE
WOODY	COVER	N	0.0	
	ABUNDANCE	N	0.0	
	POPULATION STRUCTURE	N	0.0	
	VERTICAL STRUCTURE	Y	2.0	
	RECRUITMENT	N	0.0	
	SPECIES COMPOSITION	N	0.0	
			2.0	0.0
NON-WOODY	COVER	Y	2.0	3.0
	ABUNDANCE	Y	2.0	3.0
	SPECIES COMPOSITION	Y	1.9	3.0
			2.0	3.0

RANKING

Since the woody component was not prevalent in the marginal zone, it was switched off for the marginal zone and did not contribute in the weighting (Table 5.16).

TABLE 5.16. RANKING OF VEGETATION COMPONENTS IN THE MARGINAL ZONE AT LIMPOPO EWR2.

VEGETATION COMPONENTS	CONSIDER? (Y/N)	RANK	WEIGHT	RATING	WEIGHTED RATING	MEAN CONFIDENCE
WOODY	N	2.0	0.0	2.0		0.0
NON-WOODY	Y	1.0	100.0	2.0	1.97	3.0
					1.97	1.5
CHANGE (%) IN VEGETATION COMPONENTS:OVERALL CHANGE IN LATERAL ZONE CONDITION			**39.3**			

LOWER ZONE

IMPACTS

Impacts in the lower zone are mainly from vegetation removal, exotic invasion and reduced flows (Table 5.17). Some removal of wood was prevalent, but removal was mainly due to livestock trampling and herbivory.

TABLE 5.17. IMPACT ASSESSMENT IN LOWER ZONE AT LIMPOPO EWR 2.

IMPACTS	IMPACT RATINGS		
	INTENSITY	EXTENT	CONFIDENCE
REMOVAL	2.0	4.0	3.0
EXOTIC INVASION	1.0	4.0	3.0
WATER QUANTITY	1.0	4.0	2.0
WATER QUALITY	0.0	0.0	2.0
AVERAGE			2.5

RESPONSE

The lower zone (see Fig 5 for delineation) was characterised by *P. mauritianus, S. corymbosus, P. reticulates, G. senegalensis* and *F. sycomorus*. Cover and abundance for both woody and non-woody vegetation was moderately different from reference due to vegetation removal and herbivory from livestock (Table 5.18). Species composition was near natural for woody and non-woody vegetation. Recruitment of woody vegetation was prevalent, but reduced by browsing of seedlings and saplings. This, in turn, affected population structure, especially for *F. sycomorus*, which lacked recruitment (see VEGRAI model for data & curves).

TABLE 5.18. RIPARIAN VEGETATION RESPONSE IN LOWER ZONE AT LIMPOPO EWR 2.

		RESPONSE METRIC RATINGS		
VEGETATION COMPONENTS	**RESPONSE METRIC**	**CONSIDER? (Y/N)**	**RATING**	**CONFIDENCE**
WOODY	COVER	Y	2.0	4.0
	ABUNDANCE	Y	2.0	3.0
	POPULATION STRUCTURE	Y	1.3	2.0
	VERTICAL STRUCTURE	Y	2.0	
	RECRUITMENT	Y	1.0	2.0
	SPECIES COMPOSITION	Y	0.9	3.0
			1.5	2.3
NON-WOODY	COVER	Y	2.0	3.0
	ABUNDANCE	Y	2.0	3.0
	SPECIES COMPOSITION	Y	1.0	2.0
			1.7	2.7

RANKING

Woody vegetation was ranked highest in the lower zone due to its role in bank stabilization (especially extensive shrub layer), but non-woody (mainly *P. mauritianus*) was also weighted high since it provides marginal vegetation cover and breeding habitat for instream fauna at higher flows (Table 5.19).

TABLE 5.19. RANKING OF VEGETATION COMPONENTS IN THE LOWER ZONE AT LIMPOPO EWR 2.

VEGETATION COMPONENTS	CONSIDER? (Y/N)	RANK	WEIGHT	RATING	WEIGHTED RATING	MEAN CONFIDENCE
WOODY	Y	1.0	100.0	1.5	1.54	2.3
NON-WOODY	Y	1.0	60.0	1.7	1.00	2.7
					2.54	2.5
CHANGE (%) IN VEGETATION COMPONENTS:OVERALL CHANGE IN LATERAL ZONE CONDITION			**31.8**			

UPPER ZONE

IMPACTS

Impacts in the upper zone (see Fig. 5 for delineation) are mainly from vegetation removal due to the chopping of woody vegetation (especially *Acacia* spp) and browsing from livestock (Table 5.20). A single exotic occurred (see Appendix 1) and no clear impacts due to flow quantity and quality were discernible. Vegetation in the upper zone is more likely to be dependent on lateral ground water movement and rainfall rather than channel flow.

TABLE 5.20. IMPACT ASSESSMENT IN UPPER ZONE AT LIMPOPO EWR 2.

	IMPACT RATINGS		
IMPACTS	INTENSITY	EXTENT	CONFIDENCE
REMOVAL	3.0	4.0	3.0
EXOTIC INVASION	1.0	4.0	2.0
WATER QUANTITY	0.0	0.0	2.0
WATER QUALITY	0.0	0.0	2.0
AVERAGE			2.3

RESPONSE

The upper zone was characterised by extensive shrub/tree woodlands with *Acacia sp* thickets in places. Shrubs included *G. senegalensis, G. flavescence* and *P. reticulates* while trees included *F. albida, A. xanthophloae, L. capasa, D. mespiliformis, F. sycomorus* and *K. africana.* As in the lower zone, woody and non-woody cover and abundance were lower than expected due to removal and browsing (Table 5.21). Agricultural activity was much higher at this site. Browsing also reduced recruitment, which skewed population structure curves (see population structure & recruitment in VEGRAI assessment). Species composition changed moderately due to selective harvesting of wood and agricultural practices.

TABLE 5.21. RIPARIAN VEGETATION RESPONSE IN UPPER ZONE AT LIMPOPO EWR 2.

		RESPONSE METRIC RATINGS		
VEGETATION COMPONENTS	RESPONSE METRIC	CONSIDER? (Y/N)	RATING	CONFIDENCE
WOODY	COVER	Y	3.0	4.0
	ABUNDANCE	Y	2.0	3.0
	POPULATION STRUCTURE	Y	2.6	2.0
	VERTICAL STRUCTURE	Y	2.0	
	RECRUITMENT	Y	2.4	2.0
	SPECIES COMPOSITION	Y	1.3	2.0
			2.2	2.2
NON-WOODY	COVER	Y	3.0	4.0
	ABUNDANCE	Y	3.0	3.0
	SPECIES COMPOSITION	N	0.0	
			3.0	3.5

RANKING

Woody vegetation was ranked highest in the upper zone due to its dominance and its potential effect on flow by way of ground water utilization (Table 5.22).

TABLE 5.22. RANKING OF VEGETATION COMPONENTS IN THE UPPER ZONE AT LIMPOPO EWR 2.

VEGETATION COMPONENTS	CONSIDER? (Y/N)	RANK	WEIGHT	RATING	WEIGHTED RATING	MEAN CONFIDENCE
WOODY	Y	1.0	100.0	2.2	2.21	2.2
NON-WOODY	Y	1.0	60.0	3.0	1.80	3.5
					4.01	2.8
CHANGE (%) IN VEGETATION COMPONENTS:OVERALL CHANGE IN LATERAL ZONE CONDITION			**50.1**			

RIPARIAN ZONE ECOLOGICAL CATEGORY

For the calculation of the overall EC the marginal and lower zones were weighted highest due to their contribution to instream fauna habitat and bank stabilization, and the upper zone lower as the influence is more indirect (Table 5.23). The resultant EC for the Elefantes at EWR I is a C/D (60.4%) with and average confidence of 2.2. Confidence is low to medium due time constraints for site visits.

TABLE 5.23. RIPARIAN ZONE EC CALCULATION FOR ELEFANTES EWR I.

LEVEL 4 ASSESSMENT					
RIPARIAN VEGETATION EC METRIC GROUP	**CALCULATED RATING**	**WEIGHTED RATING**	**CONFIDENCE**	**RANK**	**WEIGHT**
MARGINAL	60.7	23.3	1.5	1.0	100.0
LOWER ZONE	68.2	23.6	2.8	2.0	90.0
UPPER ZONE	49.9	13.4	2.8	3.0	70.0
	3.0				260.0
LEVEL 4 VEGRAI (%)				60.4	
VEGRAI EC				**C/D**	
				C	
AVERAGE CONFIDENCE				2.2	

RECOMMENDED EC FOR LIMPOPO EWR 2

An improvement in the VEGRAI EC for Limpopo EWR 2 from 60.4% to 65.5%, the class improving from CD to C (Table 5.24), is possible for woody and non-woody cover and abundance in the marginal and lower zones. This improvement is expected if low flows are increased and zero flows eliminated, and is due to increased growth and vigour under conditions that have less water stress. Increased recruitment will also reduce the effect of herbivory. The assumption is made that seasonality of flow remains unchanged. *Schoenoplectus corymbosus* and *Phragmites mauritianus* will be the main species to respond in the marginal zone, while *P.mauritianus, G. senegalensis* and *P. reticulatus* are likely to respond in the lower zone.

TABLE 5.24. A RECOMMENDED RIPARIAN ZONE EC FOR ELEFANTES AT EWR1.

LEVEL 4 ASSESSMENT					
RIPARIAN VEGETATION EC METRIC GROUP	**CALCULATED RATING**	**WEIGHTED RATING**	**CONFIDENCE**	**RANK**	**WEIGHT**
MARGINAL	74.0	28.5	1.5	1.0	100.0
LOWER ZONE	68.2	23.6	2.8	2.0	90.0
UPPER ZONE	49.9	13.4	2.8	3.0	70.0
	3.0				260.0
LEVEL 4 VEGRAI (%)				65.5	
VEGRAI EC				**C**	
				C	
AVERAGE CONFIDENCE				2.2	

HIGH FLOW REQUIREMENTS AT EWR 2 (LIMPOPO)

Although woody riparian vegetation in the upper riparian zone is likely to depend on ground water availability for its survival at this site, high flows are required to recharge ground water, mobilise and replenish nutrients and sediments and provide microsites for recruitment and regeneration. Increased growth and vigour of vegetation at high flows also results in years where reproductive output can be markedly improved in the same or subsequent years. Suggested high flows at EWR 2 for Limpopo are outlined in Table 5.25 and shown in Fig. 6. The values for average discharge listed in Table 25 are approximate and confidence for their estimation is low.

TABLE 5.25. FLOODS REQUIRED FOR RIPARIAN VEGETATION AT EWR 2 (LIMPOPO). SEE FIG. 6 FOR STAGE LEVELS.

Approximate return period of flow	Ave Q	Approx. Flow depth
Class 2 flood 2 floods per annum in summer or late summer for a duration of 3 days or more to inundate lower level reed beds (*P. mauritianus*) and *S. corymbosus*	90 - 180	0.8
Class 3 flood 2 floods per annum in summer or late summer for a duration of 2 days or more to inundate *P. mauritianus* at upper limit	180 - 360	1.4
Class 4 flood Annual flood to occur in late summer to activate lower level of tree & shrub line (*F. sycomorus*). Facilitates regeneration episodes for *F. sycomorus.*	360 - 720	2.9
Class 5 flood every 2/3 years to inundate *P.mauritianus* reed beds, activate seasonal bars & channels which support *F. sycomorus* and maintain *P.mauritianus* low density, higher elevation reed beds and shrublands	1250 - 1850	4.1
Class 6 flood every 5 years to activate ephemeral bars & channels for *A. xanthoploea* and shrubs, and activate the more extensive upper zone	2500 - 3400	5.1
Class 7 flood every 10 years for activation of more xeric tree and shrub species (*K.africana),* these are the species with infrequent or punctuated recruitment patterns where cohort establishment may depend on flood events	4200 - 6000	6.1

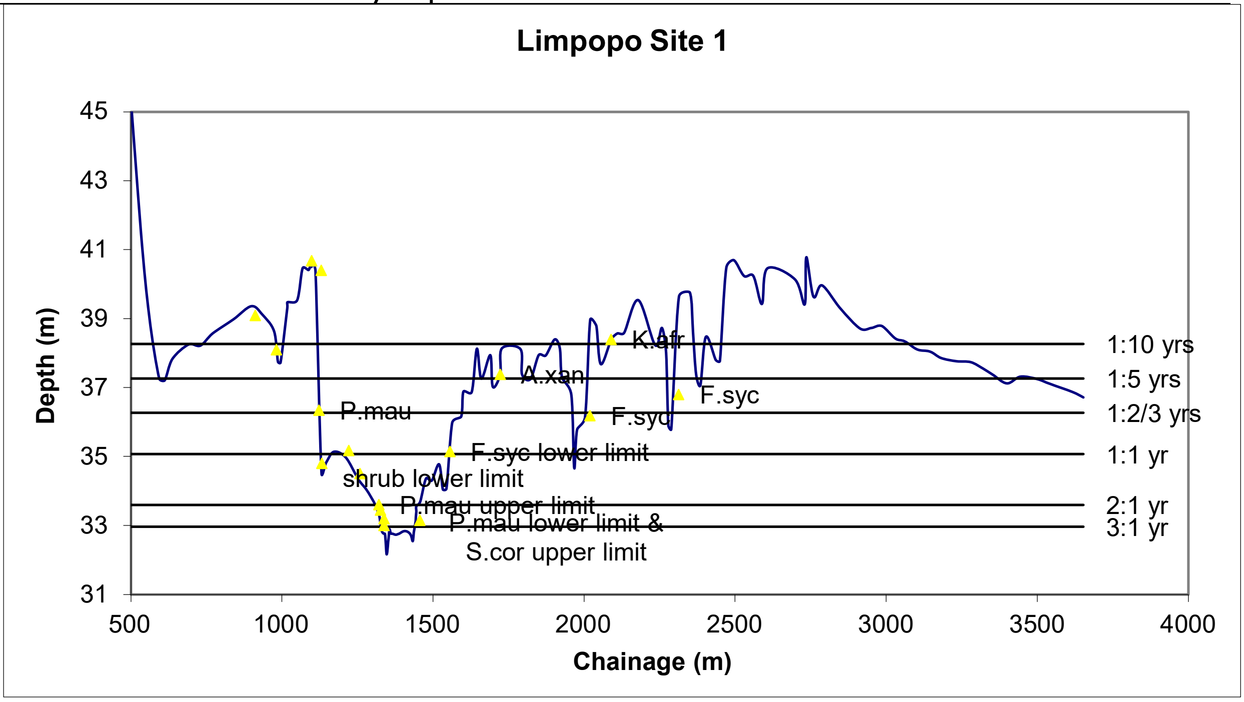

FIGURE 6. FLOODS REQUIRED FOR RIPARIAN VEGETATION AT EWR 2 (LIMPOPO). A.XAN = *ACACIA XANTHOPHLOAE*, P.MAU = *PHRAGMITES MAURITIANUS*, F.SYC = *FICUS SYCOMORUS*, K.AFR = *KIGELIA AFRICANA*, S.COR = *SCHOENOPLECTUS CORYMBOSUS*.

APPENDIX . PRELIMINARY LIST OF SPECIES AT BOTH EWR SITES

Elefantes River	Limpopo River	Lifeform	Distribution Status
Acacia nigrescens		tree	native
	Acacia robusta	tree	native
Acacia tortilis	Acacia tortilis	tree	native
Acacia xanthophloea	Acacia xanthophloea	tree	native
	Berchemia discolor	tree	native
Carissa bispinosa		shrub	native
Cassia abbreviate	Cassia abbreviata	tree	native
Cassia / Senna sp	Cassia / Senna sp	tree	exotic
Cienfuegosia hilderbrandtii		shrub	
Combretum apiculatum	Combretum apiculatum	shrub / tree	native
Cyperus sp		sedge	
	Diospyros mespiliformis	tree	native
Eichhornia crassipes		aquatic herb	exotic
	Euclea divinorum	shrub	native
Faidherbia albida	Faidherbia albida	tree	native
	Ficus capreifolia	shrub	native
Ficus sycomorus	Ficus sycomorus	tree	native
	Flueggea virosa	shrub	native
Grewia bicolour	Grewia bicolor	shrub	native
Grewia flavescens	Grewia flavescens	shrub	native
Grewia villosa	Grewia villosa	shrub	native
Gymnosporia senegalensis	Gymnosporia senegalensis	shrub	native
Hyphaene coriacea	Hyphaene coriacea	tree	endemic
	Kigelia africana	tree	native
	Lonchocarpus capassa	tree	native
	Maerua juncea	climber	
Panicum maximum		grass	
Phragmites mauritianus	Phragmites mauritianus	reed	
Schoenoplectus corymbosus	Schoenoplectus corymbosus	sedge	
Sclerocarya birrea	Sclerocarya birrea	tree	native
Trichilia emetica	Trichilia emetica	tree	native
Vernonia colorata	Vernonia colorata	shrub	native
Ziziphus mucronata		tree	native

5.9 APPENDIX 4: VEGETATION ASSESSMENT OF THE WILGE RIVER AT EWR 4

REFERENCE CONDITIONS

Component	Reference conditions	Conf
Riparian Vegetation	The assessed area at EWR 4 occurs within the Central Sandy Bushveld vegetation type, which occurs within the Savanna Biome and the Central Bushveld Bioregion. This vegetation type is poorly protected and has 75.9% remaining. Consequently it has a conservation status of "Vulnerable". Current conservation target is set at 19%. (Mucina & Rutherford, 2006). It is expected that the marginal and lower zones be dominated by a patchy mosaic of woody and non-woody rheophytic riparian obligates. The woody component will be dominated by *Gomphostigma virgatum* where cobble/boulder exists and *Salix mucronata* where cobble is embedded or where sediments have deposited. *Combretum erythrophyllum* and *Searsia gerarrdii* is expected to dominate alluvial deposits in the lower and upper zones. *Cyperus* species will dominate the non-woody clumps in the marginal and lower zones, with hydrophilic grasses on the lower and upper zones (such as *Miscanthus junceus*). The macro-channel bank is expected to be dominated by woody thicket, mainly terrestrial and kloof species (related to the Biome), but with *Celtis africana* as a riparian indicator.	4

PRESENT ECOLOGICAL STATE

Component	PES Description	EC	Conf
Riparian Vegetation	Marginal zone is a mixture of sedge and woody patches (both rheophytic), mainly *Cyperus marginatus* and *Gomphostigma virgatum / Salix mucronata* subsp. *Woodii* respectively. The lower zone is similar to the marginal zone but with high cover and abundance of *Searsia gerrardii* and *Combretum erythrophyllum*. Alluvial deposits on the lower and upper zone supports populations of *Crinum bulbispermum, C. macowanii, Kniphofia spp, Berula thunbergii*. The upper zone also has an extensive population of *Miscanthus junceus*. The macro-channel bank is dominated by woody species, and some exotics have been removed at the site. Most species are terrestrial or kloof species with riparian indicators being *Celtis africana, Ilex mitis.*	A/B (87.5%)	3

EFR 4: PES CAUSES AND SOURCES

	PES	Conf	Causes[1]	Sources[2]	F[3]/NF[4]	Conf
Riparian Vegetation	A/B (87.5%)	3	Altered species composition	Exotic vegetation	NF	5
			Elevated sedge and grass cover	Flow regulation, reduced flooding disturbance	F	3

CHANGES SINCE 1999

Note: Under conclusion, put in = for being the same as previous, + for improvement, - for degradation.

COMPONENT	1999 EC	2010 EC	COMMENT	CONCL	CONF
Riparian Vegetation	B	A/B (87.5%)	The EC shows an improvement, but it is likely that actual riparian condition is similar to previous assessments. The difference is likely due to the assessment of flooding disturbance, which previously was taken as an impact, but in this assessment is considered a largely natural impact and part of reference condition shaping.	=, but EC up	3

6 FISH

The fisheries of the Limpopo Basin are of great ecological importance as they include at least 77 species of which 52% overlap with species that occur in the Zambezi Basin and 11% overlap with species that occur in the Congo Basin. Historical linkages between the Congo, Zambezi and Limpopo Rivers have been established (A.). Today although very little is known about the wellbeing of the fishes of the Limpopo catchment on regional scales (O'Brien, 2013), seven species have conservation status and there are at least four endemic species that only occur within the basin. There is ongoing research in speciation that should result in an expansion of our knowledge of the diversity of species in the basin (Van der Walt et al., 2017). In addition, as we begin to understand the extent of the change to the wellbeing of the basin we will better understand the wellbeing of the fishes and the associated consequences of altered flows and non-flow variables to these socio-ecologically important fishes in the basin.

The Limpopo River system is one of southern Africa's most ecologically, socially and economically important ecosystems, in part due to the high diversity of fishes and the contribution that they make to the livelihoods of the human communities who live in the basin (O'Brien, 2013). Although degraded water quality, altered flows and habitat alterations have been identified as potential drivers of the fish communities in the basin (O'Brien, 2013;), and there additional stressors including barriers for migration, alien fauna and flora, disturbance to wildlife threats associated with urbanization and climate change issues that have recently been identified in the basin (Rankoana, 2016).

The Limpopo River Basin is home to more than 18 million people (2012 estimated) making it one of the most populated basins in the Southern Africa Development Community (SADC) (Limpopo River Awareness Kit 2011; FAO 2004). These human communities rely on the Limpopo River's ecosystems to provide valuable and often irreplaceable services, such as food provisioning, potable water, pollution remediation, disease regulation and climate regulation. Fish especially; anguillids, tilapias, large growing cyprinids, lepidosireniforms and siluriformes are socio-economically important in the basin because they are targeted for subsistence fisheries especially in Mozambique and Zimbabwe. Particularly because fish are breeding or migrating in spring/ early summer occurs at the same time when communities begin their planting season and normally there is little or no food left from last year's harvest.

This review provides a summary of available information pertaining to the knowledge of the following fisheries attributes of the Limpopo Basin:

- multiple stressors affecting fish communities in the basin;
- species and links including historical links with the Zambezi and Congo River;
- changes in the distribution of species and habitat deterioration including info on present site fish communities and endangered species;
- fish as ecological indicators in the basin and
- fish as ecological indicators of e-flow for the e-flow study.

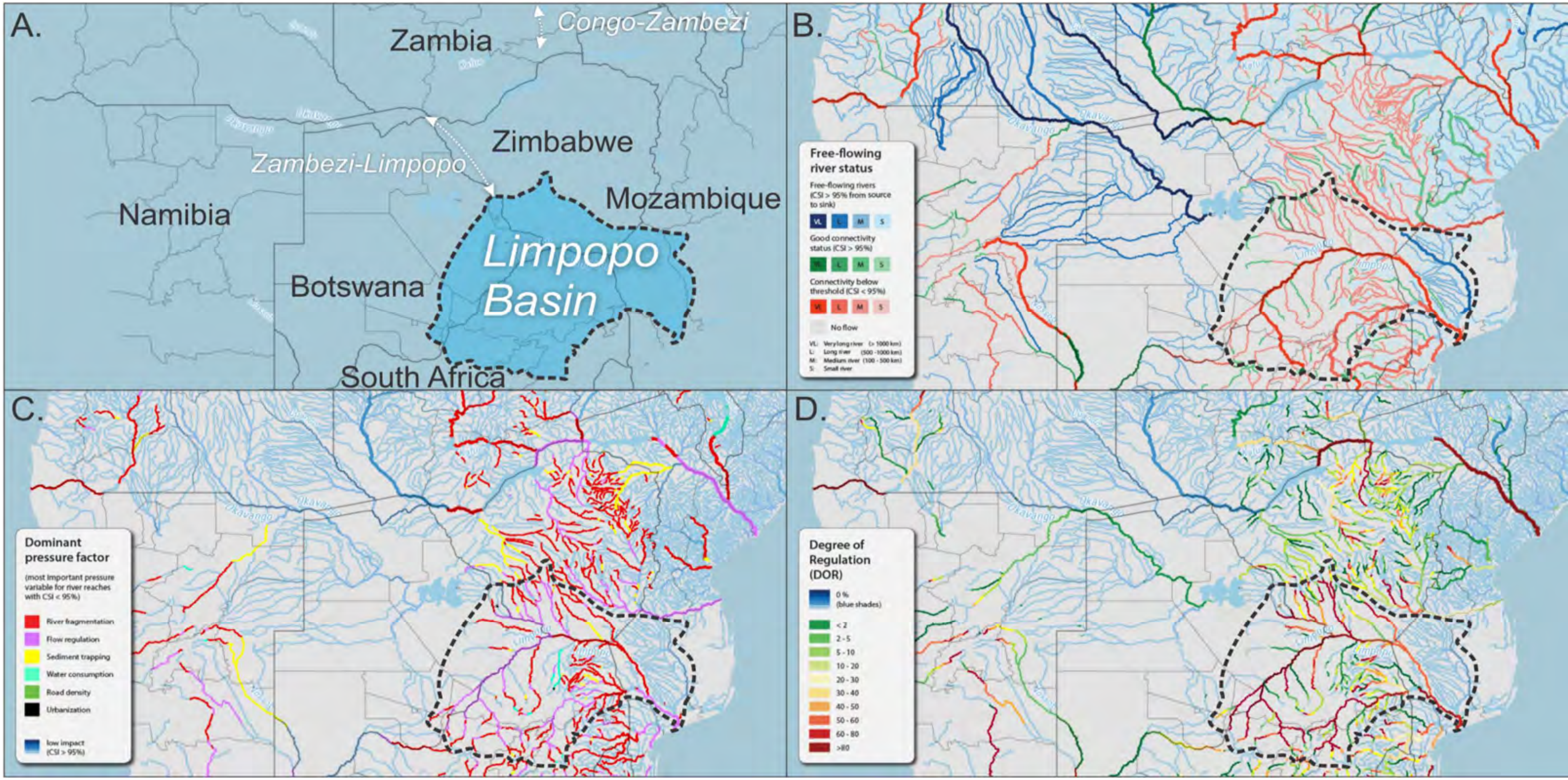

FIGURE 6.1: RIVER BASINS IN SOUTHERN AFRICA HIGHLIGHTING THE SOUTHERN PART OF THE CONGO BASIN, ZAMBEZI BASIN AND LIMPOPO BASIN (HIGHLIGHTED). HISTORICAL CONNECTIONS FACILITATING FISH MIGRATIONS INDICATES (A.), FREE-FLOWING RIVER STATUS (B.), DOMINANT PRESSURE FACTORS (C.) AND DEGREE OF REGULATIONS (D.) SPATIAL DATA (ADAPTED FROM GRILL ET AL (2019).

6.1 MULTIPLE STRESSORS AFFECTING FISH COMMUNITIES IN THE LIMPOPO BASIN

The portion of the Limpopo basin in South Africa has been particularly affected by multiple flow and water quality stressors that affect the fish communities of the Limpopo Basin (Du Preez et. al., 1997; Avenant-oldewage et al., 2000a; 2000b; 2015; Addo-Bediako et al., 2014a; 2014b; Jooste et al., 2014; 2015. Lebepe et al., 2016.). Many of the rivers within the Limpopo Basin in South Africa have been contaminated by mines, agricultural, industrial, and domestic water releases into rivers (Ashton 2007). Fish and other aquatic animals, accumulate pollutants (e.g. metals) from their environment through the food they consume (Chen *et al.* 2000; Jooste, Addo-Bediako and Luus-Powell 2014). These metals are magnified in the food webs of the rivers because of bioaccumulation posing risk of toxicity to top predators and subsistence fishermen (Goodyear and McNeill 1999). Concerns of unsuitable fish for human consumption has been identified in the Crocodile West, Olifants and Luvuvhu River catchments in the greater Limpopo Catchment (Ashton 2007; Lebepe et al., 2016; Sara et al., 2017). Fish are vital food sources for many rural communities because it is the cheapest protein, provides essential nutrients (like protein, micronutrients and essential fatty acids) and are readily available in most inland waters (Jooste, Addo-Bediako and Luus-Powell 2014). Rural communities in South Africa are depending more on freshwater fish to supplement their dietary protein requirements (Addo-Bediako *et al.* 2014a, 2014b). The rising cost in protein sources, increasing rural poverty and increase in rural populations are forcing these communities to consume fish from contaminated River systems (Addo-Bediako *et al.* 2014a). Communities that readily consume fish are at risk to genotoxic, carcinogenic and non-carcinogenic health impairment after long-term exposure to toxic contaminants (Du Preez *et al.* 2003). Freshwater ecosystems are becoming increasingly degraded and contaminated and therefore it is necessary to assess whether fish from degraded river systems are still suitable for human consumption (Heath *et al.* 2004).

The Olifants River is a major tributary of the Limpopo River and is known as the most polluted river system in South Africa (Ashton 2007, 2010). This raised concerns on what the effect will be on human health after long-term consumption of fish from the Olifants River. Several studies measured the concentrations of metal found in the muscle tissue of fish (for example *Labeo rosae, Clarias gariepinus, Schilbe intermedius, Oreochromis mossambicus, Hypophthalmichthys molitrix*) and did a human health risk assessment (Heath *et al.* 2004) in two impoundments of the Olifants River (Flag Boshielo Dam and Phalaborwa Barrage). These studies all concluded that weekly consumption of 150g of these fish species may pose an unacceptable risk to the health of rural communities (Addo-Bediako *et al.* 2014a, 2014b; Jooste *et al.* 2015; Lebepe et al., 2016; Sara *et al.* 2018).

Labeo rosae (*L. rosae*)is one of the most common pan-fish in the Limpopo River catchment and is frequently available to rural communities (Lebepe, Marr and Luus-Powell 2016). The populations of *L. rosae* seem healthy but studies have shown bioaccumulation of metals in their muscle tissue (Lebepe et al., 2016). *L. rosae* have exceeded the hazard quotient of 1 for both lead and chromium in Flag Boshielo dam and 53% exceeded that for antimony (Lebepe et al., 2016). At the Phalaborwa Barrage almost all *L. rosae* analysed exceeded the recommended Hazard quotient for lead and more than 25% exceeded that for arsenic (Lebepe et al., 2016).

Clarias gariepinus is an important source of freshwater food fish for rural communities in Africa (Jooste *et al.* 2015). However, studies have confirmed that this species, *C. gariepinus,* bioaccumulate metals from their food and environment (Avenant-oldewage 2015; Avenant-

Oldewage and Marx 2000a, 2000b; Crafford and Avenant-Oldewage 2010; Jooste *et al.* 2015; du Preez, van der Merwe and van Vuren 1997). Jooste *et al.* (2015) found that antimony, chromium, and cobalt exceeded levels for safe weekly consumption of *C. gariepinus*. Indicating that the consumption of *C. gariepinus* from, the Olifants River, in the Limpopo system, southern Africa, may pose an unacceptable health risk (genotoxic health impairment) to rural communities that rely on this species as a food source (Jooste *et al.* 2015).

The economic value of *O. mossambicus* in southern Africa are major food sources, weed control, disease control (malaria and bilharzia), prey fish, animal feed ingredient, and sport fish (Van der Bank and Deacon 2007). Addo-Bediako *et al.* (2014) measured the concentration of metals accumulated in the tissues of *O. mossambicus* in the Olifants River and conducted a human health risk assessment. Their results indicate that metals accumulate in the muscle tissue of *O. mossambicus* even when the population seem to be healthy (Addo-Bediako *et al.* 2014a). Lead, antimony, and chromium were at concentrations above acceptable levels for safe human consumption based on 150g of fishmeal per week. They concluded that the consumption of *O. mossambicus* poses an unacceptable health risk to rural communities (Addo-Bediako *et al.* 2014a).

Schilbe intermedius bioaccumulate metals in their muscle tissues (Addo-Bediako *et al.* 2014b). The human health risk assessment showed that lead and chromium were above the recommended level of safe consumption and about 50 % exceeded the recommended antimony at Flag Boshielo Dam (Addo-Bediako *et al.* 2014b). Almost all fish analysed exceeded the recommended level for lead and more than 50% exceeded the recommended level for arsenic at the Phalaborwa Barrage (Addo-Bediako *et al.* 2014b).

Lake Flag Boshielo has been proposed as a site for an inland fishery (Sara *et al.* 2018) and *Hypophthalmichthys molitrix* is one of the targeted species for such fisheries. However, studies have shown that the hazard quotient based on a weekly meal of 150 g exceeded the acceptable level for As, Cd, Cr, Co, Pb, Hg, Se, V and Zn in Lake Flag Boshielo (Sara *et al.* 2018). Based on the amount of metal and metalloid bioaccumulated in their tissues, long-term consumption of silver carp from Lake Flag Boshielo might pose a health risk to impoverished rural communities (Sara *et al.* 2018).

6.2 SPECIES AND LINKS INCLUDING HISTORICAL LINKS WITH THE ZAMBEZI AND CONGO RIVER

The evolution of rivers has had a major influence on the distribution of aquatic vegetation and fish species (Moore *et al.* 2007). River captures played an important role in species dispersions and particularly in the Paleo-Pleistocene, have disrupted formerly continuous populations, providing a driving force for speciation (Moore *et al.* 2007). Many of the rivers in Africa have complex histories, which involve shifts in their catchments and courses (Goudie 2005). This was mainly caused by the splitting up of Gondwanaland in the early Cretaceous (Goudie 2005).

The upper Zambezi and the middle Zambezi have evolved as two separate systems, with the middle Zambezi previously joined to the Shire system and the upper Zambezi joined to the Limpopo system (Goudie 2005; Moore *et al.* 2007). The Kafue River was originally the major southwest-flowing east bank tributary of the Upper Zambezi, while the Palaeo-Chambeshi (which forms part of today's upper Congo systems) formed the upper reaches of the Paleo-Kafue.

This explains the historical connections of fish in the Limpopo River Basin to both the Zambezi River and Congo Basin (Stankiewicz and de Wit 2006). There is a 41% overlap between the fish species commonly found in the middle Zambezi and Limpopo Rivers Basin (Moore *et al.* 2007). Dating the timing of species divergence, using genetic markers, offers the potential to refine our understanding of the chronology of major River captures.

Oreochromis macrohir, Oreochromis andersonii, Serranochromis angusticeps, Serranochromis codringtonii, Serranochromis robustus, Serranochromis thumbergi and *Pharyngochromis acuticeps* are upper Zambezi species from the Okavango system that was introduced into the Shashe Dam (Limpopo system, Botswana) (Kleynhans and Hoffman 1993). In 1991, the first two specimens of *O. macrochir* have been recorded in natural pools in the Limpopo River and have likely escaped from the Shashe dam (Kleynhans and Hoffman 1993). *O. macrochir* and *O. andersonii* may have interbred with *O. mossambicus* in the Limpopo River (Kleynhans and Hoffman 1993). The *Serranochromis spp.* could be damaging to feeding relationships in the Limpopo catchment (Kleynhans and Hoffman 1993). It appears that *B. poechii* coexist with *Enteromius trimaculatus* of the Limpopo River system (Kleynhans and Hoffman 1993).

6.3 CHANGES IN THE DISTRIBUTION OF SPECIES AND HABITAT DETERIORATION INCLUDING INFO ON PRESENT SITE FISH COMMUNITIES AND ENDANGERED SPECIES

The indigenous freshwater fish of South Africa comprises >103 species, >350 in southern Africa (Skelton 2001), making them the least species-rich of all the large vertebrate, 45% of freshwater fish is endemic to South Africa making them the second-highest only to amphibians (56%) (Minter *et al.* 2004) and 23% of species are in the IUCN threatened categories which is the most of all vertebrate groups (Russell, 2011). Fish communities do not recover from negative anthropogenic threats like the introduction of invasive species and habitat destruction, which are two of the main factors causing species extinction (Van der Bank and Deacon, 2007).

Although degraded water quality conditions continue to pose the greatest threat to fish health in this system, additional impacts such as habitat alteration, flow regime modifications, barriers for migration, disturbance to wildlife and or the impact of non-endemic alien or introduced fishes may be affecting the fish communities in the Limpopo River. There are seven fish species (*Barbus motebensis, Barbus sp. 'Banhide', Barbus sp. 'Waterberg', Barbus treurensis, Kneria sp. 'South Africa', Oreochromis mossambicus, Serranochromis meridianus*) with an IUCN status and additional five species (*Barbus anoplus, Barbus sp. neefi, Barbus sp. 'Ohrigstad', Marcusenius pongolensis, Silhouettea sibayi*) with too little information for assessment. This suggests that there may be even more fish species that need conservation considerations.

The fish communities of the Limpopo are dynamic and may shift following the perennially changes of areas in the catchment. As such when some areas of the Limpopo Catchment become seasonal and episodic, other areas act as refugia for fishes. Historically, fish communities have been able to shift across the catchment in response to these changes. These communities can be relatively more intolerant to anthropogenic impacts than communities that have stable refuge areas. It appears that due to existing water quality and flow impacts from South Africa predominantly, that appear to affect the upper south and eastern parts of the Limpopo Catchment the importance of the northern, western, and lower parts of the catchment has increased.

The introduction of invasive species and habitat destruction are among the leading causes of extirpations and extinctions of species in freshwater systems (Sala *et al.* 2000). The antagonistic ecological impacts of Nile tilapia, *Oreochromis niloticus*, on River systems worldwide has highlighted the problem associated with fish introduction (Canonico *et al.* 2005; de Vos, Snoeks and Thys van den Audenaerde 1990). This species was introduced into southern Africa for aquaculture because it is hardy, has a range of trophic and ecological adaptations, have high fidelity, fast growth rate and parental care (Njiru *et al.* 2004). These characteristics make this species a successful invader. This explains their spread from the Cape Town and KwaZulu-Natal into Limpopo and other eastern Rivers in South Africa and Mozambique (Weyl 2007).

The invasion of *O. niloticus* in the Limpopo River system has caused great concern for the conservation of indigenous congeneric species (Van der Bank and Deacon 2007; Van der Waal and Bills 2000), for example, *O. mossambicus,* which may become extirpated from River system through hybridization and competition exclusion (Zengeya *et al.* 2011) through their similar habitat and trophic requirements with *O. niloticus* (Cambray and Swartz 2007; Van der Bank and Deacon 2007; Weyl 2007). Studies have found hybridization between *O. mossambicus* and both *O. niloticus* and *O. macrochir* (Chao *et al.* 1987; Kleynhans and Hoffman 1993; Van der Waal and Bills 2000; Wolfarth and Hulata 1981), thus *O. mossambicus* may lose their genetic integrity and be replaced by hybrid populations (Van der Waal and Bills 2000). Van der Bank and Deacon (2007) found that neither allozyme analyses nor morphological characters are accurate enough to differentiate between *O. mossambicus* and *O. niloticus* and that other molecular techniques need to be deployed to get address this problem. To understand the extent to which *O. niloticus* has spread in the Limpopo River further monitoring is needed (Van der Bank and Deacon 2007).

Zengeya *et al.* (2013) used the physiological tolerance limits (minimum water temperatures, presences of dam infrastructures, flow seasonality of the River) of *O. niloticus* and the presence of indigenous fish species of concern to identify River system that will be suitable for *O. niloticus* establishment (Zengeya *et al.* 2013). The results indicated that the main Limpopo River channel and the tributaries after the Limpopo/Lephalala River confluence along with the Botswana-South Africa- Zimbabwe borders were at high risk (Zengeya *et al.* 2013).

Tigerfish *Hydrocynus vittatus* has high social, economic, and ecological importance because they are used as food sources and indicators of ecological health throughout southern Africa (Næsje *et al.* 2001, Gerber *et al.* 2009, Tweddle 2010, McHugh *et al.* 2011). In South Africa but particularly in the Limpopo River catchment, their distribution and abundances are declining due to multiple anthropogenic threats (Skelton 2001). Thus, this species has been put onto the South Africa protected species list (RSA 2007). This species needs to be conserved because it will prove social, economic, and ecological benefits to local communities (O'Brien *et al.* 2012). O'Brien *et al.* (2012) showed that this species could be conserved by introducing them into man-made lakes such as Letsibogo. However, the effect of tigerfish on the indigenous fishes in these lakes is unknown and should be considered.

Freshwater fishes are the most threatened of all vertebrate groups exploited by humans. For the survival of fish, they depend on the effective conservation actions against threats of invasive species, pollution, habitat loss and altered water regimes (Tweddle *et al.* 2009), both outside and inside formal conservation areas (Russell 2011). (Darwall *et al.* 2009).

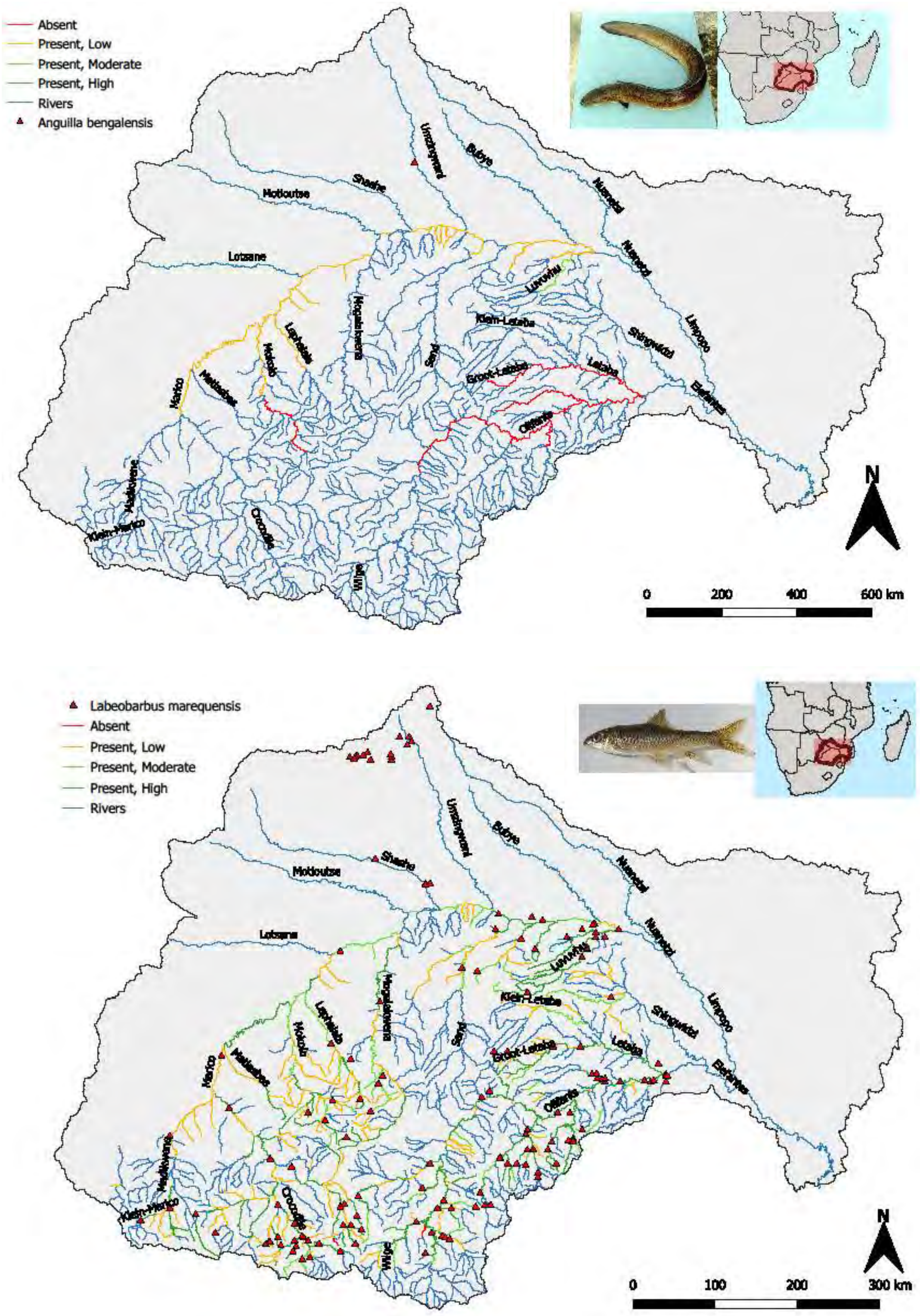

FIGURE 6.2 EXAMPLES OF FISH DISTRIBUTION MAPS MAKING USE OF FISHBASE DATA. OVER 70 SPECIES ARE MAPPED BUT NOT INCLUDED IN THIS REPORT.

6.4 FISH AS ECOLOGICAL INDICATORS IN THE BASIN

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, 2012). 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, and identification in the field, and high public awareness value (Whitfield and Elliott, 2002). 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).

In South Africa, the attributes of fishes are made use of in two widely used community metric measures namely the Fish Assessment Integrity Index (FAII, Kleynhans 1999) and the Fish Response Assessment Index (FRAI, Kleynhans 2005) which in many instances is an upgrade and replacement of the FAII. 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).

During the 2012 Monograph study of the Limpopo Basin, fish were included as an ecological component of the study (O'Brien 2013). This study was the first to consider fish on a regional scale in the Limpopo Basin. Although rapid, the 2012 survey carried out to the eight sites in the Limpopo Catchment allowed for the assessment of the FRAI and fish community structures using multivariate statistical techniques. In addition, with available hydrology and hydraulic data a Fish Flow Habitat Assessment Index (FFHA) assessment was also carried out. During the survey from 4 to 21 June 2012, 46 sampling efforts were carried out which resulted in the collection of 1501 fish from the eight sights selected for the study. Twenty-one species were collected (of the expected 73. Only the two cichlids *O. mossambicus* and *C. Rendalii* were collected at all eight sites. Other cosmopolitan species included the sharptooth catfish (*Clarius gariepinus*) and tank goby (*Glossogobius giuris*) that were obtained at six and five sites respectively. The highest diversity of fishes (12 species) were obtained at the upper site in the Limpopo at Spanwerk. Thereafter between seven and nine species were obtained at the sites including the main stem Limpopo River, Mwanedzi. Although sampling was limited to one day per site fishes observed in relatively good abundances ranging between 122 and 485 individuals at all of the sites. The explanatory data obtained from each site showed that substrate, habitat and cover features as well as depths and velocities varied considerably between sites. This data was used in the FRAI, multivariate community structure assessment and the FFHA assessment considered in the study. Knowledge of the habitat, cover, velocity-depth classes, water quality and migratory requirements of fishes from the Limpopo River Basin is presented in Table 6.2.

The findings of the 2012 assessment included fish communities observed to be in a moderately modified ecological state primarily. In response to the low flows observed in the study area during the survey, it is likely that the fish communities were in a stressed or impacted state. The present seasonal nature of the rivers in the Limpopo Basin suggests that this impacted state may be unnatural. The absence of many species known to be tolerant to low and no flow conditions and corresponding absence of species intolerant to water quality alterations suggests that the rivers in the study area are being impacted on by flow and water quality alteration impacts associated with anthropogenic activities. The statistical assessment of fish community structures using Redundancy Analyses supports these arguments showing that a significant relationship between Present Ecological State (PES) scores and the community structures. These findings show that large shifts in the community structures of fishes in the study area occur. Differences seem to be further driven by flows and depths, which were key features of remaining refuge areas where fish populations were being maintained.

These results when compared to historical data suggest that the fish communities of the Limpopo are dynamic and may shift in accordance with the perennially changes of areas in the catchment. As such when some areas of the Limpopo Catchment become seasonal and episodic, other areas act as refugia for fishes. Historically, fish communities have been able to shift across the catchment in response to these changes. These communities can be considered relatively more intolerant to anthropogenic impacts than communities that have stable refuge areas. It appears that due to existing water quality and flow impacts from South Africa predominantly, that appear to affecting the upper south and eastern parts of the Limpopo Catchment the importance of the northern, western, and lower parts of the catchment has increased.

The outcomes of the FFHA application show that the volume, timing and duration of flows in the upper portion of the Limpopo River are being affected by activities associated with elevated flow releases into the Crocodile River, Gauteng. From the Mapungubwe site to the Combomune site on the Limpopo River, the flows in the Limpopo River appearing in 2012 to be largely natural to moderately modified where local fish communities are undergoing highly stressed states during dry periods. Flows in the Limpopo River at Chokwe and in the Mwanedzi River at the Malipati site appear to be elevated during dry periods, which may be facilitating the survival of fishes.

The dynamic seasonal flow fluctuations in the Limpopo River which are now being impacted on by anthropogenic activities should be managed to ensure that refugia for many species is maintained and that the existing "boom" and "bust" establishment and loss of populations across the catchment is maintained.

Consider that in 2012 during the evaluation of the present ecological state of the fish communities and drivers of change the present seasonal nature of the Limpopo River was considered to be largely natural. New information suggests that this may not be the case and that the river has changed from a largely perennial system into a seasonal system. This new information suggests that the Limpopo basin would have maintain all of the fishes that occur in the basin from linkages with the Zambezi to modern times with additional contributions of species from the Inkomati and Phongolo Rivers during extreme floods in the plains of Mozambique. Due to multiple stressors and new understanding of the noticeable shift in perreniality of the rivers in the basin. The wellbeing of the fish communities must now be re-evaluated with this new information. We hypothesize that the fish communities will be in a significantly altered state and that without restoration the system may not be able to maintain the diversity of fishes that have historically be collected in the basin. This hypothesis will be tested in this study.

6.5 FISH AS ECOLOGICAL INDICATORS OF ENVIRONMENTAL FLOW

The concept of e-flows has taken root in many countries around the world and has become the baseline for most water resource assessments (Tharme 2003; King *et al.* 2008; King & Brown 2018). The concept is based on three important components of water in a water resource namely quantity, quality and timing and links these with the ecological needs of a resource (Tharme 2003; King *et al.* 2008; King & Brown 2018). The EWR represents the amount of water that must remain behind in a river, this amount may differ in wet and dry years and the summer and winter seasons, to keep the ecological integrity of the river intact so that the river may continue to provide ecosystem services to society (Tharme 2003; King *et al.* 2008; King & Brown 2018).

Water resources infrastructures (for example dams and weirs) are used to regulate waterways and provides multiple societal benefits, but this is at the cost of aquatic ecosystems and the ecological services that they provide (Baron *et al.* 2002; Baumgartner *et al.* 2014; Kingsford, Biggs and Pollard 2011). Overexploitation of freshwater systems is one of the main threats these ecosystems face (Allan *et al.* 2005; Kingsford, Biggs and Pollard 2011). This is made worse with the most conventional water management policies focusing on human needs rather than the needs of the ecological systems (Baumgartner *et al.* 2014). Harsh experience is now available from all around the world, that where the EWR is lost, society also loses the benefits it gained from that resource. Improved ecosystems provided important ecosystem services to society (Baumgartner *et al.* 2014; Karr 1991; Salles 2011) and granting water rights to ecosystems is a logical policy progression. Major sources of conflict in this policy progression are to find quantifiable information regarding the amount of water required to have positive ecological changes in the context of a regulated water delivery framework (Poff *et al.* 2003).

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 *et al.* 2010). Hydrological variability influences the physical habitat of Riverine systems and thus shapes the structure and diversity of aquatic fauna and flora communities (Cattanéo 2005; Poff and Allan 1995). Hydrological variability, therefore, plays an important factor in population maintenance and it is important to remember that fish has evolved life history strategies specifically adapted to this variability.

Previous approaches of e-flow delivery only required that a limited amount of water needed to be secured and released as a single pulse with the assumption that all fish would benefit equally (MDBA 2011). But evidence shows that only a limited number of species have benefited with this flow regime presumably because only a few species are adapted to this type of water release (King, Brown and Sabet 2003; King, Tonkin and Mahoney 2009). Individual species have different life-history strategies, habitat, spawning and feeding requirements and have evolved to survive in different flow regimes (Baumgartner *et al.* 2014). Different species have evolved different cues for migration, spawning and recruitment depending on their optimal strategy (Baumgartner *et al.* 2014). It is therefore unlikely that a single flow regime will provide equal benefits to all the species in the fish community (King *et al.* 2010). Different approaches can be to divide the species into groups with similar physiological or behavioural similarities that can be linked to flow (Baumgartner *et al.* 2014).

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TABLE 6.1: TABLE OF THE FRESHWATER FISH KNOWN TO OCCUR WITHIN THE LIMPOPO BASIN (SCOTT ET AL. 2006 & FISHBASE).

Family	Species	IUCN Category	Criteria
Anguillidae			
	Anguilla bengalensis labiata	Least Concern	
	Anguilla bicolor bicolor	Least Concern	
	Anguilla marmorata	Least Concern	
	Anguilla mossambica	Least Concern	
Aplocheilidae			
	Nothobranchius furzeri	Least Concern	
	Nothobranchius orthonotus	Least Concern	
	Nothobranchius rachovii	Least Concern	
Poeciliidae			
	Aplocheilichthys johnstoni	Least Concern	
	Aplocheilichthys katangae	Least Concern	
Characidae			
	Brycinus imberi	Least Concern	
	Hydrocynus vittatus	Least Concern	
	Micralestes acutidens	Least Concern	
Cyprinidae			
	Barbus afrohamiltoni	Least Concern	
	Barbus annectens	Least Concern	
	Barbus anoplus	Data Deficient	
	Barbus lineomaculatus	Least Concern	
	Barbus motebensis	**Vulnerable**	**B1ab(i,ii,iii,iv,v)+2ab(i,ii,iii,iv,v)**
	Barbus pallidus	Least Concern	
	Barbus paludinosus	Least Concern	
	Barbus radiatus	Least Concern	
	Barbus rapax	Least Concern	
	Barbus sp. 'Banhine'	**Critically Endangered**	**B1ab(iii)c(iv)+2ab(iii)c(iv): D2**
	Barbus sp. 'neefi cf. South Africa'	Data Deficient	
	Barbus sp. 'Ohrigstad'	Data Deficient	
	Barbus sp. 'viviparus cf. Mozambique'	Least Concern	
	Barbus sp. 'Waterberg'	**Near Threatened**	**B2b(iii,v)**
	Barbus spp. 'eutaenia complex'	Least Concern	
	Barbus toppini	Least Concern	
	Barbus treurensis	**Endangered**	**B1ab(I,ii,iv,v)+2ab(I,ii,iv,v)**
	Barbus trimaculatus	Least Concern	
	Barbus unitaeniatus	Least Concern	
	Barbus viviparus	Least Concern	
	Labeo altivelis	Least Concern	
	Labeo congoro	Least Concern	
	Labeo cylindricus	Least Concern	

	Labeo molybdinus	Least Concern	
	Labeo rosae	Least Concern	
	Labeo ruddi	Least Concern	
	Labeo umbratus	Least Concern	
	Labeobarbus marequensis	Least Concern	
	Labeobarbus polylepis	Least Concern	
	Mesobola brevianalis	Least Concern	
	Opsaridium peringueyi	Least Concern	
Kneriidae			
	Kneria sp. 'South Africa'	**Critically Endangered**	**B2ab(i,ii,iii,iv,v)**
Protopteridae			
	Protopterus annectens	Least Concern	
Mormyridae			
	Marcusenius pongolensis	Data Deficient	
	Petrocephalus wesselsi	Least Concern	
Anabantidae			
	Ctenopoma multispine	Least Concern	
Cichlidae			
	Chetia flaviventris	Least Concern	
	Oreochromis mossambicus	**Near Threatened**	**A3e**
	Oreochromis placidus	Least Concern	
	Pharyngochromis acuticeps	Least Concern	
	Pseudocrenilabrus philander	Least Concern	
	Serranochromis meridianus	**Endangered**	**B2ab(iii,v)**
	Tilapia rendalli	Least Concern	
	Tilapia sparrmanii	Least Concern	
Eleotridae			
	Eleotris fusca	Least Concern	
	Eleotris melanosoma	Least Concern	
Gobiidae			
	Awaous aeneofuscus	Least Concern	
	Croilia mossambica	Least Concern	
	Glossogobius callidus	Least Concern	
	Glossogobius giuris	Least Concern	
	Mugilogobius mertoni	Least Concern	
	Silhouettea sibayi	Data Deficient	
	Stenogobius kenyae	Least Concern	
Amphiliidae			
	Amphilius natalensis	Least Concern	
	Amphilius uranoscopus	Least Concern	
Clariidae			
	Clarias gariepinus	Least Concern	
	Clarias ngamensis	Least Concern	
	Clarias theodorae	Least Concern	

Mochokidae		
	Chiloglanis paratus	Least Concern
	Chiloglanis pretoriae	Least Concern
	Chiloglanis swierstrai	Least Concern
	Synodontis zambezensis	Least Concern
Schilbeidae		
	Schilbe intermedius	Least Concern
Syngnathidae		
	Microphis brachyurus millepunctatus	Least Concern
	Microphis fluviatilis	Least Concern

TABLE 6.2: SUMMARY OF THE HABITAT, COVER, VELOCITY-DEPTH CLASSES, WATER QUALITY AND MIGRATORY REQUIREMENTS OF FISHES FROM THE LIMPOPO RIVER BASIN.

Species	Species Abbr.	Velocity-depth classes				No flow tolerance	Cover features					Water quality tolerance	Migration requirements	Distance migrating (km)
		Fast-deep	Fast-shallow	Slow-deep	Slow-shallow		Overhanging vegetation	Undercut banks	Substrates	Aquatic macrophytes	Water column			
Amphilius natalensis	ANAT	5.0	4.7			4.9			5.0			4.9	1.0	Local, 0-20
Amphilius uranoscopus	AURA	4.6	4.6			4.8			5.0			4.8	1.0	Very local
Anguilla bengalensis labiata	ABEN			4.6		2.8		4.0	4.2			2.7		
Anguilla bicolor bicolor	ABIC					0.0						0.0	5.0	Coastal, >100km
Anguilla marmorata	AMAR			4.4		2.8		3.9	4.2			2.5	5.0	>100km (C1Up to 100 miles)
Anguilla mossambica	AMOS	3.4	3.3	3.4		2.8		4.1	4.9			2.5	5.0	Up to watershed, >100km
Aplocheilichthys johnstoni	AJOH			3.3	4.0	1.5	3.5					3.8	1.0	Very local movement
Aplocheilichthys katangae	AKAT				3.9	1.2	4.6			3.9		3.0	1.0	Very local movement (0-20km)
Awaous aeneofuscus	AAEN			3.5	4.0	2.0	3.7		4.9			2.8	1.0	n/a
Barbus afrohamiltoni	BAFR			4.7	4.3	2.8					4.0	2.5	3	Far (50km?)
Barbus annectens	BANN			5.0		2.8					4.7	3.0	3.0	Far (50km?)
Barbus anoplus	BANO			4.1	4.3	2.3	4.0			3.2		2.6	3.0	10km
Barbus lineomaculatus	BLIN			3.7	4.7	4.4			3.9			4.6	3.0	Local
Barbus motebensis	BMOT				4.7	3.0	4.7	4.4				3.1	1.0	Very local movement
Barbus pallidus	BPAL				3.8	2.8			3.5			3.3	1.0	Very local movement
Barbus paludinosus	BPAU			3.9	3.9	2.3	4.2			3.6	3.5	1.8	3.0	V28km reported / specialist thinks much further (50km)
Barbus radiatus	BRAD			4.7	5.0	2.8	4.7					1.4	3.0	Local
Barbus rapax	BMAT			4.7	4.0	3.0			4.1		4.2	3.2	3.0	Wash down great distances (40km)
Barbus toppini	BTOP			3.3	4.3	1.1	4.7					3.0	3.0	Far (50km?)
Barbus treurensis	BTRE			4.7		3.0			5.0			4.7	1.0	Very local movement
Barbus trimaculatus	BTRI			3.9	3.2	2.7	3.9					1.8	3.0	Far (50+km?)
Barbus unitaeniatus	BUNI			5.0	4.3	2.3	4.6					2.2	3.0	Far (50km?)
Barbus viviparus	BVIV				4.8	2.3	4.9			3.2		3.0	3.0	0-10km

Brycinus imberi	BIMB			4.7		3.0					4.7	3.2	3.0	Local - restricted to Lowveld
Brycinus imberi	BIMB			4.7	4.3	2.8					4.0	2.5	3.0	Far (50km?)
Chetia flaviventris	CFLA			4.7	3.7	1.3	4.7			3.3		2.0	1.0	Local
Chiloglanis paratus	CPAR	4.2	4.9			3.2			4.9			3.1	3.0	Local
Chiloglanis pretoriae	CPRE	4.3	4.9			4.8			4.9			4.5	3.0	Local
Chiloglanis swierstrai	CSWI		4.7			4.8			4.9			3.3	3.0	Local
Clarias gariepinus	CGAR			4.3	3.4	1.7						1.0	3.0	Long distances
Clarias theodorae	CTHE			4.5		1.0	3.5					2.0	3.0	up to 20km
Ctenopoma multispine	CMUL					0.0						0.0	1.0	0-20
Glossogobius callidus	GCAL				4.7	1.5			4.9			2.3	1.0	Local
Glossogobius giuris	GGUI				4.6	1.7			4.9			2.5	1.0	From the coast - might breed in estuaries and move up into Lowveld
Hydrocynus vittatus	HVIT	3.6		4.7		2.7	3.4				4.9	3.1	3.0	Local - restricted to Lowveld
Kneria sp. 'South Africa'	KAUR				4.2	2.5	4.7		3.6			4.1	1.0	Very local movement
Labeo congoro	LCON	5.0		5.0		3.3			5.0		3.4	3.0	3.0	up to 100km
Labeo cylindricus	LCYL	3.4	4.8			3.1			4.9			3.1	3.0	Far (50km?)
Labeo molybdinus	LMOL	3.3	4.3	3.7		3.3			4.7			3.2	3.0	Far (50km?)
Labeo rosae	LROS			4.7		2.5			5.0			3.0	3.0	Far (50km?)
Labeo ruddi	LRUD			4.7		2.9			4.7			3.0	3.0	Far (50km?)
Labeobarbus marequensis	BMAR	4.1	4.4	4.4	3.4	3.2			4.5		4.1	2.1	3.0	Far (100km?)
Labeobarbus polylepis	BPOL	3.7	4.3	4.2		3.3			5.0		3.6	2.9	3.0	Local
Marcusenius pongolensis	MPOL			4.2	3.7	3.0	3.8	5.0				3.4	3.0	Far (50km?)
Mesobola brevianalis	MBRE			4.3	4.2	1.1					5.0	2.8	3.0	Local
Micralestes acutidens	AACU			4.3	4.3	3.1	3.1				4.0	3.1	3.0	50 km
Nothobranchius furzeri	NORT				5.0	2.3	4.7			4.7		4.9		
Nothobranchius orthonotus	NORT				5.0	2.3	4.7			4.7		4.9		
Nothobranchius rachovii	NRAC				4.3	2.3	4.7			4.7		4.9		
Opsaridium peringueyi	OPER	3.2		3.3		4.9					4.4	4.4	3.0	Local (10-20km)
Oreochromis mossambicus	OMOS			4.6	3.8	0.9					3.9	1.3	3.0	0-20km
Oreochromis placidus	OPLA					0.0						0.0	1.0	0-20
Petrocephalus wesselsi	PWES				4.3	1.0	4.5	3.2				1.4	1.0	V28km reported
Protopterus annectens	PANN					0.0						0.0		

Pseudocrenilabrus philander	PPHI	4.7	4.3	2.8	3.3	5.0				3.0	3.0	Far (50km?)
Schilbe intermedius	SINT	5.0		1.3					4.7	1.8	3.0	Far (50km?)
Serranochromis meridianus	SMER	4.3	3.3	1.0	4.7					3.0	1.0	Very local movement
Silhouettea sibayi	SSIB		4.0	0.0			5.0			0.0		
Synodontis zambezensis	SZAM	5.0		1.8		5.0				3.0	3.0	Further than local (10 km)
Tilapia rendalli	TREN	4.9	3.9	1.8	4.3			4.1		2.1	3.0	V28km reported
Tilapia sparrmanii	TSPA		4.3	0.9	4.5			3.6		1.4	3.0	V28km reported

7 AQUATIC INVERTEBRATES

7.1 INTRODUCTION

This literature review follows up on an initial review carried out for the LIMCOM 2012 macroinvertebrate survey (Dickens, et al. 2013). The aim is to document new available information post 2012, specifically focusing on aquatic macro-invertebrate studies in the Limpopo-Olifants system.

The main threat to the Limpopo-Olifants system is over abstraction, with contaminated water returned to the system in the form of industrial, urban, and agricultural run-off (River Health Programme, 2001a). Further research has indicated that deterioration is ongoing (Ashton & Dabrowski 2011; Baker, 2018; Baker & Greenfield, 2019; CSIR, 2012; Dabrowski, et al., 2015; De Villiers & Mkwelo, 2009; Kemp, et al., 2014; Kemp, et al., 2016; Malakane, 2019; Marr, et al., 2017a; Marr et al., 2017b; Matlou, et al., 2017; Pollard & Retief, 2017; Rasifudi, et al., 2018: Riddell, et al., 2019).

Most of the work was carried out in the Olifants Catchment, with work in the Limpopo Catchment mainly on tributaries. In terms of aquatic macroinvertebrates, publications have focused primarily on biomonitoring using the SASS5 sampling method (Dickens & Graham, 2002) to determine ecological conditions. These assessments were commonly in combination with other biotic indices (i.e. fish, diatoms), in situ water measurements, water chemistry, sediment samples, and more. Aquatic macroinvertebrate data (mostly family level) was generally analysed statistically against various environmental variables (Kemp, et al., 2014; Malakane, 2019; Matlou et al., 2017; Rasifudi et al., 2018; Riddell, et al., 2019; Wolmerans, et al., 2014), and in some cases using the Macroinvertebrate Response Assessment Index or MIRAI (Thirion, 2008). The LIMCOM study was a once-off survey, with aquatic macroinvertebrates representing one of the biotic components assessed to determine ecological conditions (Dickens et al. 2013).

Several papers investigated longitudinal deterioration along pollution gradients (Malakane, 2019; Marr, et al., 2017a; Marr, et al., 2017b; Matlou, et al., 2017; Rasifudi, et al. 2018). Two publications assessed the potential accumulation of heavy metals in aquatic macroinvertebrates (Malakane, 2019; Kemp, et al., 2017).

Only a few papers centred on species level identification and ecology of certain taxa (De Kock & Wolmerans, 2017; Malzacher & Barber-James, 2020; Kemp, et al., 2016).

The main findings of these publications are summarised briefly in terms of their relevance to the Limpopo-Olifants Basin e-flows project.

7.2 LITERATURE

Published papers with information on river systems in the Limpopo (A) and Olifants (B) catchments are listed in Table 7.1 that follows, and each paper briefly summarized.

TABLE 7.1 SUMMARY OF EXISTING DATA AND LITERATURE FOR AQUATIC MACROINVERTEBRATES OF THE LIMPOPO-OLIFANTS SYSTEM POST 2012 (TABLE FORMAT ADAPTED FROM DICKENS ET AL. 2018).

Literature/database source	Type of data available	Comments on data suitability for E-Flows
Dickens et al. 2013; Kemp et al. 2014; Wolmerans et al. 2014; Dabrowski et al. 2015; Kemp et al. 2016; Kemp et al. 2017; Matlou et al. 2017; Marr et al. 2017a; Marr et al. 2017b; Pollard & Retief 2017; Rasifudi et al. 2018; Baker & Greenfield 2019; Malakane 2019; Riddle et al. 2019; Malzacher & Barber-James 2020.	General reports on the Limpopo basin	Summary of catchment conditions, water quality, and the responses of macroinvertebrate communities on family level, and some species ecology.
Strachan et al. 2015; Thorat & Nath 2018	Reports/papers for invertebrates in similar systems elsewhere	Specifically, invertebrate adaptations to desiccation
Dickens et al. 2013; Kemp et al. 2014; Wolmerans et al. 2014; Dabrowski et al. 2015; Kemp et al. 2016; Kemp et al. 2017; Matlou et al. 2017; Marr et al. 2017a; Marr et al. 2017b; Rasifudi et al. 2018; Baker & Greenfield 2019; Malakane 2019; Riddle et al. 2019	Broad papers on invertebrates of the Limpopo basin	Family level information mostly associated with some water quality parameters
Kemp et al. 2016; Malzacher & Barber-James 2020.	Invertebrates of the Limpopo basin (Biology/ecology)	Detailed species ecology
Comment on the overall strength of the data for the E-Flows assessment		
Fairly comprehensive family index-based data set with responses to water quality parameters for rivers draining from South Africa. Information available at family or genus level can be used to inform EWR assessments. Several of the studies highlight the importance of contributions from tributaries towards the improvement or deterioration of the main channel some tributaries as sources of pollution affecting the main channel. or responsible refugia and		
Comment on the overall weakness of the data for an E-Flows assessment		
Limited data on invertebrate species occurrence and ecology. The intermittent nature of for example the Limpopo and Shingwedzi suggest the presence of several aquatic invertebrates adapted to desiccation through avoidance and tolerance.		

Literature/database source	Type of data available	Comments on data suitability for E-Flows
Gaps: Data on the Limpopo River and its northern tributaries are extremely limited, with available invertebrate data mainly from the LIMCOM 2012 study (Dickens et al. 2013). Responses and adaptations of taxa-species to desiccation is limited, and the occurrence, distribution, and ecological data for most species unknown. Influence and importance of groundwater (e.g. hyporheic zone) and subsurface flows in maintaining specific invertebrate populations is not yet clear. Thus, the contributions of groundwater to e-flows and the adaptivity and reliance of stream communities remains to be clarified. Most of the published data exists for sites in the Olifants Catchment, with publications on the Limpopo River limited and restricted to some of the tributaries. Excepting for the Dickens et al. (2013) report, extremely limited data on the Limpopo River and no data on major tributaries draining from Botswana (e.g. Bonwapitse, Mhlatswe, Molapo, etc.), Zimbabwe (e.g. Shashe, Mzingwane, Bubi, etc.) and Mozambique (Nuanetsi, Chize, Munhuana, etc.) could be traced.		

7.3 CONCLUSION

Most assessments of aquatic macroinvertebrates have been carried out at family level, with the focus on families (not species) as biological indicators. These studies were predominantly in the South African portions of the Limpopo - Olifants Catchment, with studies on the Limpopo main channel extremely limited. In most of these assessments, the macroinvertebrate community on family level was compared to environmental data collected, mainly water quality, to determine ecological conditions along longitudinal gradients and for specific systems and subsystems. Current family-taxa based water quality index ratings are based on "expert" opinion rather than evidence based. The interactions between aquatic macroinvertebrates at a species level and physico-chemical variables are therefore critically important to improve the understanding of responses to environmental conditions.

It is important to distinguish between physico-chemical and flow responses, even though these responses are often interlinked. For example, in a study conducted by Dr Rob Palmer, suitable habitat was present for Simuliidae, but no Simuliidae were recorded during their field survey. On investigating the water column, high quantities of naturally suspended silica were found, which partially explained the absence of Simuliidae due to abrasion (Dr Rob Palmer 2020, personal communication, 8 September 2020). Flow is required for Simuliidae, but other factors could limit its presence.

Other factors important to consider are the resilience of species or taxa to desiccation. Some of the taxa recorded in the Shingwedzi River (Kruger National Park, South Africa) in January 2020 (e.g. Mutelidae: *Mutela zambesiensis*, and the nymphs of Gomphidae: *Paragomphus genei*), depend on subsurface flows to maintain populations through dry periods. The important contributions of groundwater inflows and hyporheic zones in maintaining some aquatic communities in "dry" river channels needs more attention.

Very few papers focus on the taxonomy and ecology of macroinvertebrate species, which is key to understanding rivers and responses to changes. For example, changes in flow requirements varies for Odonata:Coenagrionidae species, with *Pseudagrion spernatum* preferring vegetation in flowing waters, while *Pseudagrion salisburyense* prefers marginal vegetation in stagnant water in dams or/and in slow flowing rivers. Within the family of

Coenagrionidae there are also species changes along the river gradient, generally linked to water temperature, e.g. *Pseudagrion spernatum* (headwaters) and *Pseudagrion acaciae* (lower reaches).

For the Limpopo-Olifants E-flows study, more attention will be dedicated to:

- collecting aquatic macroinvertebrates in specific biotopes in terms of velocity, substrate composition and marginal and aquatic vegetation types and composition;
- taxa collected will be counted and identified to the lowest taxonomic resolution possible;
- community composition will be analysed per biotope, building on limited data related to species flow and substrate preferences;
- available information on taxa-species tolerance and/or avoidance to desiccation will be incorporated to improve insight into community responses and system resilience.

7.4 REFERENCES

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Dabrowski, J.M., Hill, L., MacMillan, P., Oberholser, P.J. (2015) Fate, Transport and Effects of Pollutants Originating from Acid Mine Drainage in the Olifants River, South Africa, *River Research and Applications*, 31:10, 1345-1364.

Dickens, C., O'Brien, G., Stassen, R., Eriyagama, N., Kleynhans, M., Rowntree, K., Graham, M., Ross-Gillespie, V., MacKenzie, J., Wygmenga, E., Mapedza, E., Burnet, M., Desai, M. and Hean, J. (2018). *E-flows for the upper Niger River and inner Niger Delta: Specialist Response Report Vegetation, Fish, Invertebrates & Birds.* International Water Management Institute.

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Kemp, M. de Kock, K.N., Wepener, V., Roets, W., Quinn, L., Wolmerans, C.T. (2014) Influence of selected abiotic factors on aquatic macroinvertebrate assemblages in the Olifants River catchment, Mpumalanga, South Africa, *African Journal of Aquatic Science*, 39:2, 141-149.

Kemp, M., de Kock, K.N., Zaayman, J.L., and Wolmerans, C.T. (2016) A comparison of mollusc diversity between the relatively pristine Marico River and the impacted Crocodile River, two major tributaries of the Limpopo River, South Africa, *Water SA*, 42:2, 253-260.

Kemp, M., Wepener, V., de Kock, K.N., and Wolmerans, C.T. (2017) Metallothioniem induction as indicator of low level metal exposure to aquatic macroinvertebrates from relatively unimpacted river system in South Africa, *Bulletin of Environmental Contamination and Toxicology*, 99, 662-667.

Malakane, K.C. (2019) Assessment of the impact of water and sediment quality on aquatic macroinvertebrate assemblages in the Blyde River of the Olifants River System, Limpopo province, *MSc Thesis* – Faculty of Science and Agriculture, University of Limpopo.

Malzacher, P. and Barber-James, H.M. (2020) Two new Caenis species (Insecta: Ephemeroptera: Caenidae) from the Kruger National Park, *African Entomology*, 28:1, 66-77.

Marr, S.M., Mohlala, T.D., and Swemmer, A. (2017a) The ecological integrity of the lower Olifants River, Limpopo province, South Africa: 2009-2015 – Part A: Olifants River main stem, African Journal of Aquatic Science, 42:2, 171-179.

Marr, S.M., Mohlala, T.D., and Swemmer, A. (2017b) The ecological integrity of the lower Olifants River, Limpopo province, South Africa: 2009-2015 – Part B: Tributaries of the Olifants River, *African Journal of Aquatic Science*, 42:2, 181-190.

Matlou, K., Addo-Bediako, Jooste, A. (2017) Benthic Macroinvertebrates Assemblage Along a Pollution Gradient in the Steelpoort River, Olifants River System, *African Entomology*, 25:2, 445-453.

Pollard, S., and Retief, H. (2017) *The role of the Wilge River in maintaining ecosystem integrity and associated benefits in the upper Olifants Catchment: Contribution to the assessment of potential risks of the proposed KiPower plant*, Association for Water and Rural Development (AWARD).

Rasifudi, L., Addo-Bediako, A., Bal, K., and Swemmer, T.M. (2018) Benthic Macroinvertebrates in the Selati River of the Olifants River System, South Africa, *African Entomology*, 26:2, 398-406.

Riddell, E.S., Govender, D., Botha, J., Sithole, H., Petersen, R.M., and Shikwambana. (2019) Pollution impacts on the aquatic ecosystem of the Kruger National Park, South Africa, *Scientific African*, 6, e00195.

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7.5 ARTICLE SUMMARIES

Published papers with information on river systems in the Limpopo (A) and Olifants (B) catchments are listed in Table 7.2 that follows, and each paper briefly summarized.

TABLE 7.2. SUMMARY OF PAPERS WITH THEIR MAIN TOPIC AND RELEVANT RIVER-STREAM ARE LISTED.

Source	Main Topic Relevance	River/s	Sub-cathment
Wolmerans et al., (2014)	Ecosystem Health (aquatic macroinvertebrates)	• Upper Olifants • Steenkoolspruit • Blyde • Selati • Lower Olifants	Olifants (B)
Kemp et al., (2014)	Biotic community (aquatic macroinverts) response to selected abiotic	• Upper Olifants • Steenkoolspruit • Blyde • Selati • Lower Olifants	Olifants (B)
Dabrowski et al., (2015)	Olifants River response to AMD – Abiotic (water & sediment) – Biotic (inverts & algae)	• Klipspruit • Olifants • Wilge	Olifants (B)
Baker & Greenfield (2019)	Response of aquatic macroinvertebrates to urban sewage pollution	• Nyl • Mogalakwana • Limpopo	Limpopo (A)
Marr et al., (2017a)	Lower Olifants responses • Abiotic – physico-chemical • Biotic – Fish & SASS	• Olifants	Olifants (B)
Marr et al., (2017b)	Lower Olifants tributaries – responses • Abiotic – physico-chemical • Biotic – Fish & SASS	• Steelpoort • Klaserie • Blyde • Selati	Olifants (B)
Pollard & Retief (2017)	Focused on Olifants Catchment abiotic components to draw attention to importance of Wilge River system	• Koffiespruit • Wilge • Blyde • Klaserie • Steelpoort	Olifants (B)

Source	Main Topic Relevance	River/s	Sub-cathment
		• Ga-Selati • Moses • Elands • Klipspruit • Zaaihoek • Steenkoolspruit • Middelspruit • Olifants • Klein Olifants	
Riddle et al., (2019)	Review of 7 years of abiotic, SASS and fish data for rivers flowing through KNP	• Luvuvhu • Letaba • Shingwedzi • Olifants	Limpopo (A) Olifants (B)
Matlou et al., (2017)	Steelpoort River • Abiotic – physico-chemical • Biotic – SASS	• Steelpoort	Olifants (B)
Malakane (2019)	Blyde River • Abiotic – physico-chemical • Biotic – SASS	• Blyde	Olifants (B)
Rasifudi et al., (2018)	Ga-Selati River • Abiotic – physico-chemical • Biotic – SASS	• Blyde	Olifants (B)
Kemp et al., (2017)	Metallothionine induction indicators of trace metal bioaccumulation	• Marico	Limpopo (A)
Kemp et al., (2016)	Mollusc Diversity comparison	• Marico • Crocodile	Limpopo (A)
Malzacher & Barber-James (2020)	New Ephemeroptera: Caenidae species	• Luvuvhu • Letaba • Olifants	Limpopo (A) Olifants (B)

Source	Main Topic Relevance	River/s	Sub-cathment
Freshwater Biodiversity Information System (FBIS)	Freshwater database with data entered by SASS practitioners.	• Various	Limpopo (A) Olifants (B)
Unpublished Reports	Aquatic macroinvertebrate data collected in unpublished reports (e.g. EIAs, biomonitoring reports) not entered the FBIS	• Various	Limpopo (A) Olifants (B)

Wolmerans, C.T., Kemp, M., de Kock, K.N., Roets, W., van Rensburg, L. and Quinn, L. (2014) A semi-quantitative survey of macroinvertebrates at selected sites to evaluate the ecosystem health of the Olifants River, Water SA, 40:2, 245-254.

A low and high flow survey of seven sites was carried out in the upper (three sites) and lower (four sites) portions of the Olifants River. Four sites were sampled on the main stem and three on larger tributaries. The study was conducted to evaluate macroinvertebrate diversity in relation to river health. Statistical analysis was used to assess the influence of abiotic factors on biotic samples collected. The authors found relative high diversity of aquatic macroinvertebrates, with low abundances of sensitive SASS-rated taxa, and high abundances of tolerant rated SASS-taxa. Low species diversity was often linked to poor biotope diversity (bedrock and sparce marginal vegetation), and high diversity to systems perceived to be relatively undisturbed (Blyde River). Water temperature was found to be one of the most important factors, driving community composition. High abundances and the dominance of the exotic gastropod *Tarebia granifera* (Thiaridae) was linked high water temperatures and low mean biodiversity at such sites. Some taxa were found to strongly associate with electrical conductivity during low flow periods. Lack of tolerance to poor water quality was identified as the main factor affecting low family abundances for most taxa recorded.

The value of this study in terms of the Limpopo-Olifants e-flow study is that it highlights the following important issues to bear in mind:

- The importance of maintaining tributaries in the Olifants catchment in good condition in terms of habitat, flow, water quality and stream community assemblages. Such tributaries provide additional flow, mitigate impacts of poor water quality, provide refugia and should therefore be prioritized for conservation.
- The importance of monitoring water temperature along river gradients over the long term.
- The undeniable link between low flow conditions, water temperature, electrical conductivity, and biotic community responses.
- The importance of noting how a system is influenced by biotope availability and quality, in addition to anthropogenic influences such as low flow or pollution.

Kemp, M. de Kock, K.N., Wepener, V., Roets, W., Quinn, L., Wolmerans, C.T. (2014) Influence of selected abiotic factors on aquatic macroinvertebrate assemblages in the Olifants River catchment, Mpumalanga, South Africa, African Journal of Aquatic Science, 39:2, 141-149.

The paper evaluates the same data collected as in the previous paper (Wolmerans et al. 2014).

Dabrowski, J.M., Hill, L., MacMillan, P., Oberholser, P.J. (2015) Fate, Transport and Effects of Pollutants Originating from Acid MineDrainage in the Olifants River, South Africa, River Research and Applications, 31:10, 1345-1364.

The study looked at concentrations of pollutants along a longitudinal gradient of the upper Olifants River affected by Acid Mine Drainage (AMD) from the Klipspruit River. Chemical variables were measured in water, sediments, and algae. In terms of aquatic macroinvertebrates, the study indicated a decrease in macroinvertebrate diversity in the Olifants River downstream from the Klipspruit confluence, with significant improvements in the Olifants River downstream from the Wilge River confluence. The input from the acidic Klipspruit River caused and increase in total Al, Fe, and Mn in the receiving Olifants River. It was also found that Al and Fe precipitated rapidly upon entering the more alkaline Olifants River, with filamentous algae accumulating high concentrations of Al, Fe and Zn. An increase in the concentrations Mn (dissolved phase) in a downstream direction was noted.

Of importance to the Limpopo-Olifants e-flow study, this paper underlines the macroinvertebrate response to poor and good water quality, which respectively drives deterioration and recovery in communities. In this case the currently less polluted Wilge River plays an important role in the recovery of the Olifants River, emphasizing the important role tributaries play in alleviating negative impacts. Once again, the important role of tributaries and the maintenance of largely natural conditions in tributaries along the Olifants main channel gradient is accentuated.

Baker, N.J., and Greenfield, R. (2019) Shift happens: Changes to the diversity of riverine aquatic macroinvertebrate communities in response to sewage effluent run-off, Ecological Indicators, 102, 813-821.

Ten sites were sampled during low and high flow conditions in the Nyl and Mogalakwena Rivers (Limpopo catchment) in 2016 and 2017. The study investigated the spatial and temporal responses of macroinvertebrate exposed to a poorly managed sewage treatment works. An increase in Chemical Oxygen Demand and nutrients downstream from the sewage treatment plant in the form of nitrates, nitrites, ammonia, ammonium, orthophosphates, and Total N was measured. Temporal differences in macroinvertebrate community composition was found to be driven by water temperature, while spatial differences were driven by Total N, nitrogen dioxide and manganese. The influence of obstructions impeding flow and encouraging deposition was also highlighted, with highly tolerant taxa dominating depositional zones.

In terms of the Limpopo-Olifants e-flow study, the paper underscores the direct and indirect negative impacts of poorly managed wastewater treatment plants on the temporal and spatial response of receiving aquatic macroinvertebrate communities downstream. It is also noted that the poor management of wastewater is a common problem in the catchments and many of the headwaters of systems draining the Limpopo-Olifants catchment.

Marr, S.M., Mohlala, T.D., and Swemmer, A. (2017a) The ecological integrity of the lower Olifants River, Limpopo province, South Africa: 2009-2015 – Part A: Olifants River main stem, African Journal of Aquatic Science, 42:2, 171-179.

The results of a six-year monitoring programme from 2009 to 2015 focusing on physico-chemical parameters, aquatic macroinvertebrates and fish in the lower reaches of the Olifants River is presented. The study forms part of a newly initiated long-term monitoring programme. This paper focused on results for sites in the Olifants River main stem. The Olifants River is in relatively good condition when it enters the lowveld, deteriorating after its confluence with the Selati River, remaining in poor condition up to the point where it flows out of the Kruger National Park. The SASS results also indicate deterioration with no discernable improvement through the

protected area. The study concluded that there is a need to expand physico-chemical parameters measured to detect eutrophication, metals and major ions such as sulphate. The Selati River was identified as the most likely driver of poor condition in the Olifants River in the lower reaches of the Kruger National Park.
In terms of the Limpopo-Olifants e-flow study, the paper highlights the importance of tributaries on aquatic macroinvertebrate communities in the main stem of a river.

Marr, S.M., Mohlala, T.D., and Swemmer, A. (2017) The ecological integrity of the lower Olifants River, Limpopo province, South Africa: 2009-2015 – Part B: Tributaries of the Olifants River, African Journal of Aquatic Science, 42:2, 181-190.
This paper follows on from the previous paper (Marr et al., 2017a), focusing on data collected on tributaries of the Olifants River and the impact on the main stem of the river. These tributaries are from up- to downstream the Steelpoort River (one site), Blyde River (two sites), Selati River (two sites) and the Klaserie River (one site). Based on the data assimilated, the sites on the Blyde River were in the best condition, followed by the Steelpoort and Klaserie rivers. The worst condition was in the Selati River, which also negatively influenced the Olifants River below their confluence. Concerns were raised about the impact of the new De Hoop Dam and the increase in mining activities on the Steelpoort River, as well as increased agricultural activities on the Blyde River, and the consequence of these impacts on the Olifants River main channel.
In terms of the Limpopo-Olifants e-flow study, the paper further highlights the contribution of tributaries to the impacts (negative and positive) on aquatic macroinvertebrate communities and overall riverine conditions.

Pollard, S., and Retief, H. (2017) The role of the Wilge River in maintaining ecosystem integrity and associated benefits in the upper Olifants Catchment: Contribution to the assessment of potential risks of the proposed KiPower plant, Association for Water and Rural Development (AWARD).
The report evaluates water quality trends in the Olifants River, providing an overview of the water quality of the Olifants catchment. The aim of the report is to emphasize the important contribution of the Wilge River to the Olifants catchment in terms of improved water quality and flow maintenance. Analyzed data are presented as empirical evidence to support this view. A plea is made to consider the implications of deterioration in water quality of the Wilge River on the receiving Olifants system and the implications to human health, welfare, and food security.
In terms of the Limpopo-Olifants e-flow study, the report emphasizes the important contribution of good quality tributaries in mitigating poor conditions in receiving aquatic ecosystems. This also has socio-economic importance.

Riddell, E.S., Govender, D., Botha, J., Sithole, H., Petersen, R.M., and Shikwambana. (2019) Pollution impacts on the aquatic ecosystem of the Kruger National Park, South Africa, Scientific African, 6, e00195.
The KNP has applied river ecosystem research for over 30 years, and this paper evaluates the progress made towards improving their river management practices based on the rivers research investment. Aquatic macroinvertebrate data (SASS method) is available for eight sampling seasons (September) from 2010 to 2017. The aquatic macroinvertebrate data (response) is correlated to water quality parameters

measured. The Luvuvhu River appeared to be in good condition, weakly correlating to water quality parameters, while the Olifants River macroinvertebrate response correlated strongly with N, Cl, F, Mg, P, and moderately to dissolved major salts, EC and SO_4.

The paper shows the diverse effects of diffuse pollutants on the freshwater aquatic biota, with differences in responses dependent on the nature of anthropogenic upstream (outside of KNP) activities. Noticeable effects of major salts, and high sediment delivery during large peak flow events were identified as key characteristics of larger systems.

Matlou, K., Addo-Bediako, Jooste, A. (2017) Benthic Macroinvertebrates Assemblage Along a Pollution Gradient in the Steelpoort River, Olifants River System, African Entomology, 25:2, 445-453.

Five sites were sampled during high and low flow conditions along the Steelpoort River gradient, measuring physico-chemical parameters and benthic macroinvertebrate assemblages. The study indicated a change in physico-chemical and macroinvertebrate assemblages from upstream to downstream sites, which is expected even under natural conditions.

The value of the paper to the Limpopo-Olifants e-flows is that it emphasizes the importance of major tributaries in a system in contributing to both flow and water quality of the main stem river and hence to downstream responding biota.

Malakane, K.C. (2019) Assessment of the impact of water and sediment quality on aquatic macroinvertebrate assemblages in the Blyde River of the Olifants River System, Limpopo province, MSc Thesis – Faculty of Science and Agriculture, University of Limpopo.

Seven sites were sampled during high and low flow along the Blyde River. The survey collected data on physico-chemical parameters, the benthic macroinvertebrate community composition to determine responses. The aim of the study was to assess water and sediment quality in the Blyde River and determine responses in the aquatic macroinvertebrate community. Chemical analysis on Odonata larvae (predators) was included focusing on bioaccumulation. Higher quantities of Cd, Cu, Mn and Zn were recorded in the tissues of the Odonata larvae than in the sediments and water. Cu, Mn and Zn are metabolically essential, but not Cd. Cadmium was thought to be emitted from agricultural pesticides in the catchment. Elevated nutrients (phosphorus) and heavy metals (As, Ag, Cr, Cu, and Zn) was recorded in sediments.

The study suggested that the Blyde River, based on the benthic macroinvertebrate community and the high biotope diversity, reflected good stream conditions, but concerns were raised about the impact of increased agricultural activities.

Kemp, M., Wepener, V., de Kock, K.N., and Wolmerans, C.T. (2017) Metallothioniem induction as indicator of low level metal exposure to aquatic macroinvertebrates from relatively unimpacted river system in South Africa, Bulletin of Environmental Contamination and Toxicology, 99, 662-667.[1]

The study aimed to determine if induction of metallothionines (MTs) can be used as indicators of natural metal exposures in relatively unimpacted river systems and

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[1] Only the abstract could be accessed.

relationships between metal concentrations in water, sediment and macroinvertebrates and MT levels. Bioaccumulation of trace metals such as nickel, lead, and zinc showed correlation between sediments and macroinvertebrates, but not between water and macroinvertebrates. The authors did not find correlations between MTs and earth metal bioaccumulation (such as aluminum, iron, manganese, and titanium).

Metallothionine can potentially be used to determine the bioaccumulation of metals within aquatic macroinvertebrate predators in stream communities at specific sampling locations.

Rasifudi, L., Addo-Bediako, A., Bal, K., and Swemmer, T.M. (2018) Benthic Macroinvertebrates in the Selati River of the Olifants River System, South Africa, African Entomology, 26:2, 398-406.

Five sites were sampled during low and high flow conditions along the Ga-Selati River in 2014 and 2015. The aim of the study was to determine the ecological state of the river based on the water quality and responding aquatic macroinvertebrate community. Taxa rated as sensitive (SASS) dominated communities in the upper reaches of the Ga-Selati, while they were absent in the lower reaches, which was dominated by tolerant taxa.

The study concluded that the deterioration of the Ga-Selati River from the upper to lower portions along the longitudinal gradient was linked to the downstream change in water and habitat quality. The deterioration was attributed to mining and agricultural activities.

Kemp, M., de Kock, K.N., Zaayman, J.L., and Wolmerans, C.T. (2016) A comparison of mollusc diversity between the relatively pristine Marico River and the impacted Crocodile River, two major tributaries of the Limpopo River, South Africa, Water SA, 42:2, 253-260.

The study compared mollucs collected and identified to species level between a relatively pristine Marico River to an impacted Crocodile River, both tributaries of the Limpopo River. Surveys were carried out during high and low flow conditions in 2013 and 2014. With environmental parameters measured, species data was compared to historical data.

A higher diversity of species was recorded in the Marico River, with species more tolerant to water quality and habitat deterioration recorded at sites in the impacted Crocodile river.

The study supported the notion that species level information provides clearer insight into the impact of habitat and water quality on aquatic ecosystems.

Malzacher, P. and Barber-James, H.M. (2020) Two new *Caenis* species (Insecta: Ephemeroptera: Caenidae) from the Kruger National Park, African Entomology, 28:1, 66-77.

Rivers in the Kruger National Park was surveyed in 2015 and 2017 with the aim of working towards species level identification of aquatic macroinvertebrates within these systems. The survey focused on data collection of the nymphs-larvae-adults in its aquatic life stages as well as adult phase (light traps). Two new species were discovered, one in the Luvuvhu River and one at the confluence of the Olifants and Letaba Rivers. These two species are described in this paper, and keys provided towards the identification on male nymphs.

The discovery of new aquatic macroinvertebrate species in lower portions South African rivers, even in those rivers considered to be in poor condition, highlights our limited knowledge of freshwater ecology and lack of research. It is highly likely that species have already been lost before being described.

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