E-FLOWS FOR THE LIMPOPO RIVER BASIN:

PRESENT ECOLOGICAL STATE – DRIVERS OF ECOSYSTEM CHANGE

E-FLOWS FOR THE LIMPOPO RIVER BASIN: PRESENT ECOLOGICAL STATE - DRIVERS OF ECOSYSTEM CHANGE

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

Report citation: O'Brien, G.; Dickens, C.; Stassen, R.; Erasmus, H.; Herselman, S.; van der Waal, B.; Wepener, V.; Pearson, H.; LeRoux, H.; Villholth, K.; Ebrahim, G.; Magombeyi, M.; Riddell, E.; Petersen, R. 2022. ***E-flows for the Limpopo River Basin: present ecological state - drivers of ecosystem change.*** 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. 296p. (E-flows for the Limpopo River Basin: Report 5). doi: https://doi.org/10.5337/2022.220

The authors: Gordon O'Brien – fish biologist, e-flows and risk modeller, principal author, University of Mpumalanga and Rivers of Life, South Africa; Chris Dickens – project lead, International Water Management Institute, Sri Lanka; Retha Stassen – hydrologist, Hilton, South Africa; Hannes Erasmus, and Shaun Herselman, University of Northwest, South Africa; Bennie van der Waal – hydraulics and sediments, Hilton, South Africa; Victor Wepener - water quality, University of Northwest, South Africa; Hanro Pearson and Herman LeRoux – water quality, University of Mpumalanga and Rivers of Life; Karen Villholth, International Water Management Institute, South Africa; Girma Ebrahim - groundwater, International Water Management Institute, Ethiopia; Manuel Magombeyi - International Water Management Institute, South Africa; Eddie Riddell and Robin Petersen, SANParks, South Africa.

International Water Management Institute (IWMI)

P O Box 2075, Colombo, Sri Lanka

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:

The authors would like firstly to thank the donors USAID and the program managers from Chemonics, Resilient Waters, based in Pretoria South Africa for the support and funding for the project. In particular the support of Nkobi Moleele and Mayford Manika from Resilient Waters, Simon Johnson from JG Africa, Hilton, South Africa, and Zvikomborero Manyangadze from LIMCOM (the Limpopo Commission) for their caring and detailed project support. The support of the management of LIMCOM was much appreciated, in particular Sergio Sitoe and Eben William Chonguica and also the many technical members of the Steering Committee who were part of the LIMCOM technical team. We would particularly like to thank Eddie Riddell and Robin Peterson from SANParks, South Africa for their, and the KNP, support in hosting some of our workshops us and providing so much insight especially into groundwater issues, and also for the abundant support while surveying in the Kruger Park and elsewhere. Also, thanks to Martin Kleynhans who reviewed and gave oversight on the hydraulics. We appreciate the human resource support from the University of Mpumalanga, Rivers of Life Programme and Northwest University who contributed specialist researchers to the study, and co-funded surveys, data collection and analyses. We acknowledge the co-funding for these efforts from the WIOMSA Anguillid eel study and National Research Foundation BRICS Global Water quality monitoring studies. We would also like to thank the International Water Management Institute for management and support of this project, in particular Matthew McCartney Research Program Leader of Sustainable Infrastructure and Ecosystems, and Karen Gunter for all her admin and logistical support.

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: The Limpopo River, May 2021

SUMMARY

PROJECT TITLE:

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

REPORT TITLE:

Present Ecological State of the Limpopo River - Drivers of Ecosystem Change & Ecological Responses to Change

PROJECT OBJECTIVES:

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

CONTENT:

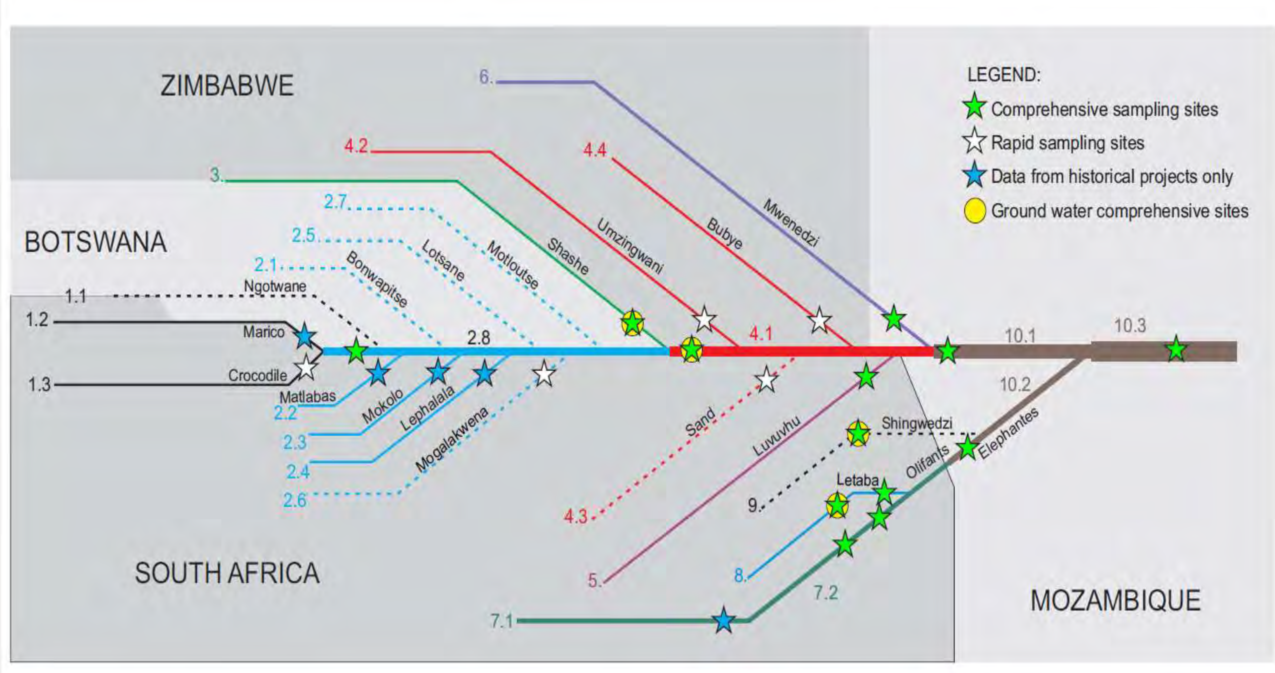
Seven reports document the outputs of this project (see above). The first four reports describe the context for the e-flow derivation i.e., the socio-economic and biophysical characteristics of the basin (the Basin Description), and all the river-related biophysical background (the Specialist Literature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

The present report (**No. 4 Present Ecological State of the Limpopo River - Drivers of Ecosystem Change**) is based on the extensive field survey that was carried out during 2020 and 2021, and documents the results directly gained from that field survey in the form of an assessment of the present ecological state.

Data and information is given that describe the field survey sites. The report also describes the status quo of the ecosystem, the Present Ecological State, in terms of the **Drivers of change in the ecosystem** (in terms of hydrology, groundwater, hydraulics, sediments and water quality).

SUMMARY RESULTS

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



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

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

Drivers of change in the ecosystem

These are the factors that are directly affected by land-use changes and developments, as well as by climate change, and have a direct impact on the instream and riparian ecosystem. Each of these is pivotal in understanding what drives the system, so that the required amounts of water at the right time can be estimated.

Hydrology

The report includes the analysis of the long-term natural hydrological flow time series at the selected e-flow sites for the main stem Limpopo River and the major tributaries. These include basic hydrographs, flow duration curves and statistics based on monthly modelled natural flow data at the e-flows sites. Additional information is also provided in terms of drought flows, sizes and duration of freshets and floods. The information used in this report is mainly based on the results from the hydrological study (Volume C – hydrological assessment, 2013) that was part of the Limpopo Monograph study as well as data from the Limpopo Reconciliation study (DWS, 2015). 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 the current e-flow study, accept the scaling of flows to a specific e-flow sites using catchment area.

The table below summarises the hydrological characteristics in terms of the Natural Mean Annual Runoff (nMAR) and the variability index (CV_Index) which indicates the seasonal, perennial or ephemeral character of the rivers (between 1 and 4 indicates a perennial system, 5 a seasonal and >6 an ephemeral system).

TABLE 0.1 SUMMARY OF NMAR AND CV_INDEX AT E-FLOW SITES IN THE LIMPOPO BASIN

Risk region	Rivers	E-flow site	nMAR (106m3)	CV_Index
RR1	Ngotwane	Lim_EF01	92	5
	Marico	Lim_EF02	154	3
	Crocodile (West)	Lim_EF03	596	2
RR2	Bonwapitse	Lim_EF04	81	11
	Matlabas	Lim_EF05	35	3
	Mokolo	Lim_EF06	230	3
	Lephalale	Lim_EF07	142	2
	Lotsane	Lim_EF08	35	10
	Mogalakwena	Lim_EF09	244	2
	Motloutse	Lim_EF10	125	8
	Limpopo to Lotsane confluence	Lim_EF11	591	2
	Limpopo – Lotsane to Shashe	Lim_EF12		
RR3	Shashe	Lim_EF13	687	9
RR4	Limpopo – Shashe to Mzingwani	Lim_EF14	1684	2
	Mzingwani	Lim_EF15	438	7
	Sand	Lim_EF16	91	6
	Bubye	Lim_EF17	200	11
RR5	Luvuvhu	Lim_EF18	560	2
RR6	Mwanedzi	Lim_EF19	412	11
RR7	Olifants – to Blyde	Lim_EF20	1322	2
	Olifants – to Letaba	Lim_EF21	1910	2

Risk region	Rivers	E-flow site	nMAR (106m3)	CV_Index
RR8	Letaba – to Little Letaba	Lim_EF22	441	2
	Letaba – to Olifants	Lim_EF23	642	3
RR9	Shingwedzi	Lim_EF24	96	9
RR10	Limpopo – Mzingwani to Mwanedzi	Lim_EF25	2792	3
	Elephantes	Lim_EF26	2712	2
	Limpopo – to estuary	Lim_EF27	5572	3

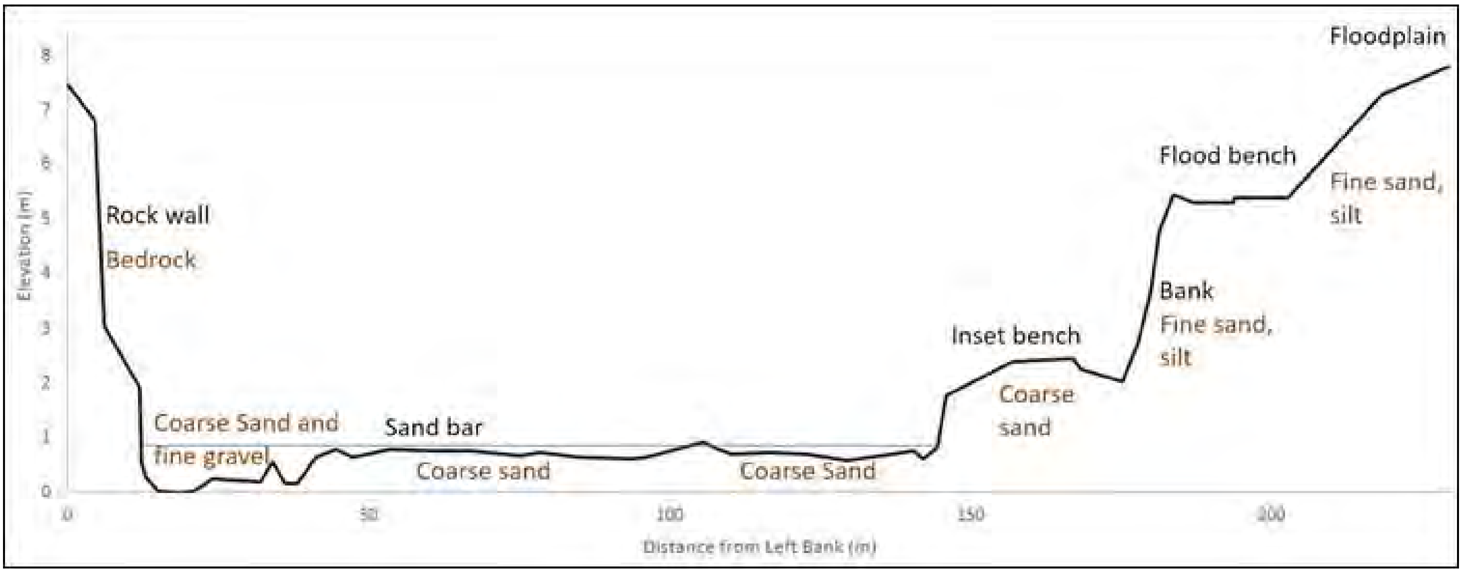
It can be seen from the table that a number of systems are naturally ephemeral, especially those in Botswana. It should be noted that this index was calculated for the flows at the e-flow sites that are mostly situated in the lower reaches of the rivers. Some systems may differ in the upper reaches.

Hydraulics and geomorphology

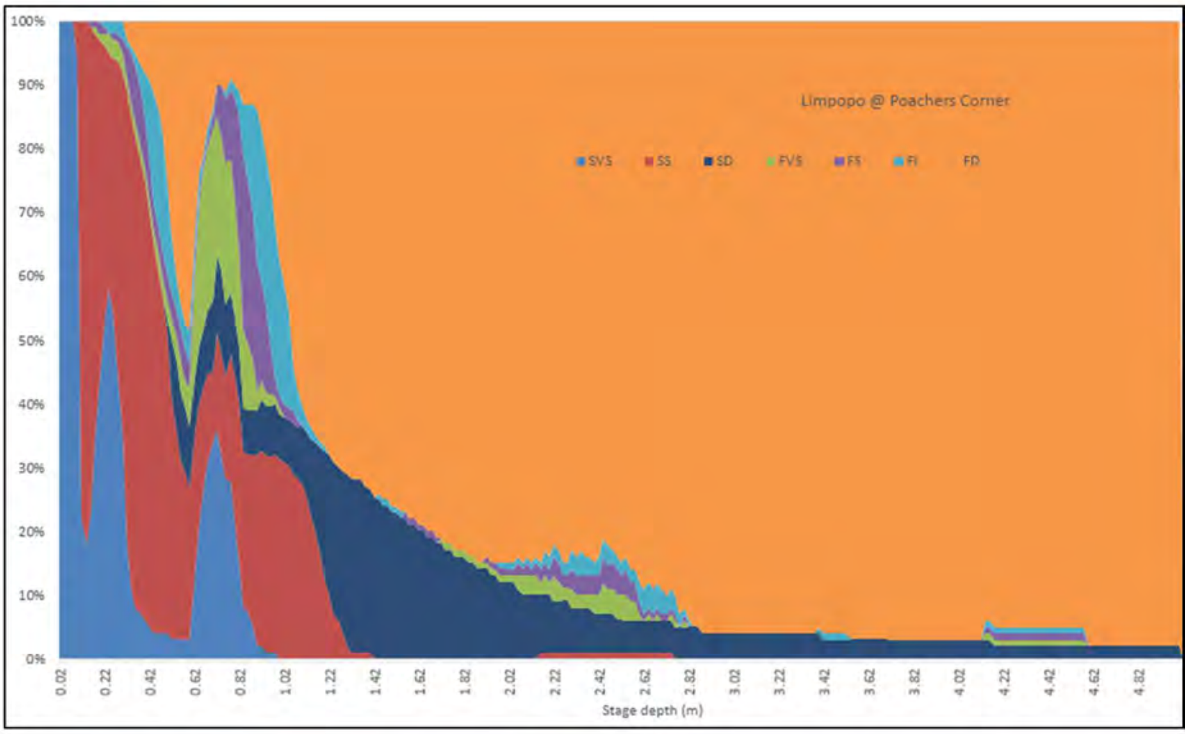
The hydraulic habitat, i.e. a combination of the water depth, velocity and the underlying sediments and river shape, are important drivers of ecosystem condition. This specialist component of the e-flow study describes this habitat at all of the available sites.

The hydraulics for 21 sites across the Limpopo Basin have been determined. The methods used, cross sections, site description and data output are presented below. A single cross section was surveyed at each site in order to capture critical hydraulic habitats that are sensitive to flow. Survey benchmarks were established, and all surveys tied into these. Data gathering consisted of transect selection and demarcation, survey of the topography along the transect (perpendicular to flow); survey of water levels, energy gradient and historical flood marks; and measurement of depth and velocity along each transect. Roughness was calculated using the Mannings n formula based on the measured data. In order to extrapolate the observed hydraulic data to other stage levels so that a continuous rating function can be determined for a wide range of discharges, 1 dimensional hydraulic modelling of higher flows was undertaken using the Mannings formula. HABFLO, a 1 dimensional free-ware empirical hydraulic habitat-flow simulation model, was used to derive frequency distribution data for the various hydraulic habitats. HABFLO is designed to simulate flow dependent, ecologically relevant hydraulic data.

The figures below illustrate an example of essential hydraulic information gained from this exercise. Firstly, an example cross section, and secondly the distribution of velocity depth characteristics i.e. the hydraulic habitat. This is the habitat characteristic that determines the suitability of the river for fish and invertebrates and to a less extent riparian vegetation. These descriptions are foundational for the consideration of ecological response.



EXAMPLE OF A CROSS-SECTION ON THE LIMPOPO RIVER SHOWING MORPHOLOGICL FEATURES.



EXAMPLE OF MODELLED VELOCITY DEPTH FREQUENCY DISTRIBUTION I.E. THE HYDRAULIC HABITAT FOR FISH AND INVERTEBRATES

Water quality

Besides the quantity of water already described above, the quality of that water is the second key driver of the condition of the ecosystem. The objective of this report is to present the water quality data that were collected at selected sites during the survey of April-June 2021. A summary of the data is presented as well as a comparison with historical data contained in the previous Specialist Report. The data are also assessed using the fitness for use.

During the survey three sites were sampled on the Limpopo River in South Africa and two sites in Mozambique. The general water quality data and metal concentrations are presented in Tables 4 and 5 respectively. Based on the classification schemes the pH at LIMP-A41D-SPANW and LIMP-A71L-MAPUN was poor while the orthophosphates at LIMP-A36C-LIMPK were at unacceptable levels. Metal concentrations were all in the "good" range with Zn at A41D-SPANW and LIMP-A71L-MAPUN being in the "acceptable" range. The current data are compared to historical data at LIMP-A41D-SPANW in Table 6. The levels of the current water quality variables are all above the mean at the site and are within the 90 to 95th percentiles.

During the survey nine sites were sampled in major tributaries of the Limpopo River in South Africa. The general water quality data and metal concentrations are presented in TABLE 5.4 and TABLE 5.5 respectively. Based on the classification schemes the pH at CROC-A24J-ROOIK, SAND-A71K-R508B and OLIF-B73H-BALUL was regarded as poor. The EC of the Matalabas River (MATL-A41D-WDRAAI) was unacceptable whereas the inorganic phosphates at the CROC-A24J-ROOIK, LEPH-A50H-SEEKO, MOGA-A63D-LIMPK and SAND-A71K-R508B sites were also at unacceptably high levels. Two of the main tributaries in the Kruger National Park also had high inorganic phosphate levels resulting in a "poor" classification. The nitrate levels at MATL-A41D-WDRAAI, SAND-A71K-R508B and OLIF-B73H-BALUL sites were also classified as "poor". The Zn concentrations at five of the nine sites as classified as acceptable.

Groundwater

The objective of this report is to summarize our understanding of the two groundwater study sites (Letaba and Mapungubwe) in the Limpopo River Basin. Comparison of baseflow indices from various methods at two sites was also done to get a feel on whether there is an agreement in the way the groundwater flow contribution to E-flows was conceptualized in the surface hydrology component.

The water samples collected throughout the Limpopo River Basin were used to analyse the proportion of groundwater to total streamflow (perennial). The separation of proportion of groundwater and surface water was based on the assumption that groundwater and surface water have different signature, and this signature can be used to assess the proportion of groundwater in total streamflow. The signature can be assessed from chemical and isotope analysis of surface water flow and groundwater near the rivers. In some cases, electrical conductivity can used where there is huge difference in levels between surface water and groundwater and there is no additional input of salts to water from other sources in the area.

The average electrical conductivity and total dissolved solids for surface water was 348 µS/cm and 226 mg/L, respectively, for Letaba, while for Mapungubwe it was 458 µS/cm and 298 mg/L, respectively. The groundwater generally showed much higher levels (about 10 times) of electrical conductivity and total dissolved solids compared to surface water. Letaba groundwater sites had an average of 4,863 µS/cm and 2,798 mg/L for electrical conductivity and total dissolved solids, respectively, while Mapungubwe sites had an average of 3,274 µS/cm and 1,232 mg/L, respectively. Surface water in Letaba was fresher compared to the one in Mapungubwe, while groundwater in Letaba was more saline compared to the one in Mapungubwe.

The quality of the groundwater considering all sites sampled in the Limpopo River Basin, was classified (in order of decreasing dominance) as Ca-HCO_3 type, (indicating reverse/ inverse ion exchange (Davis and Dewiest, 1966) responsible for controlling the chemistry of the groundwater), mixed Ca-Na-HCO_3 type, and Na-Cl type. A few (two) samples were classified as Ca-Cl type, giving an indication of groundwater from formations that are composed of limestone and dolomite or from active recharge zones with short residence time (Hounslow, 1995). River water was classified (in order of decreasing dominance) as Ca-HCO_3 type (associated with temporary hardness), Na-HCO_3 type and mixed Ca-Mg-CI-SO_4 type (associated with permanent hardness), where type of river water cannot be identified as neither anion nor cation dominant (Todd and Mays, 2005). In summary, the chemistry of groundwater and river water for sites in the Limpopo River Basin, was characterized by similar mixtures of constituents and reflects water with similar history, origin and interactions. This supports the hypothesis that there is a strong interaction between surface water (river water) and groundwater to provide environmental water flows, even under the high flows in the wet season.

Isotope analyses was also carried out in order to assess the proportion of groundwater in total river flow. Results indicate groundwater and river water samples for different sites in the Limpopo River Basin are distributed along the LMWL in a δ^2H- δ^{18}O diagram. This suggests rapid rainfall infiltration to groundwater and is not affected by evaporation processes during infiltration owing to the presence of geological faults and vegetation cover. River water and groundwater samples for ^{2}H and ^{18}O were offset to the right of the Meteoric Water Line (MWL), Global Meteoric Water Line (GMWL), Pretoria Meteoric Water Line and Taaiboschgroet (Limpopo) Meteoric Water Line), and plotted along the local evaporation trend line, indicating that groundwater and surface water were influenced by evaporation under relatively arid and semi-arid conditions. River water and groundwater samples were depleted (plotted on the left bottom quadrant) in heavy isotopes due to precipitation from higher altitudes in the basin. For Mapungubwe site, unlike Letaba site, river water samples are away from the MWL, indicating higher evaporation at this site compared to Letaba site.

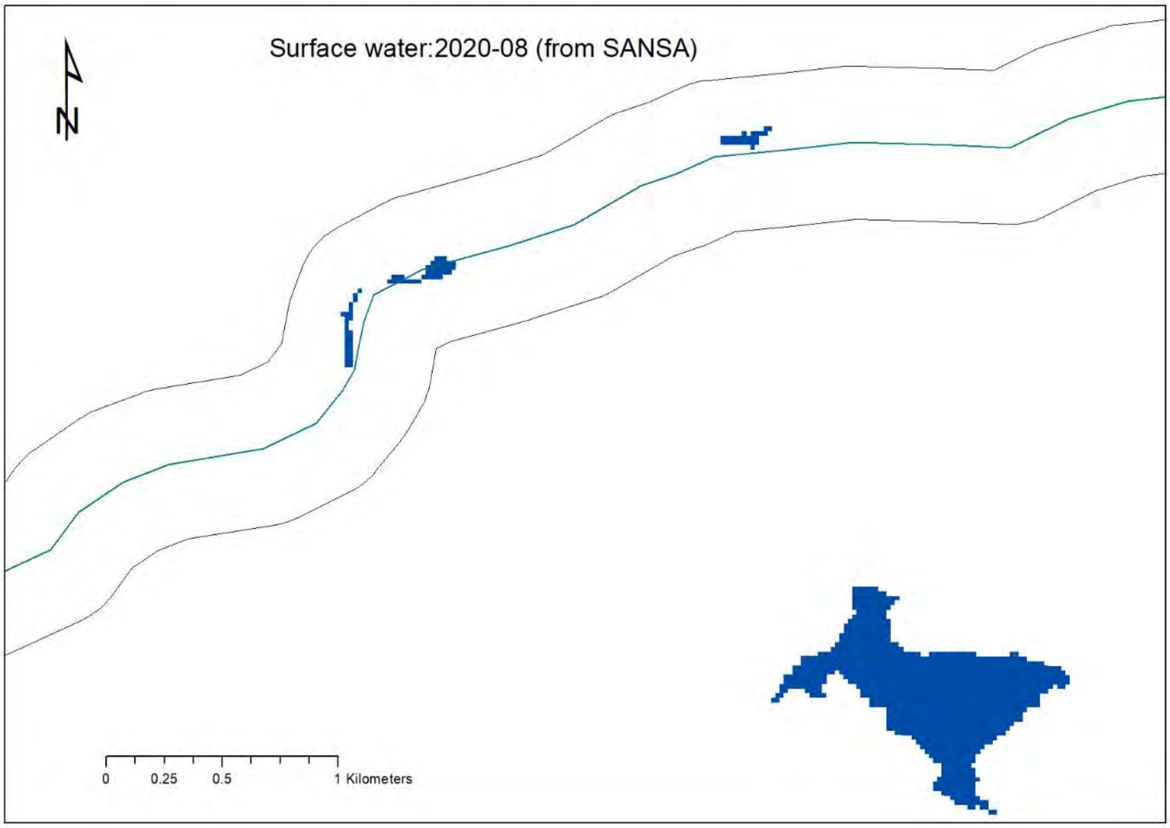
The similar isotopic signatures of the groundwater and surface (river) water or isolated pools along the river further indicate the occurrence of groundwater in the river during dry and wet periods. This confirms that the source of water in isolated pools during the dry season is groundwater. The proportion of groundwater to total river flow from isotope baseflow separation ranged from 0.19 (Mapungubwe, drier climate than Letaba) to 0.41 (Letaba).

Baseflow is the rate of groundwater flow that a given catchment provides from all upstream phreatic aquifers along the riverbanks in the absence of precipitation, melting snow or any upstream water inputs (Brutsaert and Nieber, 1977). Baseflow, in this study was then assumed to represent the groundwater discharge and is important in water allocation to both human and environmental purposes. In this study, the baseflow was used to understanding the groundwater surface water interactions, and to estimate the contribution of groundwater to the environmental water flow requirement in the Limpopo River Basin. The calibrated monthly BFI, beta and alpha values for monthly baseflow separation aggregated from daily flows were compared with an average isotope baseflow separation. The results showed that the difference in BFI between the Hughes & Smaktin Model (Hughes et al., 2003) method used by Stassen (2021) and isotope separation method ranged from -16% to 20%. However, we expected BFI by Stassen (2021) which is based on naturalized flows to be higher than the one from isotope separation, which is based on current or observed flows. This difference indicates the need for slight additional calibration of the alpha and beta parameters based on the physical data from isotope results. The suggested alpha and beta parameters for perennial rivers (e.g., Letaba) were 0.419 and 0.943, respectively; while for ephemeral rivers (e.g., Limpopo River at Mapungubwe site, downstream Limpopo/Shashe confluence) they were 0.446 and 0.977, respectively. The riverflow regime classification of rivers in the basin can be used for upscaling filter parameters from the two sites to similar sites in the basin.

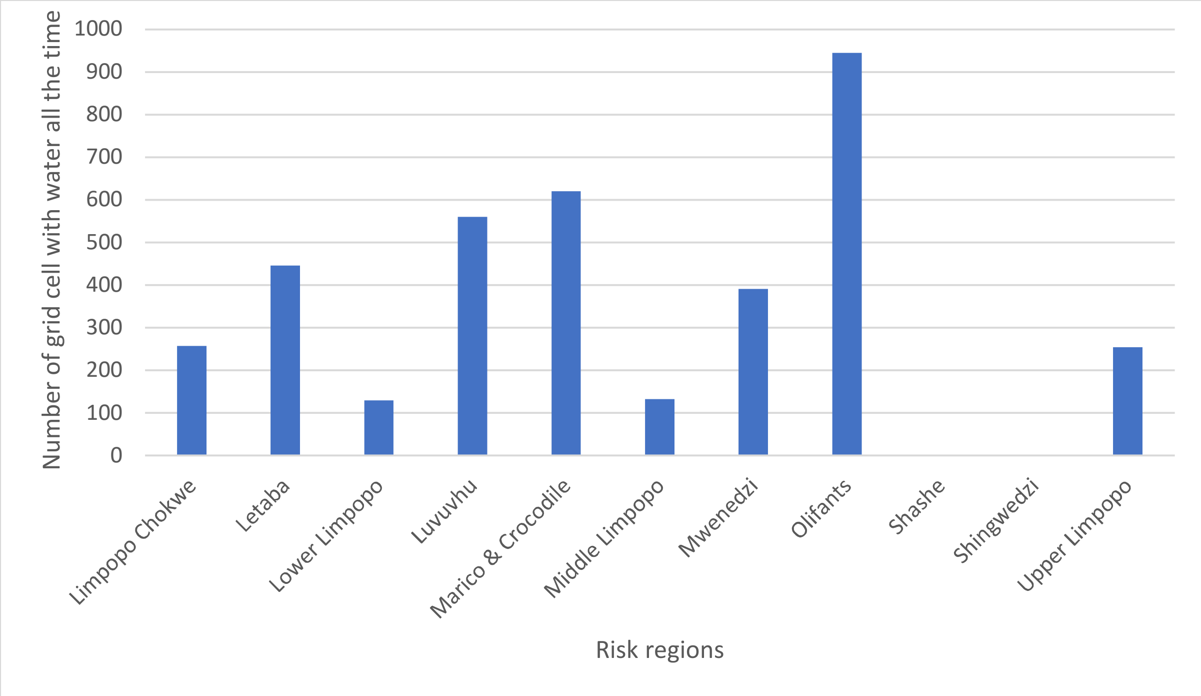
Isolated pools

Isolated pools are water features that form because of drop in flow that creates a pool of still water isolated from water flowing in the river. In non-perennial rivers one of the most critical factors impacting ecological functioning is the dynamics of pool storage, as isolated pools in temporary rivers are transitional habitats of major ecological relevance as they support aquatic ecosystems during no-flow periods, and can act as refugees for maintaining local and regional freshwater biodiversity. 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. They may be a source of water for a wide variety of wildlife and local rural people and their livestock.

Data from the South Africa National Space Agency (SANSA) was used to support isolated pool mapping. Isolated pools area for the main Limpopo River Basin have been calculated for every month of the year.



EXAMPLE SHOWING ISOLATED POOLS WITHIN THE RIVER (AND AN OFF-CHANNEL DAM). THIS DATA COLLECTED FROM SATELLITE OBSERVATIONS OVER MULTIPLE YEARS.



NUMBER OF GRID CELLS WITH WATER ALL THE TIME, PER RISK REGIONS

This groundwater information, the quality, the movement of groundwater and its contribution to baseflow, and the existence of surface pools maintained by groundwater, are all pivotal to the estimation of e-flows. This information is built into the Conceptual Models that are used to derive the e-flows and are the subject of the next report.

CONTENTS

1 INTRODUCTION

PROJECT Title:

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

1.1 OBJECTIVES

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

1.2 THE LIMPOPO RIVER BASIN

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

1.3 E-FLOWS IN THE LIMPOPO BASIN

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

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

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

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

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

1.4 STRUCTURE OF THIS REPORT

This report describes the status quo of the ecosystem in terms of the Drivers of Change in the ecosystem (hydrology, groundwater, hydraulics, sediments and water quality).

The report has been structured to include the following sections:

- **Introduction**
    - E-Flow Sites
    - Field Survey
- **Drivers of Ecosystem Change**
    - Hydrology
    - Hydraulics and Geomorphology
    - Water Quality
    - Groundwater
- **Conclusions**

- **Data appendices**
  - These include all of the detailed data from each section

Note that the next report, No. 5 includes the following:

- **Response of Ecosystem to Drivers**
  - Fish
  - Macroinvertebrates
  - Riparian Vegetation
  - Ecosystem Services

2 FIELD SURVEY, RISK REGIONS & E-FLOW SITES

2.1 RISK REGIONS

The Limpopo River catchment has initially been divided into 11 main risk regions (RR) based on a number of criteria, including hydrological considerations One of the main hydrological considerations was to select regions where the various types of rivers (seasonal, perennial or ephemeral) are grouped within one region. Additionally, changes in flows from natural to present day due to developments (dam construction, irrigation, return flows or hydropower) were also taken into consideration to assist the assessment of the habitats and biota by the ecologists. These RRs have been revised and 10 final RRs have been selected, each with a number of sub-risk regions (mainly the major tributaries contributing flow to the RR). The final RRs and main tributaries (Sub-risk regions) are listed in the table below (Table 2.1) together with greater detail Table 2.1, and are also shown in the schematic (Figure 1) and the maps in **Error! Reference source not found.**. and Figure 2.3.

2.2 SITE SELECTION

The Limpopo River Basin Monograph (Aurecon, 2013) included a supplementary report called "*Determination of Present Ecological State and Environmental Water Requirements*" that was published in 2013. Eight (8) sites that spanned the entire transboundary basin were surveyed in that report to provide data for priority reaches on the main-stem Limpopo and important tributaries. For this study in 2020/2021, additional sites were added to the above in order to ensure a better distribution of data. These sites are shown in Figure 1 and 2.3. TABLE 2.2 provides the details of each site and also indicators which biophysical characteristics were surveyed.

The sites were located based on the following criteria:

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

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

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

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

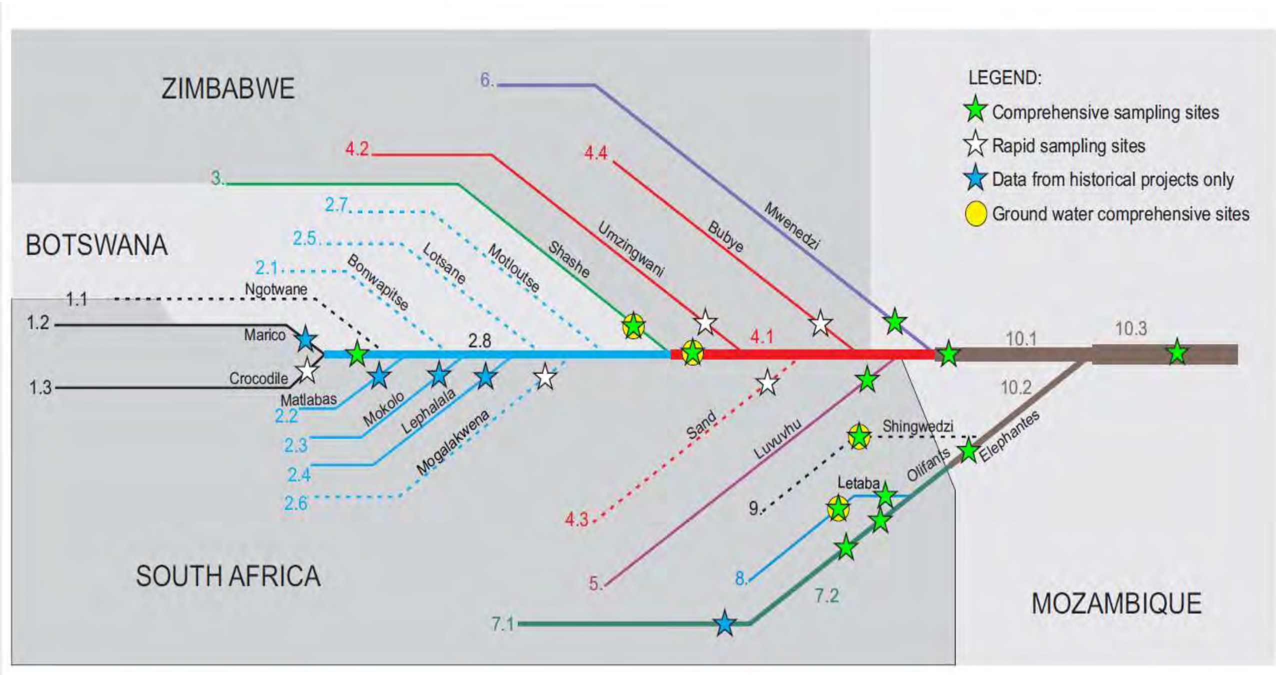


FIGURE 1 SCHEMATIC SHOWING RISK REGIONS, SUB-REGIONS AND SITES IN THE LIMPOPO RIVER BASIN

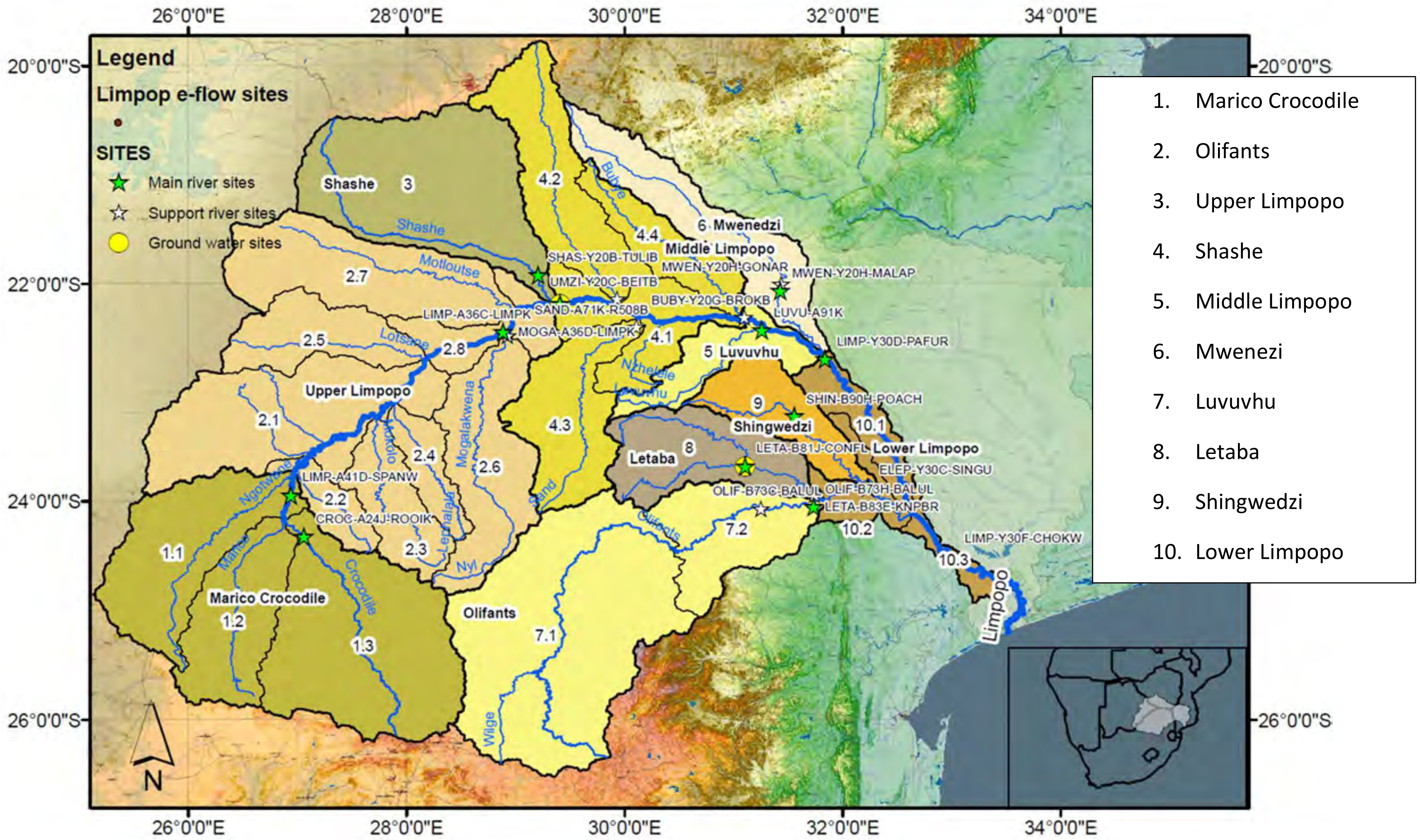


FIGURE 2 RISK REGIONS AND SITES IN THE LIMPOPO BASIN.

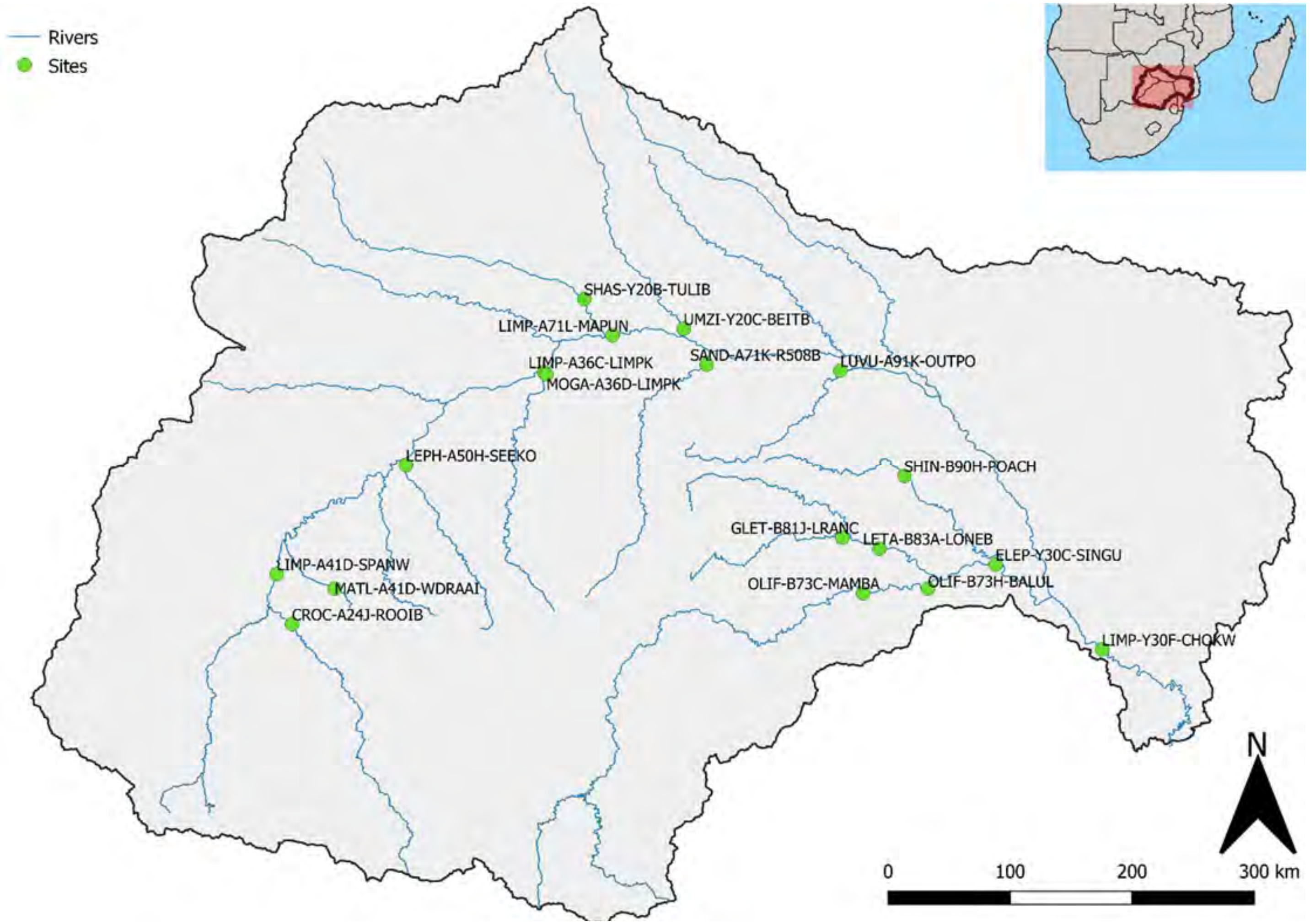


FIGURE 3 MAP OF SELECTED E-FLOW SITES

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

Name	Description	Latitude	Longitude	Type	Water quality	Ecotox	Geo-morph	Hydraulic cross-sections	Vege-tation	Macro-inverts	Fish
CROC-A24J-ROOIB	Crocodile River upstream of confluence with Marico River. Accessed site from Gerhard Diedericks of Rooibokkraal (+27824665697).	-24.314167	27.046139	Main	x	10	x	>2	x	x	x
LIMP-A41D-SPANW	Limpopo River at Spanwerk below confluence of Marico and Crocodile Rivers. Confluence on Limcroma Farm of Reinier Els (+27836259119)	-23.945556	26.932028	Main	x	10	x	>2	x	x	x
MATL-A41D-WDRAAII	Site located on the Wegdraai Farm of Mr. Tjaart vd Walt (+27603305369).	-24.051861	27.359639	Support	x	10	NA	1	x	x	x
LEPH-A50H-SEEKO	Accessed site on land of Mr. Petrie Gous (+27823718218) on farm. Zeekoegat farm.	-23.141278	27.885028	Support	x	10	NA	1	x	x	x
LIMP-A36C-LIMPK	Limpopo River located on Limpokwena Nature Reserve - Contact Manager Riley Bouchet (+27732584252)	-22.455194	28.901750	Main	x	10	x	>2	x	x	x
MOGA-A36D-LIMPK	Mogalakwena R. upstream of confluence with Limpopo River.	-22.473444	28.919500	Support	x	10	NA	1	x	x	x
SHAS-Y20B-TULIB	Shashe river in Zimbabwe	-21.916236	29.198356	Support	x	NA	x	1	x	x	x
LIMP-A71L-MAPUN	Site just upstream of poacher's corner in Mpaungopwe National Park.	-22.183833	29.405194	Main	x	10	x	>2	x	x	x
UMZI-Y20C-BEITB	Umzingwani river in Zimbabwe	-22.135897	29.930200	Support	x	N/A	x	1	x	x	N/A

Name	Description	Latitude	Longitude	Type	Water quality	Ecotox	Geo-morph	Hydraulic cross-sections	Vege-tation	Macro-inverts	Fish
SAND-A71K-R508B	Sand River upstream of R508B bridge from Messina to Tsipise.	-22.399278	30.099417	Support	x	10	NA	1	x	x	x
LUVU-A91K-OUTPO	Luvuvhu River in Kruger National Park below Outpost private lodge.	-22.444444	31.083444	Support	x	10	NA	1	x	x	x
SHIN-B90H-POACH	Shingwedzi River within Kruger National Park at Poachers Corner.	-23.221944	31.554917	Main	x	10	x	>2	x	x	x
OLIF-B73C-MAMBA	Olifants River within the Kruger National Park, South Africa at the Mamba Weir close to Phalaborwa in the Kruger National Park.	-24.086417	31.250944	Main	x	10	x	>2	x	x	x
OLIF-B73H-BALUL	Olifants River within the Kruger National Park, South Africa at the Balule Weir, below the Olifants River rest camp.	-24.052139	31.728778	Main	x	10	x	>2	x	x	x
GLET-B81J-LRANC	Groot-Letaba River, Letaba Ranch upstream of confluence with Klein Letaba River.	-23.677083	31.098333	Support	x	10	NA	1	x	x	x
LETA-B83A-LONEB	Letaba River upstream of the Letaba Rest Camp in the Kruger National Park, South Africa.	-23.758333	31.369972	Support	x	10	NA	1	x	x	x
ELEP-Y30C-SINGU	Elephantes river downstream of Lake Massingir	-23.875120	32.226237	Support	x	N/A	X	1	x	x	x
LIMP-Y30F-CHOKW	Limpopo river close to Chokwe in Mozambique	-24.500200	33.010400	Main	x	N/A	x	1	x	x	x

TABLE 2.3: TABLE OF GROUNDWATER SITES IN LETABA, MAPUNGUBWE AND OTHER SITES IN THE LIMPOPO RIVER BASIN

Name	Description	Latitude (degrees)	Longitude (degrees)	DGPS Elevation (mamsl)	Chemical water quality	Isotope water quality	Groundwater level
LR005B	Monitoring borehole in Letaba site, South Africa	-23.662242	31.049494	338.426	x	x	x
LR005A	Monitoring borehole in Letaba site, South Africa	-23.662259	31.049537	338.106	x	x	x
LR004A	Monitoring borehole in Letaba site	-23.669470	31.042411	340.062	x	x	x
LR004B	Monitoring borehole in Letaba site	-23.669452	31.042404	339.974	x	x	x
LF005C	Monitoring borehole in Letaba site	-23.671226	31.017840	343.487	x	x	x
LF005B	Monitoring borehole in Letaba site	-23.671310	31.017897	343.302	x	x	x
LF004A	Monitoring borehole in Letaba site	-23.677413	31.005057	346.035	x	x	x
F004B	Monitoring borehole in Letaba site	-23.677444	31.005060	346.041	x	x	x
LF003A	Monitoring borehole in Letaba site	-23.669491	31.016628	342.859	x	x	x
LF003B	Monitoring borehole in Letaba site	-23.669528	31.016554	342.932	x	x	x
LF0031A	Monitoring borehole in Letaba site	-23.666994	31.016219	345.473	x	x	x
LF0031B	Monitoring borehole in Letaba site	-23.667073	31.016258	345.143	x	x	x
LRW001	Monitoring borehole in Letaba site	-23.659268	31.048647	328.334	x	x	x
LR001B	Monitoring borehole in Letaba site	-23.661766	31.046813	338.792	x	x	x

Name	Description	Latitude (degrees)	Longitude (degrees)	DGPS Elevation (mamsl)	Chemical water quality	Isotope water quality	Groundwater level
LR001A	Monitoring borehole in Letaba site	-23.661756	31.046796	338.850	x	x	x
LR0011A	Monitoring borehole in Letaba site	-23.662939	31.045913	338.538	x	x	x
LR0011B	Monitoring borehole in Letaba site	-23.662921	31.045933	338.485	x	x	x
LR002B	Monitoring borehole in Letaba site	-23.666322	31.040492	339.600	x	x	x
LR002A	Monitoring borehole in Letaba site	-23.666301	31.040492	339.600	x	x	x
River at LR004	Letaba River near LR004 borehole	-23.668260	31.041500	328.212	x	x	x
Mahale Weir	Letaba River at Mahale Weir	-23.670178	30.990331	336.184	x	x	x
LF003 river at weir upstream of Mahale Weir	Letaba River near borehole LF003	-23.669926	31.017014	330.680	x	x	x
River at LR005	Letaba River near borehole LR005	-23.661988	31.048524	328.384	x	x	x
Pontdrift DWS borehole	DWS monitoring borehole in Mapungubwe National Park	-22.255852	29.301448	591.905	x	x	x
RW1	Borehole in Mapungubwe National Park	-22.182533	29.213067	534.584	x	x	x
Den Stat Farm John 1 BH	Borehole in a farm at edge of Mapungubwe National Park	-22.194689	29.255989	530.083	x	x	x
Forest tented camp reservoir fed by BH	Camp reservoir supplied by borehole in Mapungubwe National Park	-22.187131	29.206935	534.321	x	x	x

Name	Description	Latitude (degrees)	Longitude (degrees)	DGPS Elevation (mamsl)	Chemical water quality	Isotope water quality	Groundwater level
Rhodesdrift BSP1	Borehole in Mapungubwe National Park	-22.203798	29.175224	536.274	x	x	x
Rhodesdrift BSP 2	Borehole in Mapungubwe National Park	-22.202400	29.174202	542.043	x	x	x
Little Muck Artesian Well	Spring in Mapungubwe National Park	-22.250168	29.276597	557.618	x	x	x
SA22B	Borehole in Borehole in Mapungubwe National Park	-22.171273	29.446396	514.645	x	x	x
Vhembe Trails Camp borehole	Borehole at Vhembe Trails Camp in Mapungubwe National Park	-22.193180	29.408220	525.884	x	x	x
Poachers Corner borehole	Borehole near Limpopo River at Poachers Corner	-22.184338	29.406465	520.213	x	x	x
GD26B borehole	Borehole in Mapungubwe National Park	-22.194142	29.385017	521.181	x	x	x
A7 borehole	Borehole in Mapungubwe National Park	-22.198640	29.374950	522.558	x	x	x
V15 borehole	Borehole near Samaria in Mapungubwe National Park	-22.199057	29.348250	522.708	x	x	x
River near RW1	Limpopo River near RW1 borehole	-22.182586	29.209858	526.327	x	x	x
River at Rhodesdrift	Limpopo River site at Rhodesdrift	-22.201649	29.173485	528.691	x	x	x

Name	Description	Latitude (degrees)	Longitude (degrees)	DGPS Elevation (mamsl)	Chemical water quality	Isotope water quality	Groundwater level
River at SA22B	Limpopo River site near borehole SA22B	-22.170059	29.446237	509.816	x	x	x
River at Poachers Corner	Limpopo River site near Poachers Corner	-22.183407	29.405996	511.248	x	x	x
River at GD26B	Limpopo River site near GD26B borehole	-22.192277	29.382959	515.998	x	x	x
River at A7	Limpopo River site near A7 borehole	-22.196897	29.374507	516.265	x	x	x
River at V15	Limpopo River site near Poachers Corner	-22.196406	29.352007	518.781	x	x	x
Limpopo River (Out of current)	LIMP-A410-SPANW	-23.9447	26.9308	-	x	x	-
Crocodile (Borehole)	Rooibokkraal farm house	-24.20220	26.90809	-	x	x	-
Limpopo River	Croc and Lim confluence	-24.19082	26.87137	-	x	x	-
Limcroma camp borehole	Limcroma camp	-24.19600	26.91524	-	x	x	-
Matlabas River	MATL-A41D-WDRAAI	-24.051600	27.359200	-	x	x	-
Lephalale River	LEPH-A50H-CKO	-23.141278	27.885028	-	x	x	-

Name	Description	Latitude (degrees)	Longitude (degrees)	DGPS Elevation (mamsl)	Chemical water quality	Isotope water quality	Groundwater level
Limpokwena borehole	LIMP-A36C-LIMPK	-22.470920	28.918470	-	x	x	-
Mogalakwena River	MOGA-A36D-LIMPK (upstream)	-22.481807	28.918637	-	x	x	-
Sand River	SAND-A71K-R508B	-22.394852	30.099069	-	x	x	-
Luvuvhu River	LUVU-A91K-OUTPO	-22.429285	31.257614	-	x	x	-
Shingwedzi River	SHIN-B90H-POACH	-23.221056	31.555109	-	x	x	-
Shingwedzi (Dzombo River)	Poachers site	-23.221880	31.551870	-	x	x	-
Shingwedzi borehole	SHINGW	-23.116740	31.431260	-	x	x	-
Olifants River	OLIF-B73H-BALUL	-24.054077	31.726423	-	x	x	-
Letaba River	LETA-A81E-KNPBR	-23.943388	31.735113	-	x	x	-
Olifants River	OLIF-B73C-MAMBA	-24.066720	31.242488	-	x	x	-

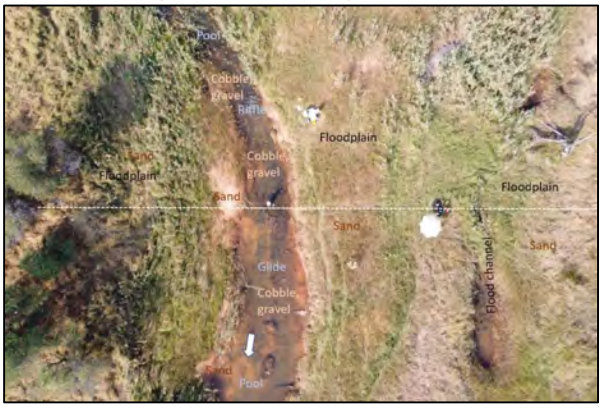
Note: LR stands for Letaba Ranch Game Reserve and LF stands for Letaba Farm for the sampling site name

2.3 SURFACE WATER SITE PHOTOGRAPHS

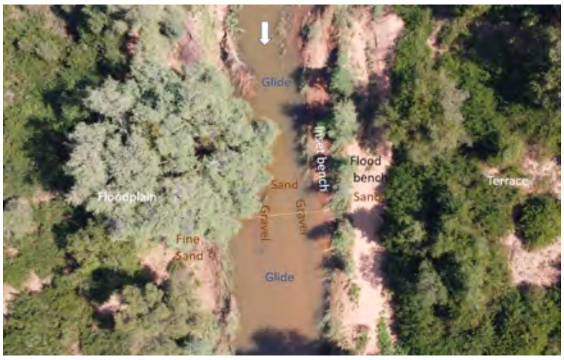
Below are aerial photographs from each site. Further pictures are shown in the various sections that follow.

Crocodile River (CROC-A24J-ROOIB)

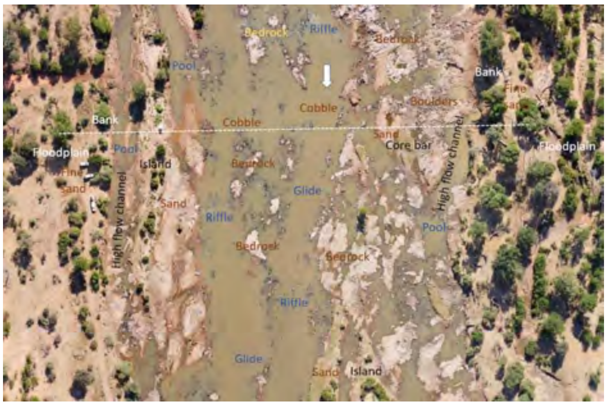
Limpopo River at Spanwerk (LIMP-A41D-SPANW)



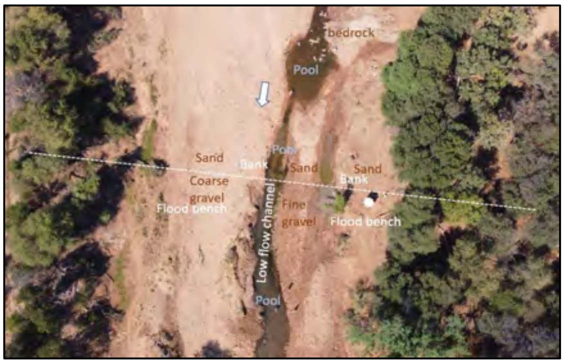
Matlabas River (MATL-A41C-WDRAA)



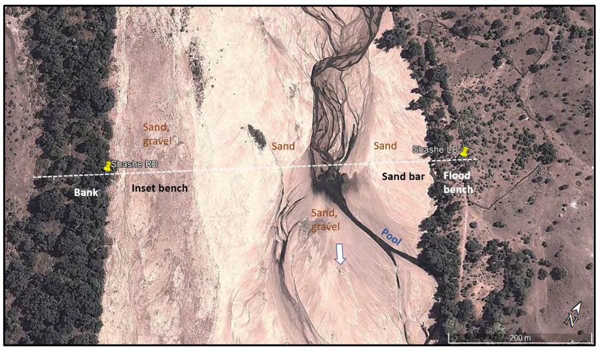
Lephalala River (LEPH-A50H-SEEKO)



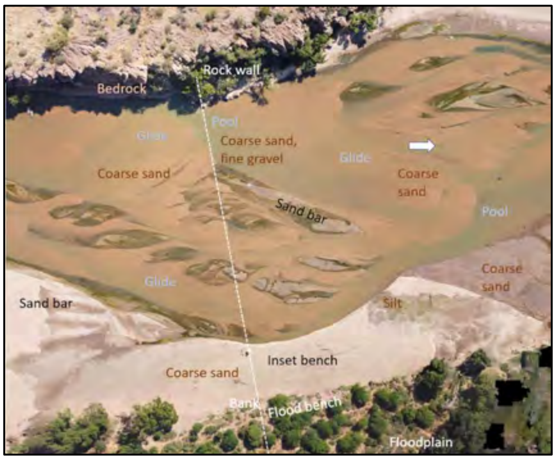
Limpopo River at Limpokwena (LIMP-A36C-LIMPK)



Mogalakwena River (MOGA-A63D-LIMPK)



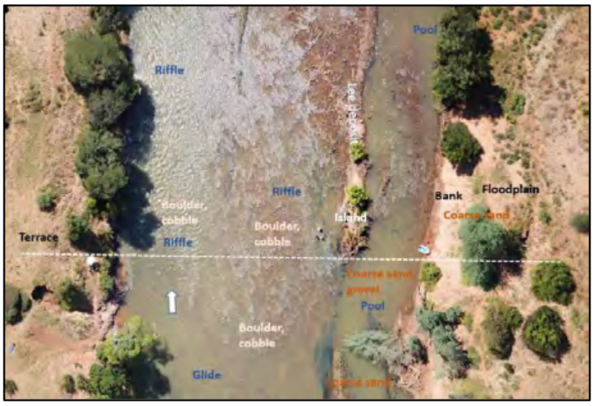
Shashe River (SHAS-Y20B-TULIB)



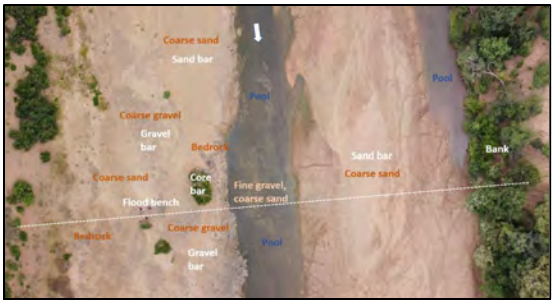
Limpopo River at Mapumgubwe (LIMP-A71L-MAPUN)

Umzingwani River (UMZI-Y20C-BEITB)

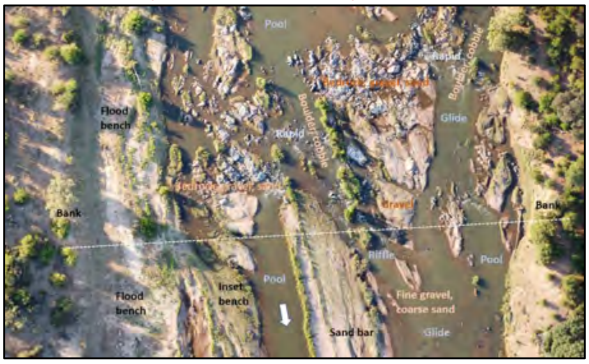
Sand River (SAND-A71K-R508B)



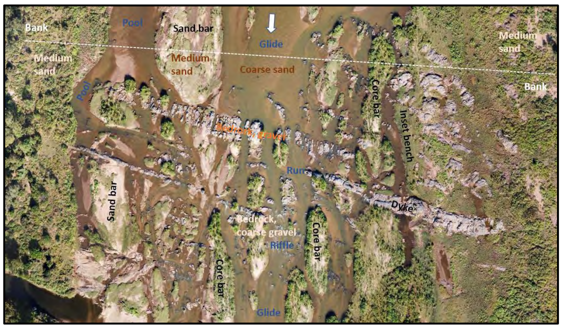
Luvuvhu River (LUVU-A91K-OUTPO)



Shingwedzi River (SHIN-B90H-POACH)



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



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

Groot Letaba River (GLET-B81J-LRANC)

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

Elefantes River at Massingir (ELEP-Y30C-SINGU)

Limpopo River at Chokwe (LIMP-Y30F-CHOK)

2.4 GROUNDWATER SITE PHOTOGRAPHS

Below are some of photographs from each site. Further photographs are shown in the various sections that follow.

Borehole sites in Letaba catchment within the Letaba Ranch Game Reserve close to LR002A and Mahale Weir

Borehole and weir site in Letaba catchment within the Letaba Ranch Game Reserve close to gauge B8H008

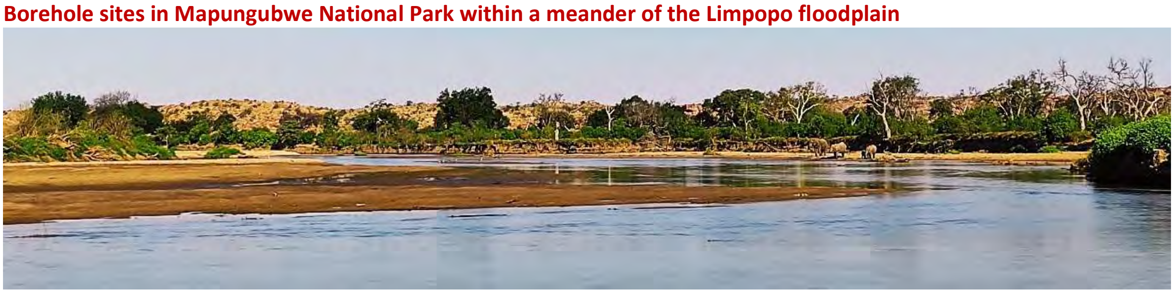
Limpopo River, upstream of Limpopo/Shashe confluence

Perennial spring in Mapungubwe National Park

Taking riverbed and water level (left) and borehole casing (right) elevation in the Limpopo River downstream of Limpopo/Shashe confluence at the beginning of the low flow season

Borehole site near Limpopo River downstream of Limpopo/Shashe confluence

Borehole sites in Mapungubwe National Park within a meander of the Limpopo floodplain



Limpopo River site upstream of Limpopo/Shashe confluence

2.5 FIELD SURVEY

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

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

2.5.1 Water Quality & Ecotoxicology

In situ water quality variables were measured at each site. Duplicate readings were taken in current and out of current. Dissolved oxygen (DO; mg/L), total dissolved solids (TDS; mg/L), pH, temperature (°C) and conductivity (µS/cm) were measured at each site during the surveys with the aid of an Extech EC500 pH/Conductivity and Extech D0600 Dissolved Oxygen meter.

Sub-surface water samples were collected in triplicate in 250 mL acid-washed polypropylene bottles. Samples were frozen and kept at -20°C until further analyses. In the laboratory, water samples were thawed and analysed using Merck photometric test kits. Samples were tested for nitrates (NO_3^{2-} as N) (09713), nitrite (NO_2^- as N) (14776), sulphate (SO_4^{2-}) (14791), turbidity (measured in NTU), chemical oxygen demand (COD) (01796), chloride (Cl-) (14897), ammonium (NH_4^+ as N) (14752) and inorganic phosphate (PO_4^{2-} as P) (14848) using a Merck Pharo 100 Spectroquant.

Defrosted water samples (50 mL) were filtered through pre-weighed cellulose nitrate filter paper (0.45 µm pore size). Filtered samples were transferred to 50 mL volumetric flasks and then acidified to 1% nitric acid using 50 µL of 65% nitric acid. Metal concentrations were determined using Inductively Coupled Plasma Mass Spectrometry (ICP-MS) (Agilent technologies, 7500CE) for the following metals Ag, Al, As, B, Ba, Ca, Cd, Co, Cu, Fe, K, Mg, Mn, Mo, Ni, Pb, Ti, Se, Sr, U, V and Zn. Chromium concentrations were measured with a PerkinElmer AAnalyst 900 graphite furnace atomic adsorption spectrophotometer (GF-AAS) equipped with Zeeman-effect background correction. All metal concentrations are expressed as mg/L and µg/L.

Ecotoxicology screening assessments for this study used liver and muscle samples collected from ten (10) Oreochromis mossambicus (Mozambique tilapia) from each site where possible. These samples will be analysed at the Northwest University for different metals accumulated in the muscle and liver tissues.

2.5.2 Geomorphology & Hydraulics

This study builds on previously surveyed sites where appropriate. Unfortunately, many of the benchmarks from the 2012 study have been lost and the channel shape has shifted, reducing the opportunity to build on the previous work. Where new sites are selected, Google Earth was used to explore the reach for sections/sites that were preferred from a hydraulics perspective. These preferably included features suitable for one-dimensional hydraulic modelling such as: simple channel cross-section; relatively straight and uniform channel reach; constant reach gradient; control feature that can be accounted for in the modelling; relatively stable channel form (this was a challenge for the sand bed rivers); critical habitat for the biota considered. These identified points and aerial images were transferred onto a GPS enabled tablet to aid with finding and deciding on sites in the field.

A single cross section was surveyed at each site in order to capture critical hydraulic habitats that are sensitive to flow. Survey benchmarks were established, and all surveys tied into these. Data gathering consisted of transect selection and demarcation, survey of the topography along the transect (perpendicular to flow); survey of water levels, energy gradient and historical flood marks; and measurement of depth and velocity along each transect as recommended by Rowlston, Jordanova and Birkhead (2008). Land based surveying was done with survey grade equipment (Total Station). For sites with deep and fast flowing water with potential wildlife dangers, a SonTek River Surveyor M9/S5 using acoustic doppler technology was used to survey the bathymetry which was tied back into the rest of the survey of the transect.

At sites where flow was deep and/or with wildlife danger, discharge was determined using the SonTek River Surveyor M9/S5 acoustic doppler profiler which also captures depth and velocity at a large number (>100) of verticals along each transect. For very shallow depths where the River Surveyor could not capture meaningful data a handheld electromagnetic OTT MFPro was used: the channel was divided into at least 20 verticals to capture depth and flow velocity data in order to calculate discharge and capture the diversity of depth-velocity classes for shallower sites (Gordon et al., 2004).

In the office, discharge, energy slope and transect data was extracted from the field observations. Roughness was calculated using the Manning's n formula based on the measured data (Gordon et al., 2004). In order to extrapolate the observed hydraulic data to other stage levels so that a continuous rating function can be determined for a wide range of discharges, 1 dimensional hydraulic modelling of higher flows was undertaken using the Manning's formula (Hirschowitz et al., 2007).

HABFLO, a 1 dimensional free-ware empirical hydraulic habitat-flow simulation model, was used to derive frequency distribution data for the various hydraulic habitats as recommended by Hirschowitz et al. (2007). HABFLO is designed to simulate flow dependent, ecologically relevant hydraulic data for Reserve determinations (Birkhead, 2010). HABFLO flow-depth frequency distribution calculations are based on the work of Lamouroux et al. (1995) and are applicable to riffle habitats. As the Limpopo river and some of its tributaries are mostly low topography sandbed rivers, the model output might have a low confidence level.

The hydraulic habitat classes were defined at a range of depths slow and fast velocities for fish and invertebrates (FIGURE 4) as recommended by Birkhead (2010).

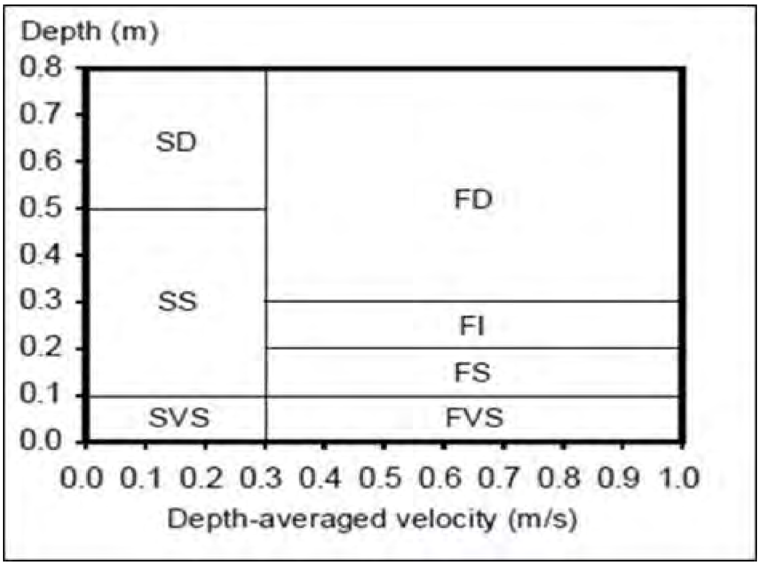


FIGURE 4: DEPTH-VELOCITY CLASSES OF HYDRAULIC HABITATS FOR FISH. FIGURE COPIED FROM BIRKHEAD (2010).

2.5.3 Groundwater

This report gives a summary of the groundwater sites sampled in May and June 2021 at locations across the Limpopo River Basin. There were two sampling campaigns involving two teams i.e. the freshwater assessment team (led by Dr. Gordon O'Brien) and the groundwater team (led by Dr. Manuel Magombeyi (IWMI). The freshwater team focused on the basin-wide water sample collection from both surface river flow (Figure 2.3) and boreholes near the river, while the groundwater team collected surface water and borehole water from Letaba and Mapungubwe sites (detail of sites is presented in Table 6.1). The samples collected during this period were taken to be representative of the wet season or low flows surface water and groundwater quality status.

Hydraulic gradients from the boreholes and rivers water levels

Hydraulic gradients from the boreholes and rivers water levels sites were assessed after taking elevations of ground surface, river water levels and borehole water levels using Differential Global Positioning System (GPS).

Mapping isolated pools in ephemeral river sections

Further work using remote sensed data to identify pools (Figure 2.5) in the ephemeral rivers was done to understand the occurrence and persistence of these pools and how they contributed to sustenance of E-flows and ecosystems during the dry season. The remote sensed data was sourced from the South Africa National Space Agency (SANSA) for the period of 2016-2021 for the whole Limpopo River Basin.

FIGURE 5 POOL NEAR LIMPOPO-SHASHE CONFLUENCE IN MAPUNGUBWE (19/11/2020)

Samples collected

Boreholes were flushed or purged by a pump until the electrical conductivity and other in-situ parameters (pH, Temperature, dissolved oxygen (DO), total dissolved solids (TDS), oxidation reduction potential (ORP) were constant, prior to sampling. The in-situ parameters were measured by a ProDSS Multiparameter Digital Water Quality Meter (https://www.ysi.com). The sample bottles were then rinsed with the sample for 3 times and then filled to capacity for isotope and chemical analysis. In-situ water quality was also collected for river water.

A total of 27 samples (19 surface water and 8 groundwater) were collected at basin-wide scale, along the Limpopo River main stem by the freshwater assessment team. The groundwater team collected a total of 43 surface water and groundwater samples from Letaba (22 samples; 4 surface and 18 groundwater) and Mapungubwe (21 samples; 8 surface and 13 groundwater) sites. Hence for the whole basin, a total of 70 samples (31 surface water and 39 groundwater) were collected to understand the interaction of groundwater and surface water.

Parameters analysed

The objective of the sampling campaign was to understand the contribution of groundwater to river surface flow or sub-surface flow in the Limpopo River Basin. The samples collected would be used to analyse the proportion of groundwater in the surface water for gaining rivers (perennial) and vice versa for losing sections of the rivers (ephemeral). Hence, the assumption is that groundwater and surface water have different signature, and this signature can be used to assess the proportion of groundwater in surface water flow. The signature can be assessed from chemical and isotope analysis of surface water flow and groundwater near the rivers.

Chemical water quality

The following anions and cations water quality parameters were selected for analysis in the laboratory:

- Total dissolved solids (TDS)
- Salinity
- Silica (SiO_2)
- Chloride (Cl-) (can be used for recharge estimations
- Sulphate (SO_2^{4-})
- Alkalinity (CO_2^{3-}; HCO_3^-)
- Calcium (Ca)
- Magnesium (Mg)
- Potassium (K)
- Sodium (Na)
- Other metals
- Isotope water quality

The oxygen-18 and deuterium analyses were used to assess the proportion of groundwater in river flow and the proportion of river water in groundwater for sections of the river that are losing water to groundwater (recharge). Tritium, especially from deep boreholes in the different sites is key in the assessments of age of water and assess the regional groundwater flow if it affects the groundwater contribution to the river and pools during the dry season.

DRIVERS OF ECOSYSTEM CHANGE

3 HYDROLOGY

Contributor: Retha Stassen

3.1 INTRODUCTION

This report is an update of the hydrological assessment undertaken for the proposed Risk Regions and e-flow sites that were selected during the initial stages of this study (see Limpopo Basin Report) and include specific results to guide the setting of the e-flows at the selected e-flow sites.

The report further includes the analysis of the long-term natural hydrological flow time series at the selected e-flow sites for the main stem Limpopo River and the major tributaries. These include basic hydrographs, flow duration curves and statistics based on monthly modelled natural flow data at the e-flows sites. 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 data from the Limpopo Reconciliation study (DWS, 2015). 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. For those e-flow sites in South Africa, where the Resource Quality Objectives (RQOs) or the Reserve were gazetted, the hydrology that was used during the studies for the gazetting, was used (see Table 3.1). No additional hydrological modelling has been undertaken for the current e-flow study, accept the scaling of flows to a specific e-flow site using catchment area.

Where daily flow data is available from gauging weirs close to the selected e-flow sites, additional information in terms of drought flows, sizes and duration of various freshets and floods have been provided to the ecologists for the setting of e-flows. It is acknowledged that the Limpopo River mainstem and tributaries have been altered substantially with the construction of numerous dams, irrigation and urban abstractions, return flows from wastewater treatment works and that the observed flows from the selected gauging weirs might not provide reference/ natural state information. However, it will provide some indication of the flows for the present state when sampling was undertaken.

Additionally, results for some of the selected e-flow sites, especially in South Africa, have been gazetted as the Reserve or Resource Quality Objectives (RQO) and are legally binding. Thus, this study will rather check for compliance with the ecological categories and flow requirements based on the sampled data, rather than setting new e-flow requirements. The rivers where requirements (Reserves/ RQOs) have been gazetted include the Crocodile (West), Marico, Matlabas, Molopo, Olifants, Letaba and Shingwedzi Rivers and will be listed as support sites. Most of the sites on these rivers have been assessed on at least an intermediate level of detail, except for the lower reaches of the Crocodile (West) and Matlabas Rivers where only desktop results were available for gazetting.

New e-flow sites were selected for these two rivers in this study to provide higher confidence results.

A general description of the catchments of the Limpopo River Basin has been provided in the Limpopo Basin report and thus no detailed discussions on this are provided in this report. However, a short description of the main activities in the upper catchments, and especially flow changes for the river reaches directly upstream of the e-flow sites, will be presented to provide the additional information to ecologists for consideration during the setting of the e-flows.

3.1.1 SELECTED E-FLOW SITES

For each of the sub-risk regions, new e-flows sites were selected and surveyed, existing e-flow sites from previous studies re-surveyed or information from previous studies was used where no new surveys were undertaken. The following table summarises the e-flow sites per sub-risk region.

TABLE 3.1. SUMMARY OF SELECTED E-FLOW SITES PER RISK REGIONS AND HYDROLOGICAL ASPECTS IN THE LIMPOPO RIVER BASIN

RR	RIVER	Hydrology SITE NUMBER	OLD NUMBER	COORDINATES	nMAR (106m3)	GAUGING WEIR	COMMENTS
RR1	1.1 Ngotwane	Lim_EF01		Confluence with Limpopo	91.99		Use LIMCOM, 2013 hydrology (1920-2010)
	1.2 Marico	Lim_EF02	MAR_EWR4	-24.7060; 26.4240	153.71	A3H007	Use intermediate Reserve, 2013 hydrology (1920-2006)
	1.3 Crocodile (West)	Lim_EF03		-24.3142; 27.0461	595.85	A2H128	Use LIMCOM, 2013 hydrology (1920-2010) adjusted to e-flow site
RR2	2.1 Bonwapitse	Lim_EF04		Confluence with Limpopo	80.68		Use LIMCOM, 2013 hydrology (1920-2010)
	2.2 Matlabas	Lim_EF05		-24.0519; 27.3596	35.28	A4H004	Use LIMCOM, 2013 hydrology (1920-2010) adjusted to e-flow site
	2.3 Mokolo	Lim_EF06	MOK_EWR4	-23.7712; 27.7553	182.22	A4H013	Use LIMCOM Recon strategy, 2015 hydrology (1920-2010) adjusted to e-flow site
	2.4 Lephalale	Lim_EF07		-23.1413; 27.8850	142.23	A5H008	Use Recon strategy, 2015 hydrology (1920-2010) adjusted to e-flow site
	2.5 Lotsane	Lim_EF08		Confluence with Limpopo	34.80	Gauge 3321	Use LIMCOM, 2013 hydrology (1920-2010)
	2.6 Mogalakwena	Lim_EF09		-22.4734; 28.9195	242.55	A6H035	Use Recon strategy, 2015 hydrology (1920-2010) adjusted to e-flow site
	2.7 Motloutse	Lim_EF10		Confluence with Limpopo	125.46		Use LIMCOM, 2013 hydrology (1920-2010)
	2.8 Limpopo to Lotsane confluence	Lim_EF11	LmEWR01 (Spanwerk)	-23.9456; 26.9320	591.49		Use LIMCOM, 2013 hydrology (1920-2010)
	2.9 Limpopo – Lotsane to Shashe	Lim_EF12	Limpokwena	-22.4552; 28.9018	801.39		Use LIMCOM, 2013 hydrology (1920-2010)

RR	RIVER	Hydrology SITE NUMBER	OLD NUMBER	COORDINATES	nMAR (106m3)	GAUGING WEIR	COMMENTS
RR3	3.1 Shashe	Lim_EF13		-22.0805; 29.2676	686.79	Gauge B85	Use LIMCOM, 2013 hydrology (1920-2010) adjusted to e-flow site
RR4	4.1 Limpopo – Shashe to Mzingwani	Lim_EF14	Lm_EWR02 (Mapungubwe)	-22.1838; 29.4052	1683.98	A7H004/ A7H008	Use LIMCOM, 2013 hydrology (1920-2010)
	4.2 Mmzingwani	Lim_EF15		-22.1408; 29.9384	437.81		Use LIMCOM, 2013 hydrology (1920-2010) adjusted to e-flow site
	4.3 Sand	Lim_EF16		-22.3993; 30.0994	74.19	A7H0105	Use LIMCOM Recon strategy, 2013 hydrology (1920-2010) adjusted to e-flow site
	4.4 Bubye	Lim_EF17		Confluence with Limpopo	200.30		Use LIMCOM, 2013 hydrology (1920-2010)
RR5	5.1 Luvuvhu	Lim_EF18		-22.4444; 31.0834	559.85	A9H010 & A9H012	Use LIMCOM, 2013 hydrology (1920-2010)
RR6	6.1 Mwanedzi	Lim_EF19	LmEWR03 (Malapati)	-22.0639; 31.4231	411.61	Gauge B37	Use LIMCOM, 2013 hydrology (1920-2010)
RR7	7.1 Olifants – to Blyde	Lim_EF20	Olifants_EWR11	-24.3076; 30.7857	1321.92	B7H009	Use DWS, 2017 Implementation of Reserve hydrology (1920-2004)
	7.2 Olifants – to Letaba	Lim_EF21	Olifants_EWR16 (Balule)	-24.0521; 31.7288	1918.30.41	B7H017	Use DWS, 2017 Implementation of Reserve hydrology (1920-2004)Use LIMCOM, 2013
RR8	8.1 Letaba – to Little Letaba	Lim_EF22	Letaba_EWR4 (Letaba Ranch)	-23.6771; 31.0983	441.39	B8H008	Use DWS, 2017 Implementation of Reserve hydrology (1920-200910)
	8.2 Letaba – Little Letaba to Olifants	Lim_EF23	LET2	-23.8268; 31.5906	641.62	B8H018	Use DWS, 2017 Implementation of Reserve hydrology (1920-2009)Use LIMCOM, 2013
RR9	9.1 Shingwedzi	Lim_EF24		-23.2219; 31.5549	96.0286.62	B9H003	Use DWS, 2017 Implementation of Reserve hydrology (1920-2010) adjusted to e-flow site
RR10	10.1 Limpopo – Mzingwani to	Lim_EF25	LmEWR04 (Pafuri)	-22.6953; 31.8336	2792.13		Use LIMCOM, 2013 hydrology (1920-2010)

RR	RIVER	Hydrology SITE NUMBER	OLD NUMBER	COORDINATES	nMAR (106m3)	GAUGING WEIR	COMMENTS
	10.2 Elephantes	Lim_EF26		-23.8751; 32.2262	2552.03711.6 6		Use LIMCOM, 2013 hydrology (1920-2010) adjusted to e-flow site
	10.3 Limpopo – to estuary	Lim_EF27	LmEWR07 (Chokwe)	-24.5002; 33.0104	5572.09		Use LIMCOM, 2013 hydrology (1920-2010)

3.2 MAIN WATER USES PER RISK REGIONS

The main water uses per risk region is listed in the table below (Table 3.2). These are the major water uses, especially those just upstream of the e-flow sites that changes the flow characteristics at the sites.

TABLE 3.2 MAJOR WATER USES PER RISK REGION IN THE LIMPOPO RIVER BASIN

Risk region	rivers	major water uses
RR1	1.1 Ngotwane	The Ngotwane is naturally a seasonal system with very low to no flows during the drier months and large floods during summer. Water use in upper catchment for urban, mining and irrigation with two dams, namely Gaborone (FSC = 141.4 MCM) and Bokaa (FSC = 18.5 MCM). Significant transmission losses in the lower reaches of the river.
	1.2 Marico	The Marico is naturally a perennial system with large quantities of dolomitic water in the upper reaches. The Molatedi Dam (FSC = 200.95 MCM) on the lower reaches release water to the Twasa Weir for irrigation downstream at Derdepoort. Water can also be transferred to Botswana if required.
	1.3 Crocodile (West)	The Crocodile (West) is naturally a perennial system. Water use is extensive in the upper reaches for urban and industrial. Large WWTW also release water into the rivers after treatment. A number of large dams are situated on the main stem as well as major tributaries, with the larger dams the Hartbeespoort (FSC = 194.8 MCM), Roodekopjes (FSC = 102.61 MCM), Vaalkop (FSC =55.3 MCM), Roodeplaat (FSC = 43.57 MCM) and Klipvoor (FSC = 42.4 MCM). Water is released from these dams for domestic, industrial and irrigation purposes. There are no major dams in the lower reach of the Crocodile (West) River, but extensive irrigation occurs, both from the river and aquifers.
RR2	2.1 Bonwapitse	The river is naturally an ephemeral system with no significant water uses. Significant transmission losses in the lower reaches of the river.
	2.2 Matlabas	The upper reaches of the Matlabas is naturally a perennial system, but the lower reaches can be dry during dry periods. Water use is mainly small dams for livestock and game watering with small areas of irrigation.
	2.3 Mokolo	The Mokolo River is naturally a perennial system.

Risk region	rivers	major water uses
		The Mokolo Dam (FSC = 146.0 MCM) in the middle reaches of the river provides water for extensive irrigation downstream.
	2.4 Lephalale	This river is naturally a perennial system. Extensive irrigation occurs in the upper and middle reaches with numerous small dams on the main stem river and tributaries.
	2.5 Lotsane	The river is naturally an ephemeral to episodic river with long periods of no flow and large floods. The Lotsane Dam (FSC = 40.0 MCM) is situated in the middle reaches with the purpose to supply urban water. Significant transmission losses in the lower reaches of the river.
	2.6 Mogalakwena	This system is naturally a perennial system. Extensive irrigation occurs in the system from numerous small dams and a few larger dams namely Doorndraai (FSC = 44.2 MCM), Rooiwal (FSC = 6.81 MCM) and Glen Alpine (FSC = 19.95 MCM).
	2.7 Motloutse	The river is naturally ephemeral with no flows for a large percentage of time during the low flow month and larger floods during the wet months. Water use is mainly by the mining sector A number of large dams are situated on the river, with the Letsibogo (FSC = 100.0 MCM) and Thune (FSC = 90.0 MCM) dams the main source of water. Significant transmission losses in the lower reaches of the river.
	2.8 Limpopo to Lotsane confluence	This reach of the Limpopo River is naturally perennial. The Crocodile, Marico, Ngotwane, Matlabas Bonwapitse, Mokolo and Lephalale contributes to the flows in this reach. Most of the water uses occur in the tributaries with some irrigation from the main stem. Significant transmission losses and alluvial storage in this reach of the river.
	2.9 Limpopo – Lotsane to Shashe	This reach of the Limpopo River is naturally perennial. The Mogalakwena, Lotsane and Motloutse contributes to the flow s in this reach of the Limpopo. Some abstractions for irrigation from the main stem. Significant transmission losses and alluvial storage in this reach of the river.
RR3	3.1 Shashe	The Shashe is naturally an ephemeral system, especially in the lower reaches with no flows during most of the winter months. A number of large dams for urban water supply are present in this catchment with the largest urban user Francistown.

Risk region	rivers	major water uses
		The larger dams are the Shashe Dam (FSC = 87.9 MCM), Ntimbale (FSC = 26.4 MCM) and the Dikgathong (FSC = 400.0 MCM). These dams are mostly for urban water use within the catchment, but water is also transferred to other catchments. Significant transmission losses and alluvial storage in the lower reaches of the river.
RR4	4.1 Limpopo – Shashe to Mzingwani	This reach of the Limpopo River is naturally perennial. The Shashe is the only major tributary of the Limpopo in this reach. Abstractions for extensive irrigation occurs in this reach. Significant transmission losses and alluvial storage in this reach of the river.
	4.2 Mmzingwani	The river is naturally ephemeral with almost no flows during the low flow months and larger floods during the wet months. A large number of dams, including the Mzingwane Dam (FSC = 42.1MCM) occur within this catchment, mostly for urban (Bulawayo and others) and irrigation demands. Significant transmission losses and alluvial storage in the lower reaches of the river.
	4.3 Sand	The Sand River is naturally a seasonal to ephemeral system. A number of dams (Houtrivier, FSC = 6.93 MCM; Turfloop, FSC = 3.35 MCM; Dikgale, FSC = 8.25 MCM) are situated within the catchment for mainly irrigation demands.
	4.4 Bubye	The river is naturally ephemeral with almost no flows during the low flow months and larger floods during the wet months. No major dams in the catchment, but a number of smaller dams mainly for irrigation purposes. Significant transmission losses and alluvial storage in the lower reaches of the river.
RR5	5.1 Luvuvhu	The Luvuvhu River is naturally a perennial system. Water uses include afforestation in upper reaches of the catchment, irrigation and domestic. A number of large dams are in the catchment, including Albasini (FSC – 28.3 MCM), Vondo (FSC = 30.3 MCM) and Nandoni (FSC = 164.0 MCM).
RR6	6.1 Mwanedzi	This river is naturally ephemeral with almost no flows during the low flow months and large floods during summer. The main water uses are irrigation and domestic. The Manyuchi Dam is the largest in the catchment (FSC = 309.0 MCM). Significant transmission losses and alluvial storage in the lower reaches of the river.
RR7	7.1 Olifants – to Blyde	The Upper Olifants River is naturally perennial with a number of large tributaries contributing to the flows, including Little Olifants, Elands, Wilge and Steelpoort as the larger rivers.

Risk region	rivers	major water uses
		Large dams in the upper catchments for irrigation, mining and urban water supply include Middleburg (FSC = 47.9 MCM), Bronkhorstspruit (FSC = 58.0 MCM), Witbank (FSC = 104.0 MCM), Loskop (FSC = 374.3 MCM), Mkhombo (FSC = 206.0 MCM), Flag Boshielo (FSC = 347.6 MCM) and De Hoop (FSC = MCM). Water is also transferred from Flag Boshielo Dam to neighbouring catchments for domestic water supply.
	7.2 Olifants – to Letaba	The river is natural perennial. The Blyde River contributes the largest percentage of flow to the lower Olifants River with smaller tributaries (Ga-Selati, Klaserie). No major dams are in the main stem river, with the Blyderivierspoort Dam the largest (FSC = 54.6 MCM) on tributaries. A number of smaller dams and weirs are in some of the other smaller tributaries. A major abstraction from the Olifants River is just downstream of the Ga-Selati confluence.
RR8	8.1 Letaba – to Little Letaba	The river is natural perennial. Extensive forestry and irrigation together with urban and industrial water use in the upper catchment. Major dams include the Ebenezer (FSC = 70.0 MCM) and Tzaneen (FSC = 157.3 MCM) and few smaller dams in tributaries.
	8.2 Letaba – Little Letaba to Olifants	The river is natural perennial. Tributaries contributing most to the flows in the lower Letaba are the Middle and Little Letaba rivers. Lorna Dawn (FSC = 11.7 MCM), Middle Letaba (FSC = 173.1 MCM) and Nsami (FSC = 29.5 MCM) are the major dams on tributaries in the lower Letaba. No major dams are situated on the main stem Letaba. Some forestry and irrigation abstractions are present in this catchment.
RR9	9.1 Shingwedzi	This river is naturally seasonal to perennial in the upper reaches where the e-flow site is situated. The lower reaches (especially in Mozambique) is ephemeral with almost no flows year round and large floods during summer. Abstractions for irrigation and domestic water use occur outside the KNP with the Makulele Dam the largest (FSC = 13.0 MCM). Significant transmission losses and alluvial storage in the lower reaches of the river.
RR10	10.1 Limpopo – Mzingwani to Mwanedzi	This reach of the Limpopo River is naturally perennial. The major tributaries contributing to flow in this reach are the Mzingwani, Nzhelele, Sand, Bubye, Luvuvhu and Mwanedzi. Very little water use occurs from the main stem river. Significant transmission losses and alluvial storage in this reach of the river.
	10.2 Elephantes	The Elephantes is naturally a perennial system.

Risk region	rivers	major water uses
		The Massingir Dam (FSC = 2840 MCM) is situated at the top of this reach and releases water for irrigation purposes in Mozambique. Significant transmission losses and alluvial storage in the lower reaches of the river.
	10.3 Limpopo – to estuary	This reach of the Limpopo River is naturally perennial. Major tributaries in this reach are the Elephantes and Changane (mainly a large wetland system). Water use is mainly abstractions for extensive irrigation in the lower reaches of the Limpopo River. Significant transmission losses and alluvial storage in this reach of the river.

3.3 FLOW STATISTICS AT E-FLOW SITES

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

Baseflow separation has been undertaken at each of the e-flow sites based on the natural flow time series, 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.

A variability index (CV_Index) was also calculated at each of the e-flow sites to get an indication of the seasonal, perennial or ephemeral character of the rivers. 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). A CV_Index between 1 and 4 indicates a perennial system, 5 a seasonal and >6 an ephemeral system.

The table below (Table 3.3) presents the natural and present day mean annual runoff (nMAR) and the calculated CV_Index at each e-flow site.

TABLE 3.3 SUMMARY OF NMAR AND CV_INDEX AT E-FLOW SITES IN THE LIMPOPO BASIN

Risk region	Rivers	E-flow site	MAR ($10^6 m^3$)		CV_Index	
			Natural	Present day	Natural	Present day
RR1	Ngotwane	Lim_EF01	92	62	5	10
	Marico	Lim_EF02	154	24	2	6
	Crocodile (West)	Lim_EF03	596	399	2	5
RR2	Bonwapitse	Lim_EF04	81	81	11	11
	Matlabas	Lim_EF05	40	39	3	3

Risk region	Rivers	E-flow site	MAR ($10^6 m^3$)		CV_Index	
			Natural	Present day	Natural	Present day
	Mokolo	Lim_EF06	182	144	5	10
	Lephalale	Lim_EF07	142	82	2	7
	Lotsane	Lim_EF08	35	22	10	10
	Mogalakwena	Lim_EF09	243	125	2	4
	Motloutse	Lim_EF10	125	86	8	8
	Limpopo to Lotsane confluence	Lim_EF11	591	373	2	3
	Limpopo – Lotsane to Shashe	Lim_EF12	801	523	2	2
RR3	Shashe	Lim_EF13	687	513	9	9
RR4	Limpopo – Shashe to Mzingwani	Lim_EF14	1684	1201	2	4
	Mzingwani	Lim_EF15	438	261	7	7
	Sand	Lim_EF16	74	40	7	14
	Bubye	Lim_EF17	200	187	11	12
RR5	Luvuvhu	Lim_EF18	560	455	2	2
RR6	Mwanedzi	Lim_EF19	412	332	11	11
RR7	Olifants – to Blyde	Lim_EF20	1322	568	2	2
	Olifants – to Letaba	Lim_EF21	1918	947	2	3
RR8	Letaba – to Little Letaba	Lim_EF22	441	196	2	4
	Letaba – to Olifants	Lim_EF23	642	371	3	3
RR9	Shingwedzi	Lim_EF24	87	84	5	5
RR10	Limpopo – Mzingwani to Mwanedzi	Lim_EF25	2792	1970	3	3
	Elephantes	Lim_EF26	2552	1236	2	2
	Limpopo – to estuary	Lim_EF27	5572	3325	3	2

It can be seen from the table that a number of systems are naturally ephemeral, especially those in Botswana. It should be noted that this index was calculated for the flows at the e-flow sites that are mostly situated in the lower reaches of the rivers. Thus, some systems might still be perennial or seasonal in the upper reaches.

The detailed statistics and monthly seasonal distribution graphs and flow duration curves are available electronically for interpretation with the setting of the e-flows.

3.4 CONCLUSIONS

Adequate hydrological data is available for the Limpopo Basin and the major tributaries from the 2013 Limpopo Monograph and 2015 Limpopo North Reconciliation Strategy studies. Although these two data sets cover the same record periods (1920-2010), the natural MARs simulated are different as the rivers included in the Reconciliation Strategy (Matlabas, Mokolo, Lephalala, Mogalakwena, Sand and Nzhelele) have been studied in detail, including extensive calibration of the flows at selected gauging weirs.

Thus, without a combined hydrological model to incorporate these new flow time series from the tributaries, the nMAR for the mainstem Limpopo River as simulated during the 2013 LIMCOM study will not reflect any changes in MAR.

For the support e-flow sites (those where the Reserve and RQOs have been gazetted), flow data from the original Reserve studies were used (see comments in Table 2).

3.5 HYDROLOGY REFERENCES

DWS (2015). Limpopo Water Management Area North Reconciliation Strategy – Hydrological Analysis

Hughes DA & Munster F (1999). A decision support system for an initial “low confidence” estimate of the quantity component of the Reserve for rivers. Unpublished Report, Institute for Water Research, Rhodes University. pp. 32.

Hughes DA, Hannart P and Watkins D (2002). Continuous baseflow separation from time series of daily and monthly streamflow data. Institute for Water Research, Rhodes University, PO Box 94, Grahamstown 6140, South Africa

Hughes, DA and Hannart, P. 2003. A desktop model used to provide an initial estimate of the ecological instream flow requirements of rivers in South Africa. Journal of Hydrology 270 (2003) 167–181.

Limpopo River Basin Monograph (2013) – Surface Water Hydrology. LIMCOM with support of GIZ.

Smakhtin, VU. 2001. Estimating continuous monthly baseflow time series and their possible applications in the context of the ecological reserve. ISSN 0378-4738 = Water SA Vol. 27 No. 2 April 2001.

4 HYDRAULICS AND GEOMORPHOLOGY

Contributor: Benjamin van der Waal

4.1 INTRODUCTION

This report presents the hydraulics for 21 sites across the Limpopo Basin for the determination of environmental flows. The methods used, cross sections, site description and data output are presented.

4.2 METHODOLOGY

This study builds on previously surveyed sites where appropriate. Unfortunately, many of the benchmarks from the 2012 study have been lost and the channel shape has shifted, reducing the opportunity to build on the previous work. Where new sites are selected, Google Earth was used to explore the reach for sections/sites that were preferred from a hydraulics perspective. These preferably included features suitable for one-dimensional hydraulic modelling such as: simple channel cross-section; relatively straight and uniform channel reach; constant reach gradient; control feature that can be accounted for in the modelling; relatively stable channel form (this was a challenge for the sand bed rivers); critical habitat for the biota considered. These identified points and aerial images were transferred onto a GPS enabled tablet to aid with finding and deciding on sites in the field.

A single cross section was surveyed at each site to capture critical hydraulic habitats that are sensitive to flow. Survey benchmarks were established and all surveys tied into these. Data gathering consisted of transect selection and demarcation, survey of the topography and sediment composition along the transect (perpendicular to flow); survey of water levels, energy gradient and historical flood marks; and measurement of depth and velocity along each transect as recommended by Rowlston, Jordanova and Birkhead (2008). Land based surveying was done with survey grade equipment (Total Station). For sites with deep and fast flowing water with potential wildlife dangers, a SonTek River Surveyor M9/S5 using acoustic doppler technology was used to survey the bathymetry which was tied back into the rest of the survey of the transect.

At sites where flow was deep and/or with wildlife danger, discharge was determined using the SonTek River Surveyor M9/S5 acoustic doppler profiler which also captures depth and velocity at a large number (>100) of verticals along each transect. For very shallow depths where the River Surveyor cannot capture meaningful data, a handheld electromagnetic OTT MFPro was used: the channel was divided into at least 20 verticals to capture depth and flow velocity data to calculate discharge and capture the diversity of depth-velocity classes for shallower sites (Gordon et al., 2004).

In the office, discharge, energy slope and transect data were extracted from the field observations. Roughness was calculated using the Mannings n formula based on the measured data (Gordon et al., 2004). In order to extrapolate the observed hydraulic data to other stage levels so that a continuous rating function can be determined for a wide range of discharges, 1 dimensional hydraulic modelling of higher flows was undertaken using the Mannings formula (Hirschowitz et al., 2007).

HABFLO, a 1 dimensional free-ware empirical hydraulic habitat-flow simulation model, was used to derive frequency distribution data for the various hydraulic habitats as recommended by Hirschowitz et al. (2007). HABFLO is designed to simulate flow dependent, ecologically relevant hydraulic data for Reserve determinations (Birkhead, 2010). HABFLO flow-depth frequency distribution calculations are based on the work of Lamouroux et al. (1995) and apply to riffle habitats. As the Limpopo river and some of its tributaries are mostly low topography sandbed rivers, the model output might have a low confidence level.

The hydraulic habitat classes were defined at a range of depths slow and fast velocities for fish (Figure 4.1) as recommended by Birkhead (2010).

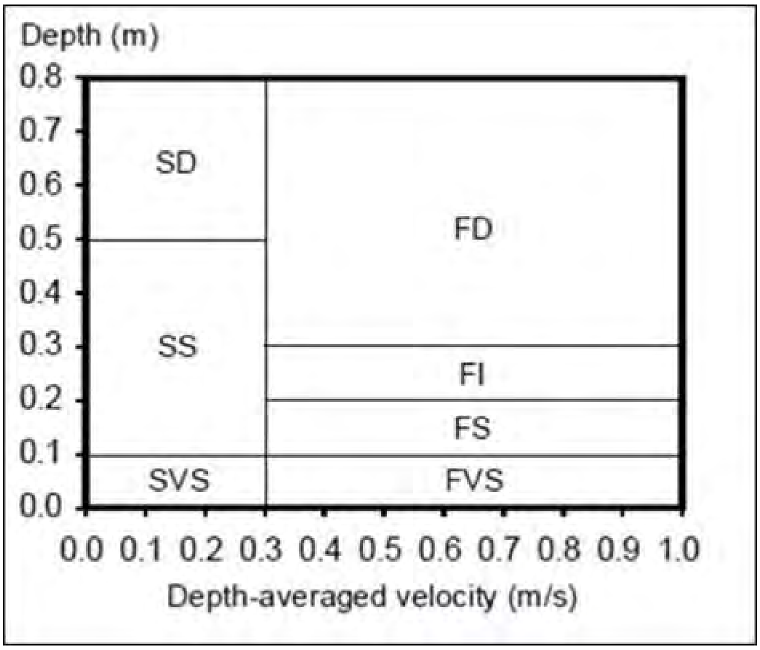


FIGURE 6: DEPTH-VELOCITY CLASSES OF HYDRAULIC HABITATS FOR FISH. FIGURE COPIED FROM BIRKHEAD (2010).

The geomorphic zones were determined based on river gradient at the site as defined by Rowntree and Wadeson (1999). Geomorphic site descriptions were done of key morphological features (benches, banks, floodplain, etc.) and physical habitats (riffles, pools, lateral sand bars, marginal zones, etc.). The embeddedness, general particle size, particle sorting and imbrication were described for each morphological feature.

Georeferenced land-based photos were taken of channel features and their sediment composition. The information was captured on air photos or satellite images for each site. Sediment from the riverbanks and river bed (key geomorphological features) were described using the Eijkelkamp Sand Ruler or in-field measurents (a sample of 100 randomly selected particles will be measured along the b-axis to determine the D16, D50 and D84 (Gordon et al., 2004)). Table 4.1 defines the particle size classes for the substrate descriptions.

TABLE 4.1: PARTICLE SIZE CLASSES FOR SITE DESCRIPTIONS (ADAPTED FROM GORDON ET AL. (2004) AND ROWNTREE (2013)).

Wentworth size class	Grain diameter (mm)	Feel or analogy
Very large boulder	2048 - 4096	Compact car
Large boulder	1024 - 2048	Small trailer
Medium boulder	512 - 1024	Wheel barrow
Small boulder	256 - 512	Day pack
Large cobble	128 - 256	Soccer ball
Small cobble	64 - 128	Coffee mug
Coarse gravel	16 - 64	Cricket ball
Medium gravel	8 - 16	Golf ball
Fine gravel	2 - 8	Pea
Coarse sand	0.5 - 2	Brown sugar
Medium sand	0.125 - 0.500	White sugar
Fine sand	0.063 - 0.125	Caster sugar
Silt	0.002 - 0.063	Silky
Clay	< 0.002	Sticky

A rapid catchment evaluation in terms of land cover was done in GIS using the South African National Land cover dataset for 2020. Sediment yield predictions were available for the South Afrcan catchments, and the data was sourced from Msadala et al. (2010).

Field surveys were conducted in 2 to 5 hours due to logistical challenges. The data reduction and hydraulic modelling and reporting had a time budget of 6 hours per site.

4.3 RESULTS

The field observations and model outputs are presented in this section. The tabulated cross sectional data and modelled hydraulic data are presented in Appendix A and B.

4.4 Site locations

The basic site information is presented in TABLE 4.2.

TABLE 4.2: SUMMARY OF THE FIELD SITES WITH SLOPE AND DISCHARGE

River/site name	Site code	Latitude	Longitude	Date	Slope	Geomorphic Zone	Discharge (m^3/s)
Crocodile	CROC-A24J-ROOIB	-24.314167	27.046139	21/04/2021	0.00034	Lowland river	7.21
Limpopo @ Spanwerk	LIMP-A41D-SPANW	-23.945556	26.932028	22/04/2021	0.00102	Lower foothills	6.59
Matlabas	MATL-A41D-WDRAAI	-24.051861	27.359639	23/04/2021	0.00136	Lower foothills	0.18
Lephalala	LEPH-A50H-SEEKO	-23.141278	27.885028	24/04/2021	0.00051	Lowland river	3.51
Limpopo @ Limpokwena	LIMP-A36C-LIMPK	-22.455194	28.901750	25/04/2021	0.00134	Lower foothills	10.04
Mogalakwena	MOGA-A36D-LIMPK	-22.473444	28.919500	26/04/2021	0.00011	Lowland river	0.0001
Shashe	SHAS-Y20B-TULIB	-22.081648	29.273501	25/07/2021	0.0011	Lower foothills	0.00
Limpopo @ Poachers Corner	LIMP-A71L-MAPUN	-22.183833	29.405194	27/04/2021	0.00102	Lower foothills	9.74
Umzingwani	UMZI-Y20C-BEITB	-22.137350	29.935554	26/07/2021	0.00125	Lower foothills	0.00
Sand	SAND-A71K-R508B	-22.399278	30.099417	28/04/2021	0.0018	Lower foothills	0.01
Luvuvhu	LUVU-A91K-OUTPO	-22.444444	31.083444	29/04/2021	0.004	Lower foothills	17.43
Mwenedzi	MWEN-Y20H-MALAP	-22.063900	31.423100	9/06/2012	0.00152	Lower foothills	0.56
Limpopo @ Pafuri	LIMP-Y30D-PAFUR	-22.695322	31.833644	12/06/2012	0.00034	Lowland river	0.637
Limpopo @ Combomune	LIMP-Y30D-COMBO	-23.471700	- 23.471700	13/06/2012	0.00046	Lowland river	0.333
Olifants @ Mamba	OLIF-B73C-MAMBA	-24.086417	31.250944	05/05/2021	0.0014	Lower foothills	8.07
Olifants @ Balule	OLIF-B73H-BALUL	-24.052139	31.728778	03/05/2021	0.00195	Lower foothills	10.67
Groot Letaba	GLET-B81J-LRANC	-23.677083	31.098333	06/05/2021	0.00152	Lower foothills	1.79

River/site name	Site code	Latitude	Longitude	Date	Slope	Geomorphic Zone	Discharge (m^3/s)
Letaba @ Lonely Bull	LETA-B83A-LONEB	-23.758333	31.369972	04/05/2021	0.0035	Lower foothills	1.66
Elephantes Below Massingir	ELEP-Y30C-SINGU	-23.875120	32.226237	09/06/2021	0.00056	Lowland river	30.29
Shingwedzi	SHIN-B90H-POACH	-23.221944	31.554917	01/05/2021	0.00011	Lower foothills	0.01
Limpopo @ Chokwe	LIMP-Y30F-CHOKW	-24.500200	33.010400	10/06/2021	0.00026	Lowland river	35.06

4.4.1 CROC-A24J-ROOIB (Crocodile)

The Crocodile River site is located along a pool riffle/glide sequence with a wandering river plan form (FIGURE 7). The channel cross section can be seen in FIGURE 8 with some site images shown in FIGURE 9. Flood debris was visible at 7.2 m on the flood plain.

FIGURE 7: ORTHOPHOTO SHOWING HYDRUALIC BIOTYPES, MORPHOLOGICAL FEATURES AND SEDIMENT COMPOSITION

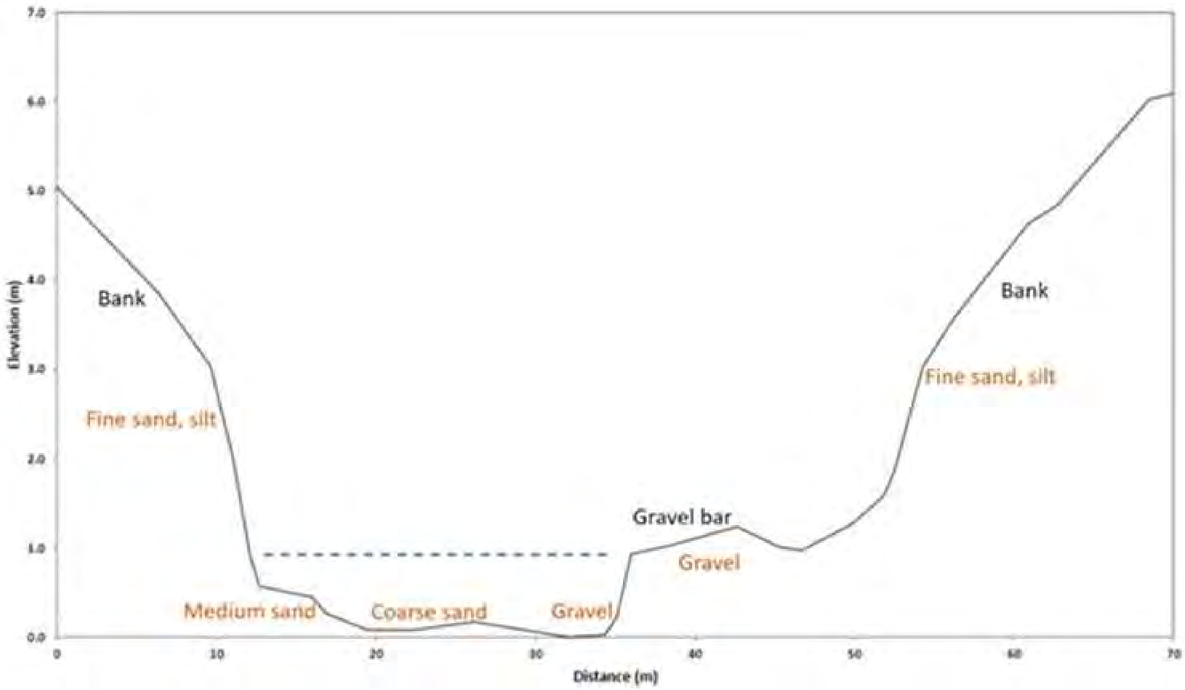


FIGURE 8 CROSS SECTION OF THE CROCODILE RIVER SHOWING THE OBSERVED WATER LEVELS, MORPHOLOGICAL FEATURES AND SEDIMENT COMPOSITION

FIGURE 9: SITE IMAGES SHOWING A) GRAVEL BAR IN THE FOREGROUND AND SAND BAR IN THE DISTANCE; B) PARTLY EMBEDDED GRAVELS; C) WELL VEGETATED BANKS; AND D) COARSE SAND AND FINE GRAVEL FROM SAND BARS.

The observed and modelled data are presented in TABLE 4.3, TABLE 4.4, FIGURE 10 and FIGURE 11.

TABLE 4.3: 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	0.0	N/A	N/A	0.000	0.000	Modelled
21-Apr-2021	0.92	0.035	0.000339	7.21	0.413	Observed
Flood 1	4	0.03	0.000339	179	1.202	Modelled

TABLE 4.4: EQUATION FOR THE RATING CURVE

Power Fit: y=axb + c	
Coefficient Data:	
a =	0.37
b =	0.457
c =	0

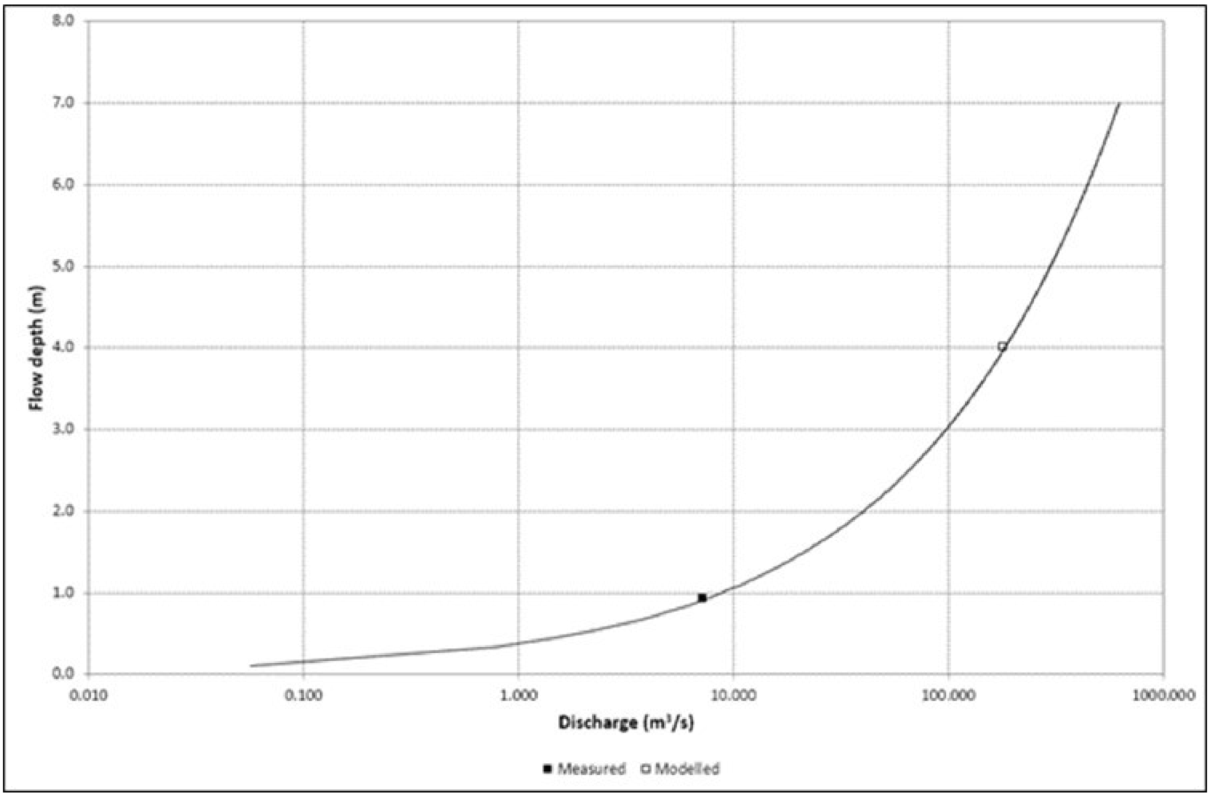


FIGURE 10: RATING CURVE FOR THE CROCODILE RIVER SITE

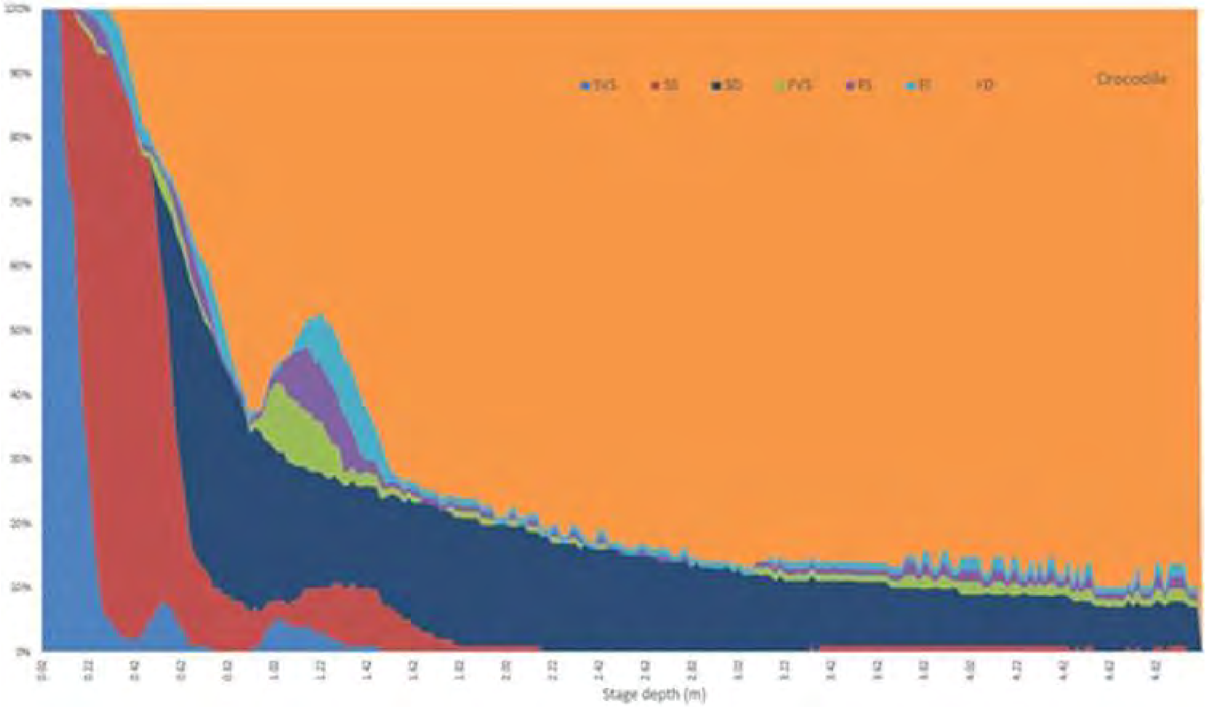


FIGURE 11: MODELLED VELOCITY DEPTH FREQUENCY DISTRIBUTIONS FOR VARIOUS MAXIMUM DEPTH LEVELS AT THE CROCODILE RIVER SITE

4.4.2 LIMP-A41D-SPANW (Limpopo at Spanwerk)

Spanwerk is situated at the end of a long pool that is dammed by a natural dyke (FIGURE 12). The river has cut multiple channels through the dyke forming an anastomosing pattern mostly on bedrock (FIGURE 12, FIGURE 13). There is a strong progression from:

- Pool with deep slow flow in a single channel and silty substrates.
- Multi channel on bedrock with rapids, runs and glides. Gravel is trapped in bedrock pockets and sandy lee deposits are located downstream of islands or higher protrusions.
- The multi channels converge to form two channels with boulder, cobble and gravel riffles.
- The two channels converge into a single channel with gravel (run) and sandy (pool) habitats.
- The banks are steep and composed of fine sand and silt (FIGURE 14).

Due to the complexity of the site and the lack of time, the modelling for 2012 was adopted as is as the observed data could not be tied together in a high confidence manner. The flood banch was 2.2 m higher than the water level and terrace 5.4m higher than the water level. No flood level recorded.

FIGURE 12: ORTHOPHOTO SHOWING MORPHOLOGICAL FEATURES AND SEDIMENT COMPOSITION OF THE LIMPOPO RIVER AT SPANWERK.

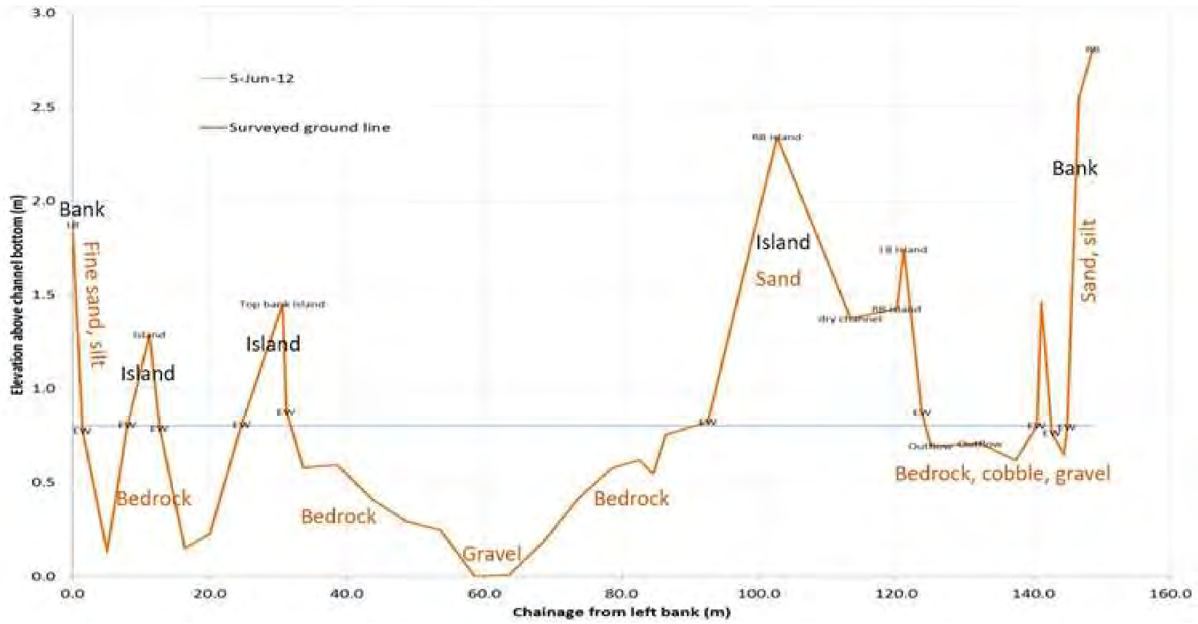


FIGURE 13: CROSS SECTION OF THE LIMPOPO AT SPANWERK SHOWING MORPHOLOGICAL FEATURES AND SEDIMENT COMPOSITION. GRAPH FROM MONOGRAPH.

FIGURE 14: SITE IMAGES SHOWING A) EMBEDED GRAVEL BAR IN THE FOREGROUND AND BEDROCK AND BOULDER SUBSTRATES; B) COHESIVE BANKS SHOWING EROSION; C) FINE GRAVEL AND COARSE SAND DEPOSITED IN THE RIFFLES; AND D) PARTLY EMBEDDED GRAVEL SUBSTRATES

The observed and modelled rating data for 2012 are presented in TABLE 4.5, TABLE 4.6, with the rating curve presented in FIGURE 15 and the velocity depth distributions presented in FIGURE 16.

TABLE 4.5: 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	0.58	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 4.6: EQUATION FOR THE RATING CURVE

Power Fit: y=axb + c	
Coefficient Data:	
a =	0.195
b =	0.352
c =	0.580

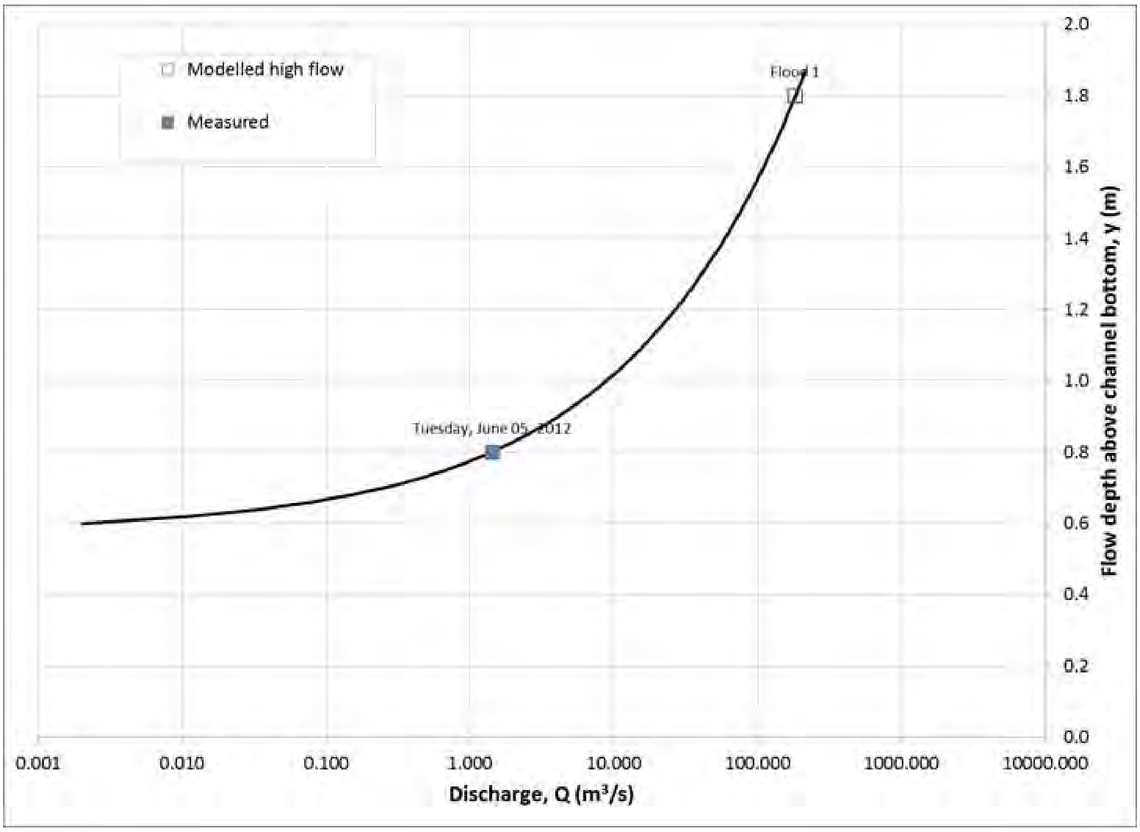


FIGURE 15: RATING CURVE FOR THE LIMPOPO RIVER AT SPANWERK SITE (FROM MONOGRAPH)

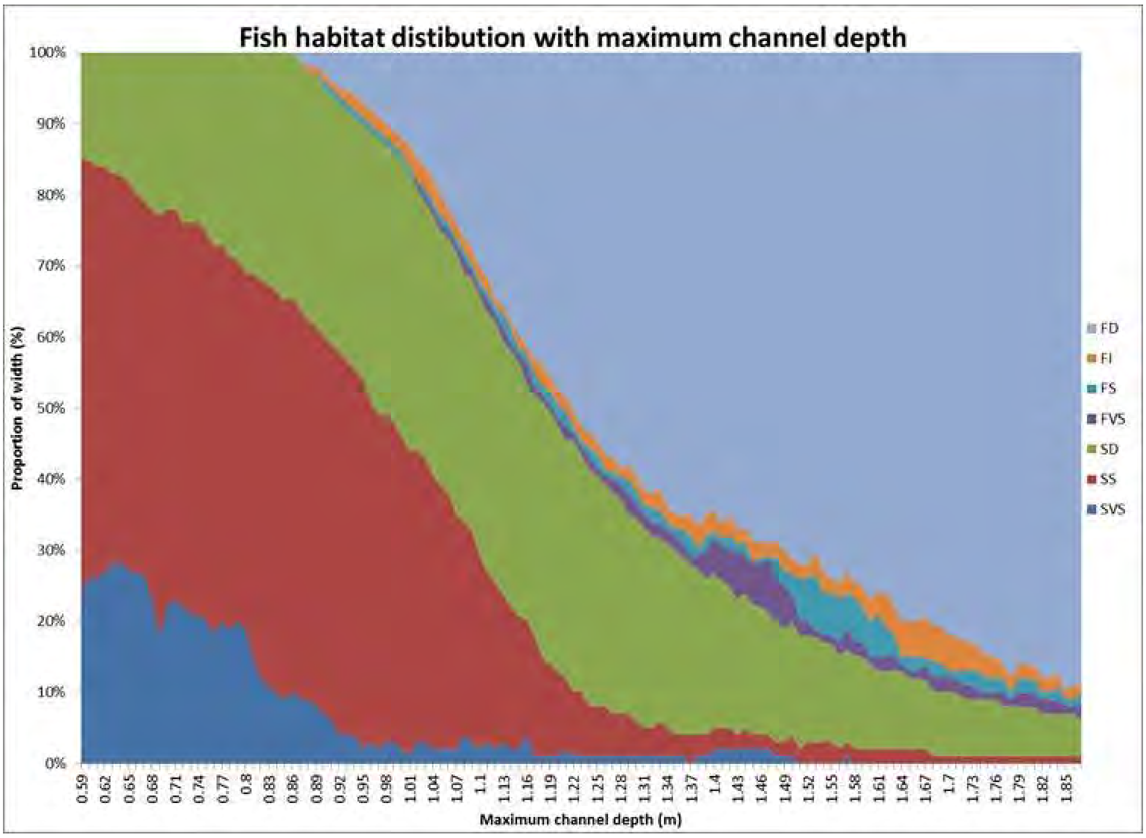


FIGURE 16: MODELLED VELOCITY DEPTH FREQUENCY DISTRIBUTIONS FOR VARIOUS MAXIMUM DEPTH LEVELS AT THE LIMPOPO RIVER SPANWERK SITE (FROM MONOGRAPH)

4.4.3 MATL-A41D-WDRAAI (Matlabas)

This relatively small river is in a good condition. The single channel follows a pool riffle section with some localised bedrock (FIGURE 17). Small cobble and gravel form the riffle areas, with sandy sections where flow velocities are lower (wider shallow sections or pool areas) (FIGURE 18). The cobbles are moderately embedded with sand and gravel, resulting in partly fixed substrates. Sandy habitats dominate upstream and downstream of the site with multiple channels, mainly high flow channels, between sandy islands (FIGURE 19). The vegetation cover is good with low evidence of trampling at the site. No flood level recorded.

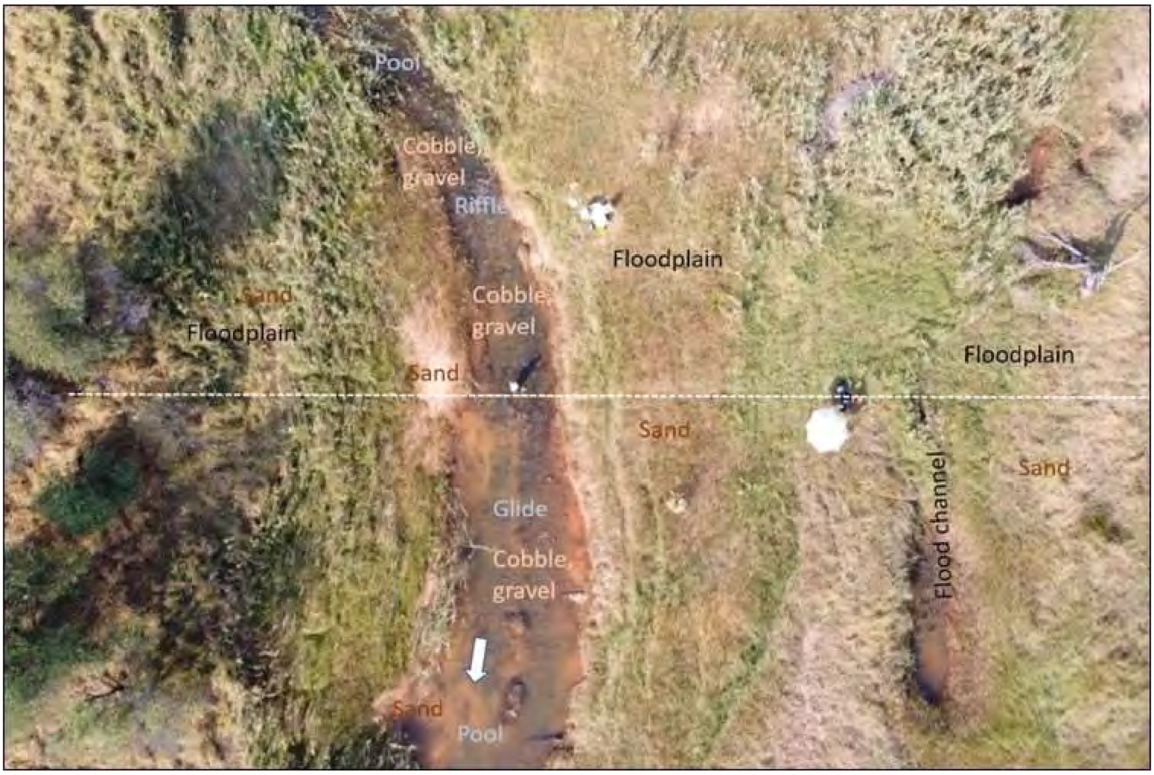


FIGURE 17: ORTHOPHOTO SHOWING MORPHOLOGICAL FEATURES AND SEDIMENT COMPOSITION OF THE MATLABAS RIVER.

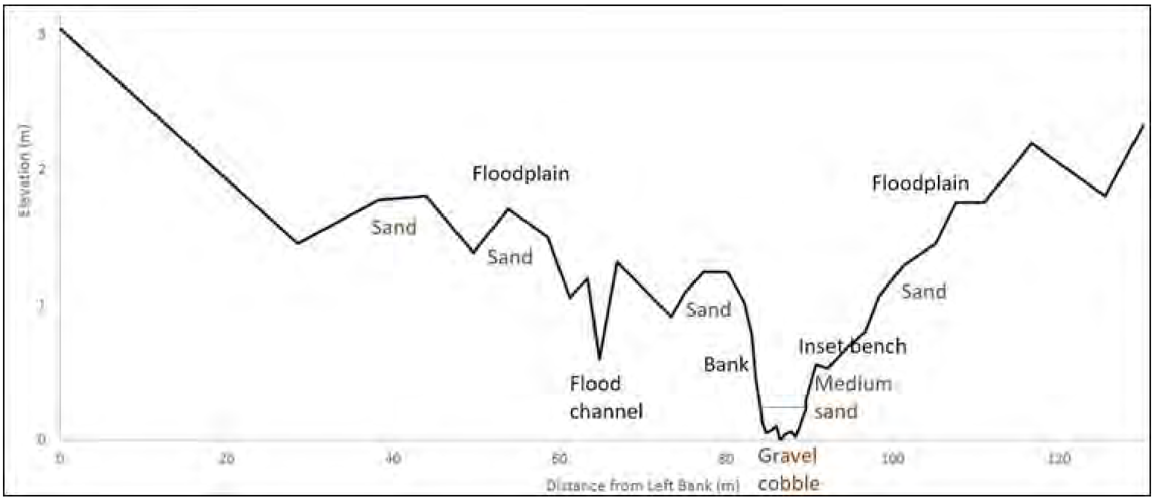


FIGURE 18: CROSS SECTION OF THE MATLABAS RIVER SHOWING MORPHOLOGICAL FEATURES AND SEDIMENT COMPOSITION.

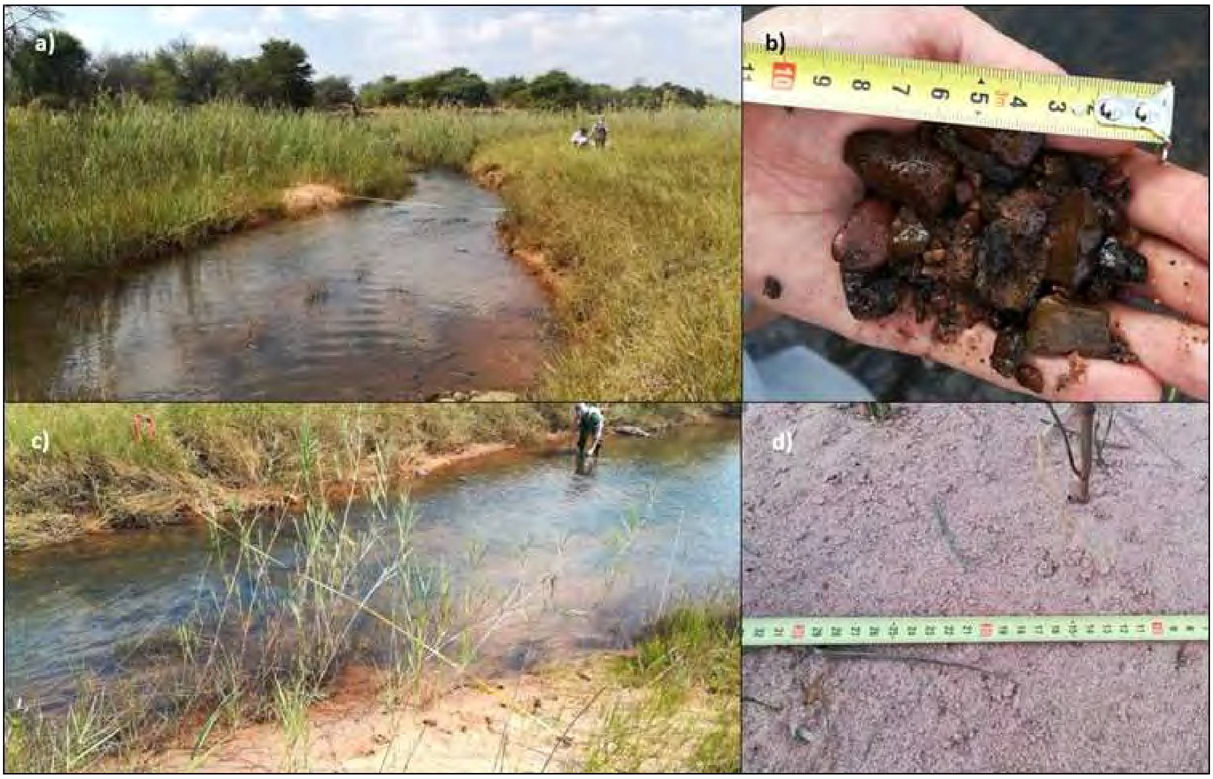


FIGURE 19: SITE IMAGES SHOWING A) AN UPSTREAM VIEW OF THE WELL VEGETATED CHANNEL; B) FINE GRAVEL FROM THE RIFFLE SECTION; C) SAND INSET BENCH ALONG RIGHT BANK; D) RECENT SAND DEPOSIT ALONG THE CHANNEL MARGIN

The observed and modelled data are presented in TABLE 4.7 and TABLE 4.8, with the rating curve presented in FIGURE 20 and the velocity depth frequency distribution presented in FIGURE 21.

TABLE 4.7: OBSERVED AND MODELLED DATA USED TO DERRIVE THE RATING CURVE

Date	Depth (m)	Mannings n	Energy gradient	Discharge (m3/s)	Velocity (m/s)	Comment
Zero flow	0.0	N/A	N/A	0.000	0.000	Modelled
21 April 2021	0.22	0.042	0.00136	0.18	0.238	Observed
Flood 1	2	0.040	0.00136	46	0.693	Modelled

TABLE 4.8: EQUATION FOR THE RATING CURVE

Power Fit: y=axb + c	
Coefficient Data:	
a =	0.427
b =	0.403
c =	0

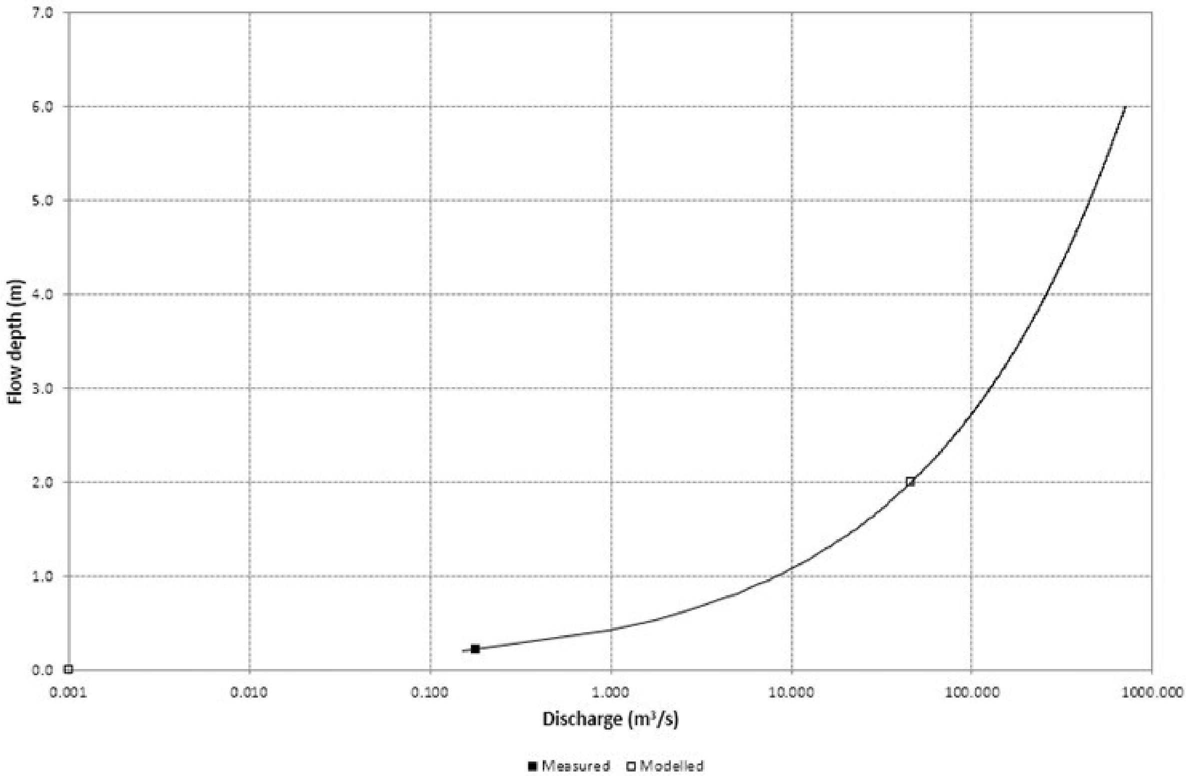


FIGURE 20: RATING CURVE FOR THE MATLABAS RIVER SITE

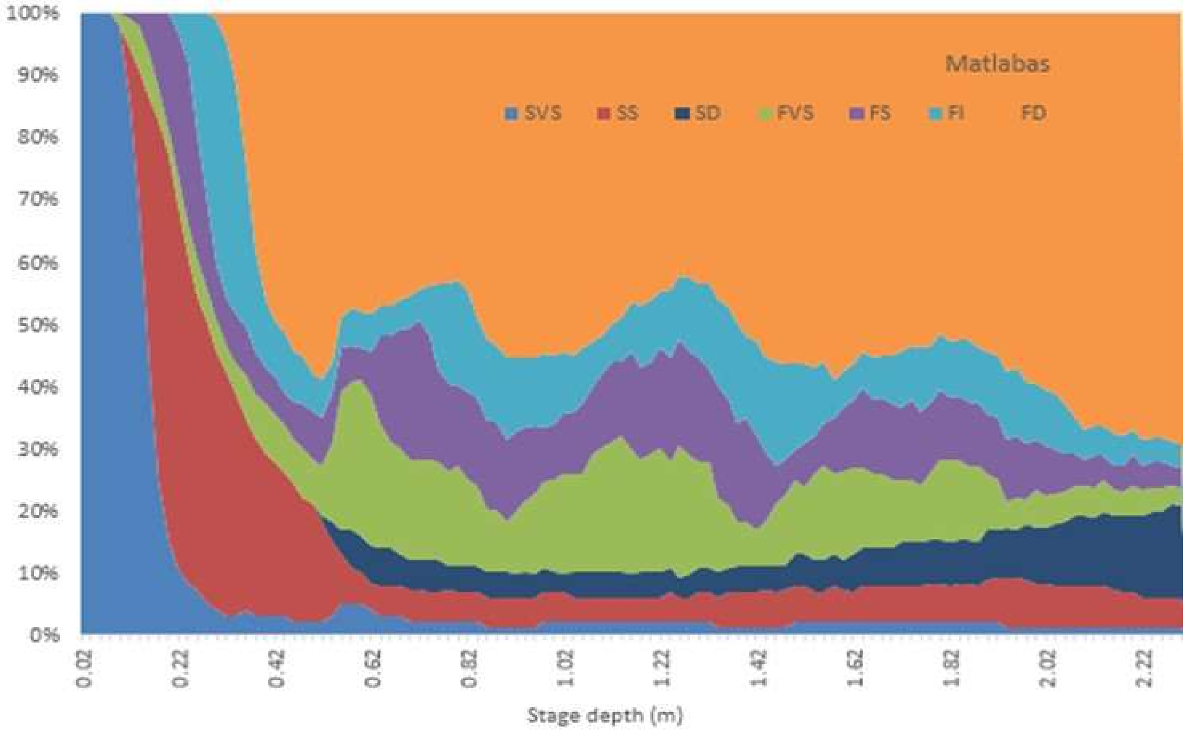


FIGURE 21: MODELLED VELOCITY DEPTH FREQUENCY DISTRIBUTIONS FOR VARIOUS MAXIMUM DEPTH LEVELS AT THE MATLABAS RIVER SITE

4.4.4 LEPH-A50H-SEEKO (Lephalala)

The site is situated along a sandy reach immediately downstream of a steep bedrock section with a weir and bridge. It has a single channel with inset benches, flood benches and a high floodplain/terrace (FIGURE 22, FIGURE 23). The bed consists mostly of fine gravel and coarse sand (FIGURE 24). Narrow elongated medium gravel bars form in the channel and provide anchor to reeds. The Banks are composed of fine sand and silt, with recent medium grained sand deposits on the flood benches. There is evidence of recent high flows with extensive sand deposits and flood debris on flood prone areas. Shallow sandy pools are likely at low flow, with deeper pools associated with bedrock sections. The observed flow was mostly a glide type due to the largely uniform bed structure. Flood debris surveyed at 6.8m.

Some bank erosion is evident around exposed tree roots on near vertical banks and associated with the recent floods.

FIGURE 22: ORTHOPHOTO SHOWING MORPHOLOGICAL FEATURES AND SEDIMENT COMPOSITION OF THE LEPHALALA RIVER.

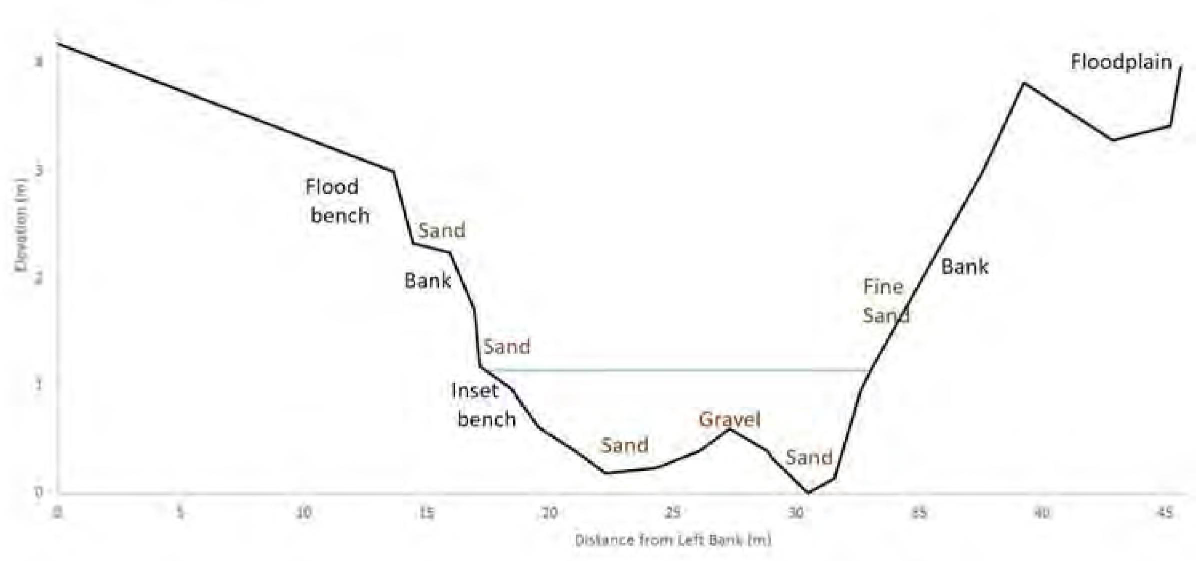


FIGURE 23: CROSS SECTION OF THE LEPHALALA RIVER SHOWING MORPHOLOGICAL FEATURES AND SEDIMENT COMPOSITION.

FIGURE 24: SITE IMAGES SHOWING A) VIEW OF THE CHANNEL FROM THE RIGHT BANK; B) GRAVEL FROM ELONGATED GRAVEL BARS; C) CHANNEL VIEW FROM LEFT BANK; D) RECENTLY DEPOSITED SAND FROM FLOOD BENCH

TABLE 4.9: 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	0.0	N/A	N/A	0.000	0.000	Modelled
24-Apr-2021	0.96	0.037	0.00051	3.5	0.422	Observed
Flood 1	3	0.035	0.00051	46	0.971	Modelled

TABLE 4.10: EQUATION FOR THE RATING CURVE

Power Fit: y=axb + c	
Coefficient Data:	
a =	0.55
b =	0.443
c =	0

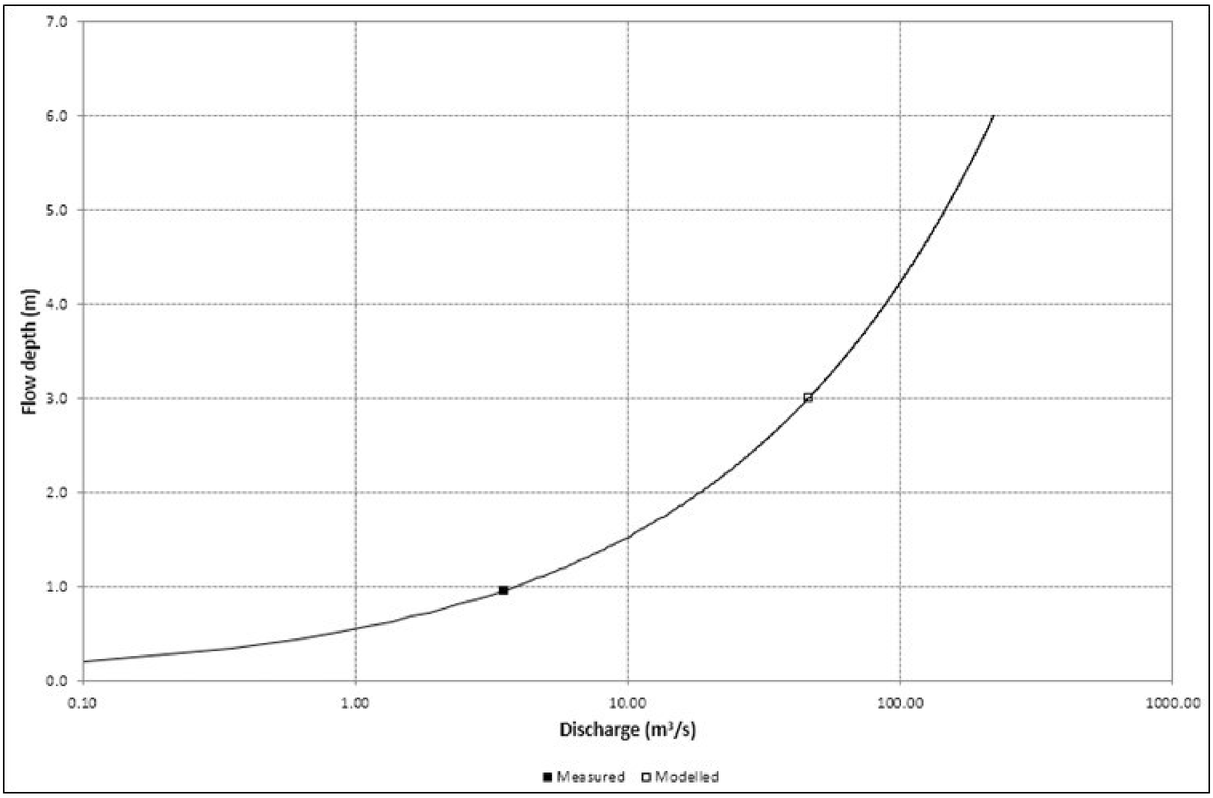


FIGURE 25: RATING CURVE FOR THE LEPHALALA RIVER SITE

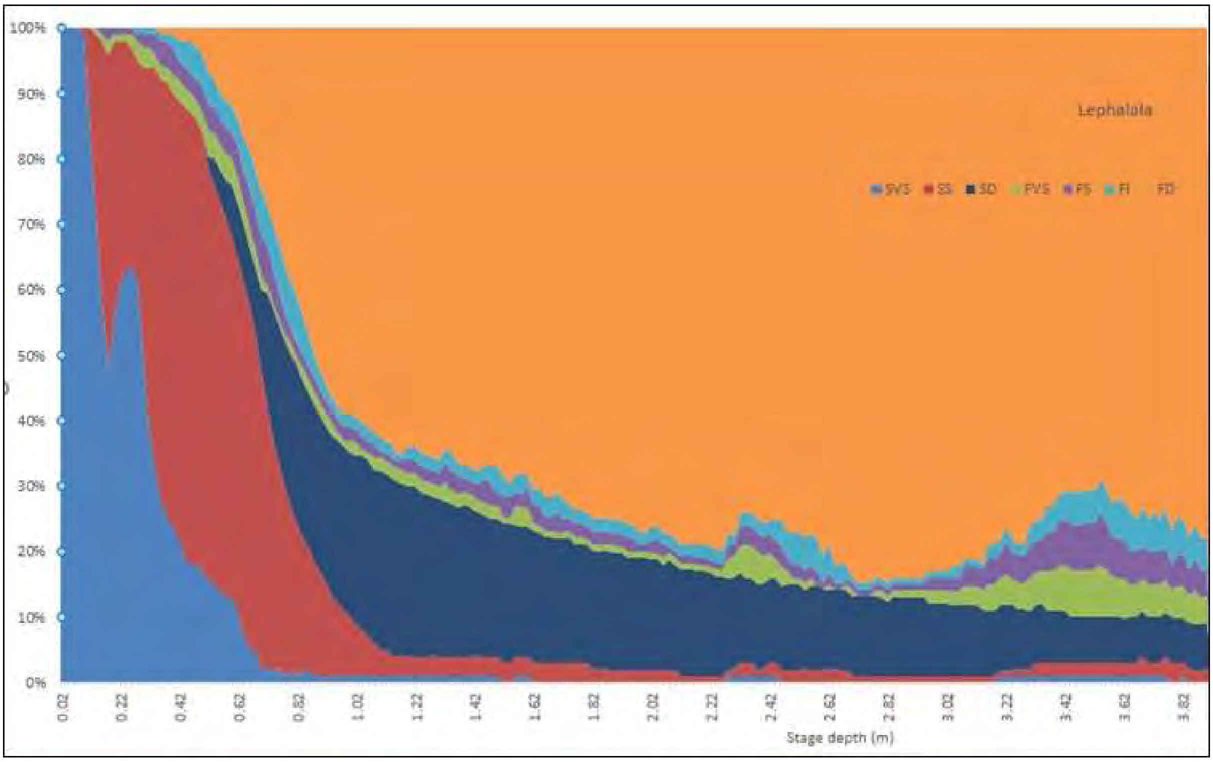


FIGURE 26: MODELLED VELOCITY DEPTH FREQUENCY DISTRIBUTIONS FOR VARIOUS MAXIMUM DEPTH LEVELS AT THE LEPHALALA RIVER SITE

4.4.5 LIMP-A36C-LIMPK (Limpopo at Limpokwena)

Bedrock controlled single channel section between multiple islands upstream and downstream (FIGURE 27, FIGURE 28). There is a good variety of habitats, mostly situated in-between bedrock high points, forming a diverse habitat mosaic (FIGURE 29). The banks are composed of fine sand and silt. Boulders, cobble and gravel are lining the lower portions of the channel in-between bedrock high points. Boulders are mainly associated with higher bedrock sections and are angular and locally produced. Cobbles are rounded and likely from upstream sources. Bedrock core bars develop with sand and grass cover stabilising the bars. A range of hydraulic habitats were observed, such as pool, riffle and glides. No clear flood level was observed.

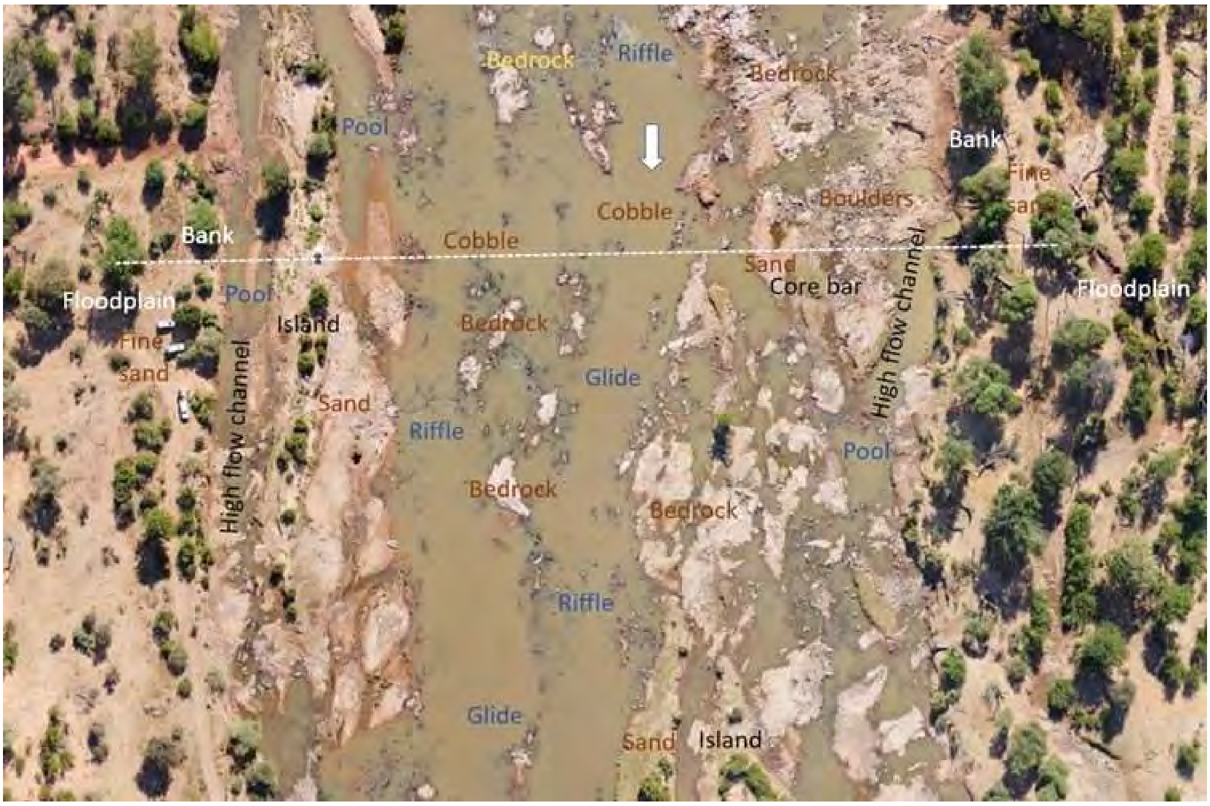


FIGURE 27: ORTHOPHOTO SHOWING MORPHOLOGICAL FEATURES AND SEDIMENT COMPOSITION OF THE LIMPOPO RIVER AT LIMPOKWENA.

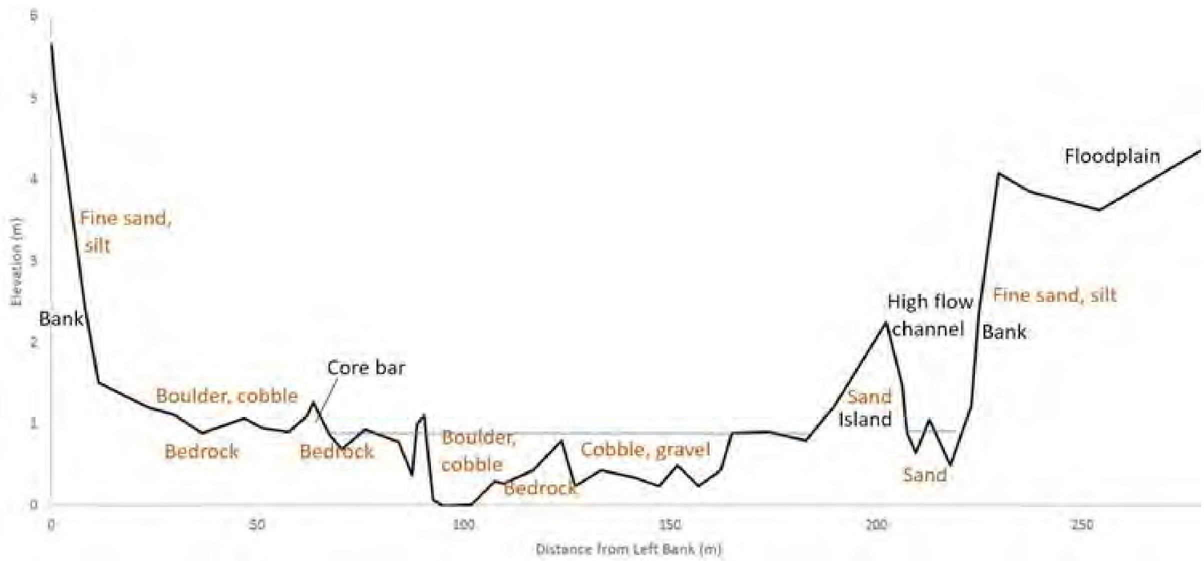


FIGURE 28: CROSS SECTION OF THE LIMPOPO AT LIMPOKWENA SHOWING HYDRUALIC BIOTOPES, MORPHOLOGICAL FEATURES AND SEDIMENT COMPOSITION.

FIGURE 29: SITE IMAGES SHOWING A) SCATTERED BOULDERS OVER BEDROCK ALONG THE LEFT BANK; B) SAND AND FINE GRAVEL BAR IN A HIGH FLOW CHANNEL ALONG THE RIGHT BANK; C) FINE GRAVEL DEPOSITS AND BEDROCK CORE BAR; D) COBBLE AND BOULDER SUBSTRATES; E) AND GRAVEL SUBSTRATES

FIGURE 30 shows the observed velocities and depth of the main channel. The observed and modelled parameters are presented in Table 4.11 and Table 4.12. The rating curve is presented in FIGURE 31 and the modelled velocity depth frequency data is presented in FIGURE 32.

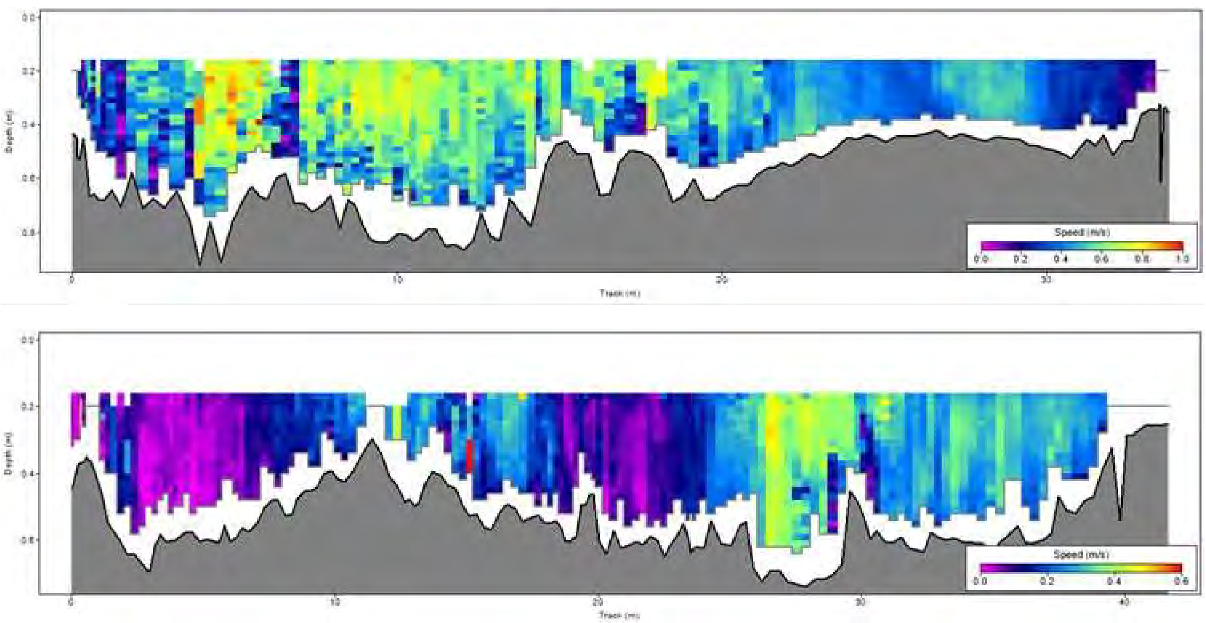


FIGURE 30: OBSERVED VELOCITY DEPTH DATA FOR THE LEFT (TOP) AND RIGHT (BOTTOM) SIDE OF THE CHANNEL.

TABLE 4.11: 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	0.0	N/A	N/A	0.000	0.000	Modelled
25-Apr-2021	0.88	0.088	0.001384	10.04	0.228	Observed
Flood 1	3	0.055	0.001384	516	1.101	Modelled

TABLE 4.12: EQUATION FOR THE RATING CURVE

Power Fit: y=axb + c	
Coefficient Data:	
a =	0.43
b =	0.31
c =	0

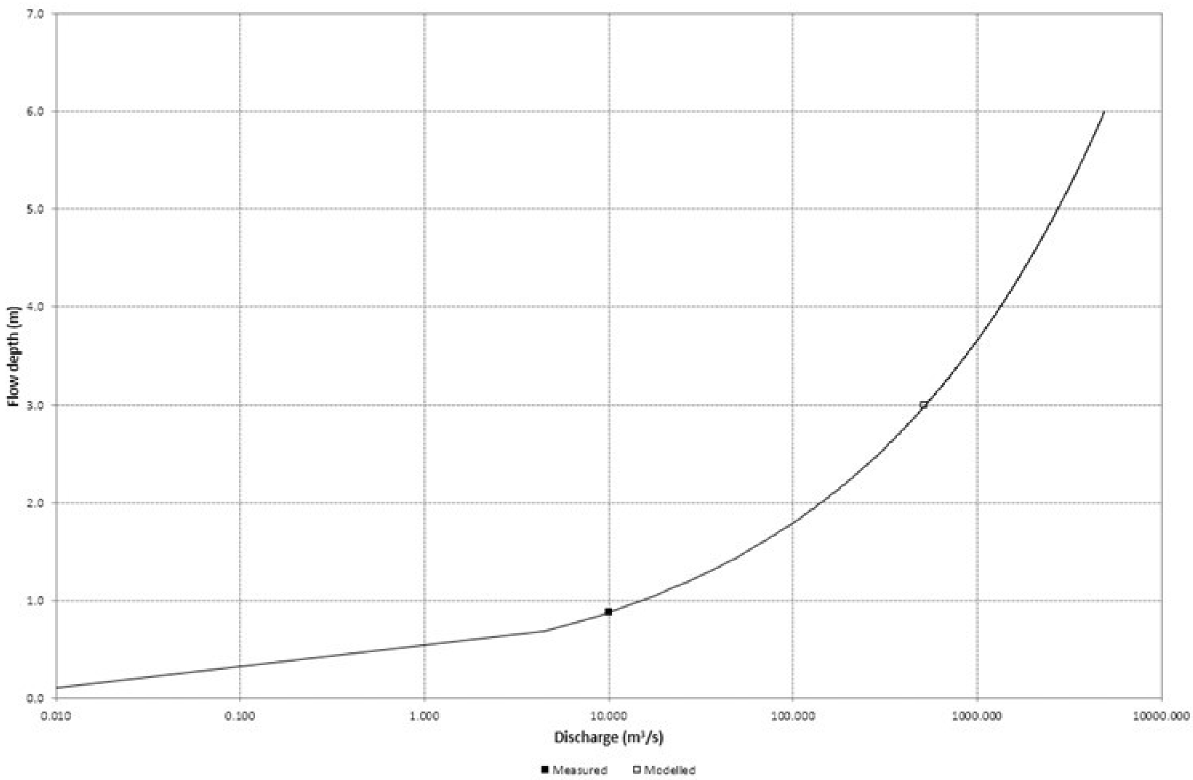


FIGURE 31: RATING CURVE FOR THE LIMPOPO RIVER AT THE LIMPOKWENA SITE

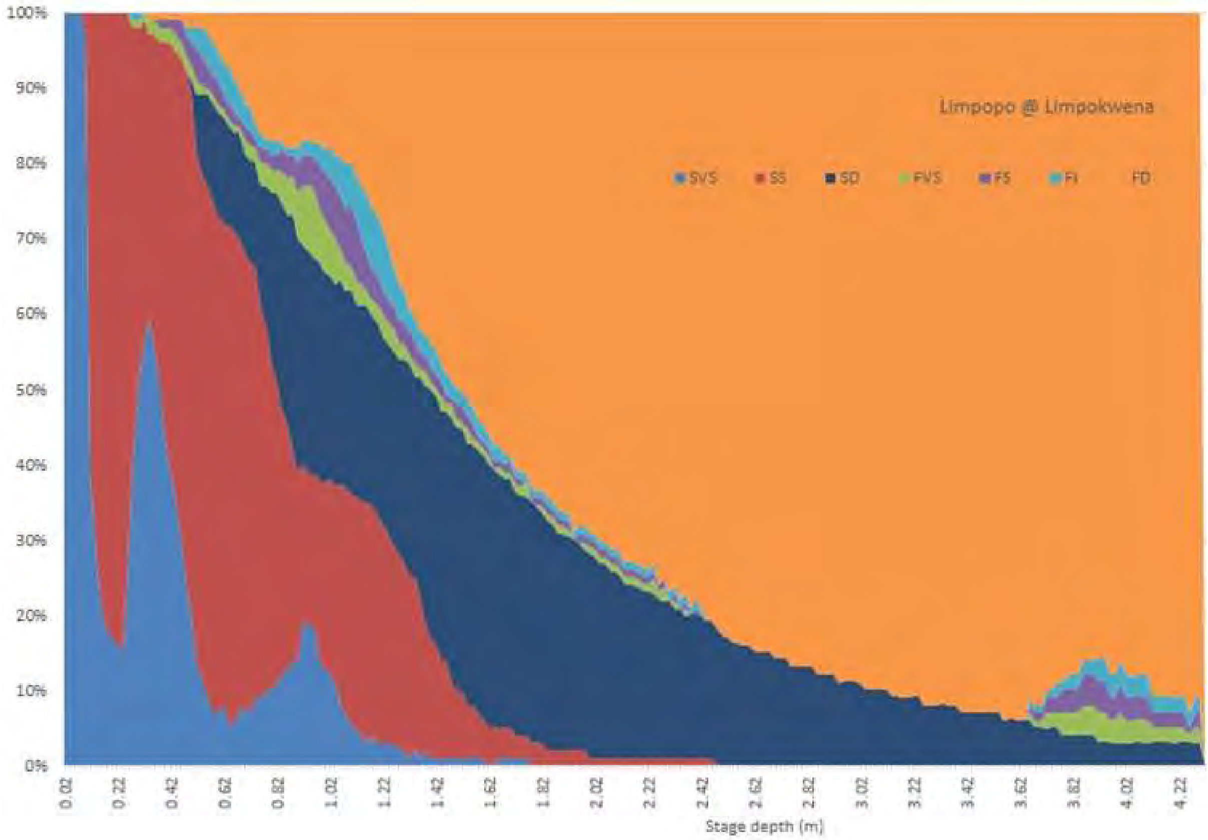


FIGURE 32: MODELLED VELOCITY DEPTH FREQUENCY DISTRIBUTIONS FOR VARIOUS MAXIMUM DEPTH LEVELS AT THE LIMPOPO RIVER LIMPOKWENA SITE

4.4.6 MOGA-A36D-LIMPK (Mogalakwena)

The Mogalakwena is a mixed bed single channel with a wandering planform (FIGURE 33, FIGURE 34). The site is located downstream of a steep bedrock section with a weir on it. The river follows a pool riffle sequence when there is flow (no perceptible flow during field visit; FIGURE 35). Coarse sand and gravels dominate the relatively flat bed. Banks consist of fine sand and silt, with medium sand deposits on the left flood bench. The right flood bench has a gravel cover. Low signs of siltation in the pools. The banks are poorly vegetated and eroding, with short sections of bank that is undercut. The banks are trampled by game.

FIGURE 33: ORTHOPHOTO SHOWING MORPHOLOGICAL FEATURES AND SEDIMENT COMPOSITION OF THE MOGALAKWENA RIVER.

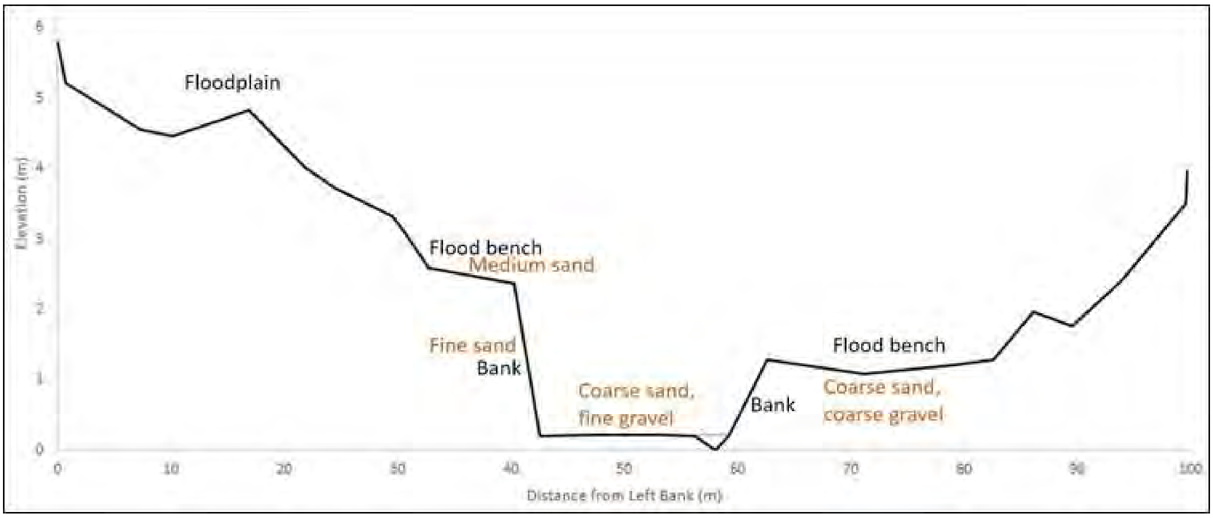


FIGURE 34: CROSS SECTION OF THE MOGALAKWENA RIVER SHOWING MORPHOLOGICAL FEATURES AND SEDIMENT COMPOSITION.

FIGURE 35: SITE IMAGES SHOWING A) AN UPSTREAM VIEW OF THE SANDY CHANNEL; B) COARSE SAND ON THE CHANNEL BED; C) ERODING LEFT BANK; D) GRAVEL DEPOSIT ON RIGHT FLOOD BENCH

The observed and modelled hydraulic parameters and rating equation are presented in Table 4.13 and Table 4.14. The rating cure is presented in FIGURE 36 and the modelled velocity depth data are presented in FIGURE 37.

TABLE 4.13: OBSERVED AND MODELLED DATA USED TO DERIVE THE RATING CURVE

Date	Depth (m)	Mannings n	Energy gradient	Discharge (m3/s)	Velocity (m/s)	Comment
26-Apr-2021	0.2	N/A	0.00011	0.0001	0.0	Observed
Flood 1	1	0.035	0.00011	3.55	0.242	Modelled
Flood II	2	0.032	0.00011	18.5	0.34	Modelled
Flood III	3.8	0.030	0.00011	100	0.59	Modelled

TABLE 4.14: EQUATION FOR THE RATING CURVE

Power Fit: y=axb + c

Coefficient Data:	
a =	0.502
b =	0.429
c =	0.2

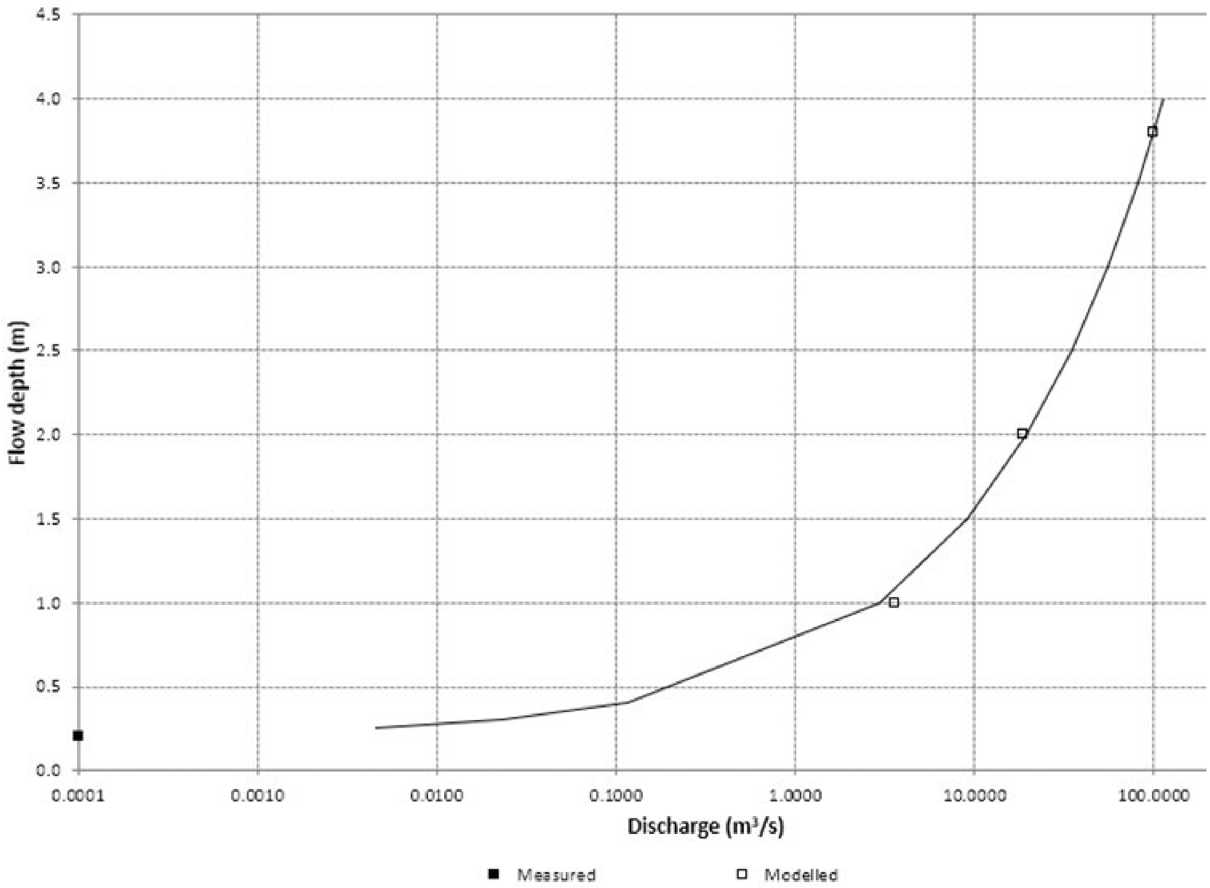


FIGURE 36: RATING CURVE FOR THE MOGALAKWENA RIVER SITE

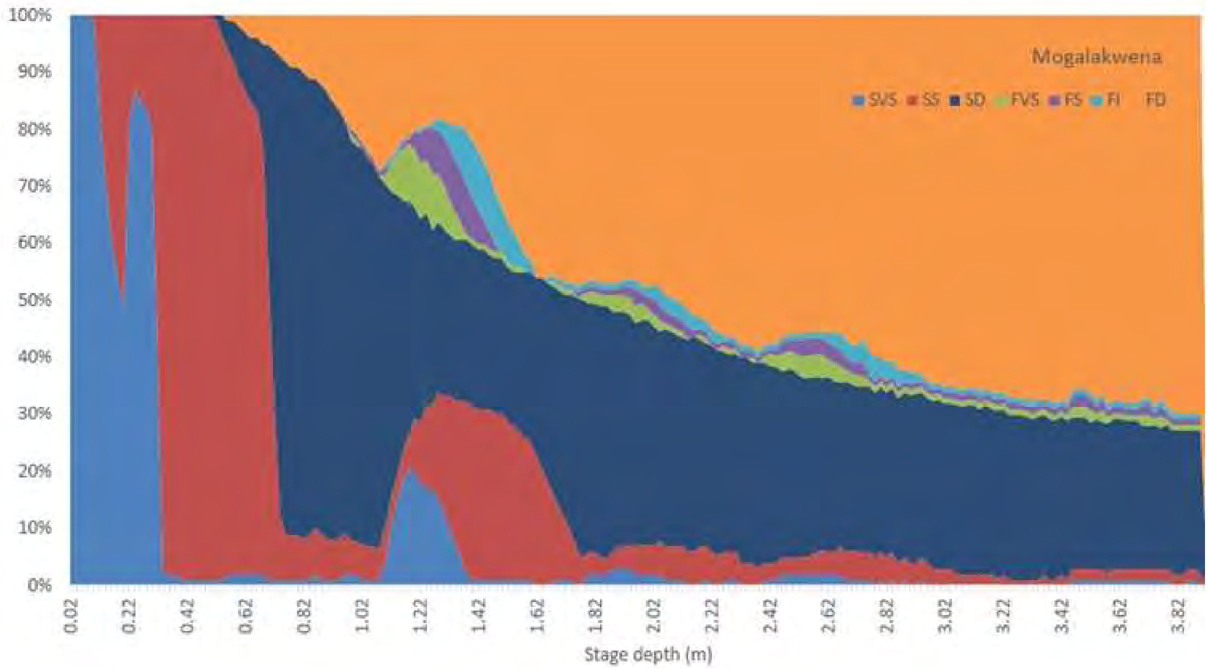


FIGURE 37: MODELLED VELOCITY DEPTH FREQUENCY DISTRIBUTIONS FOR VARIOUS MAXIMUM DEPTH LEVELS AT THE MOGOLAKWENA RIVER SITE

4.4.7 SHAS-Y20B-TULIB (Shashe)

The Shashe River is a wide alluvial river with a coarse sand bed. At the site it falls in the lower foothills zone and is over 500 m wide. It has a narrow floodplain and is set in a gently undulating landscape. The low flow channel has a braided flow pattern and becomes straight to wandering pattern at higher flows (**Error! Reference source not found.**). The banks are composed of fine sand and silt and lined with trees and shrubs. The sandy bed has some gentle undulations with an inset bench along the right bank and sand bars along the left bank (Figure 39). The bed of the channel was mostly composed of coarse sand and fine gravel (Figure 40).

During the field visit no surface flow was observed with shallow pools present along low point along the bed. No flood debris was observed in the field.

The upper Shashe catchment has a moderate cover of woodland that is used for extensive grazing, with extensive areas used for low density settlements and subsistence agriculture. Several dams are present. The lower catchment is less extensively farmed, with a large proportion of woodland.

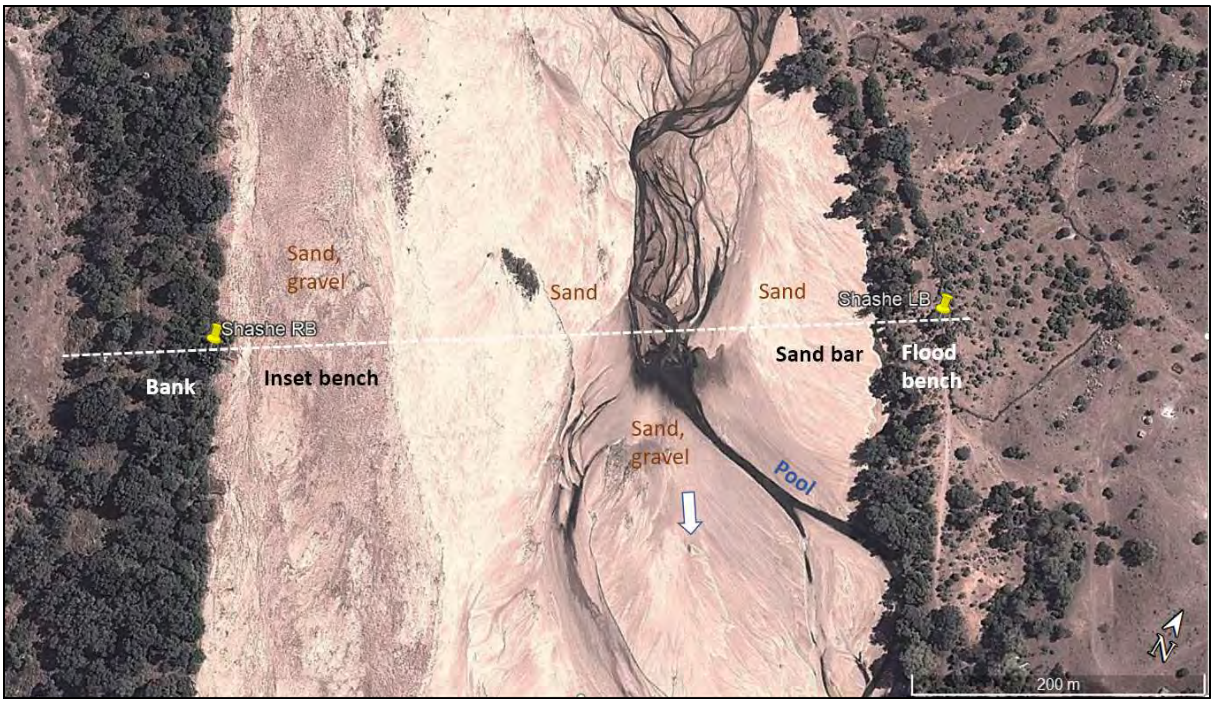


FIGURE 38 ORTHOPHOTO SHOWING MORPHOLOGICAL FEATURES AND SEDIMENT COMPOSITION OF SHAS-Y20B-TULIB (SHASHE RIVER).

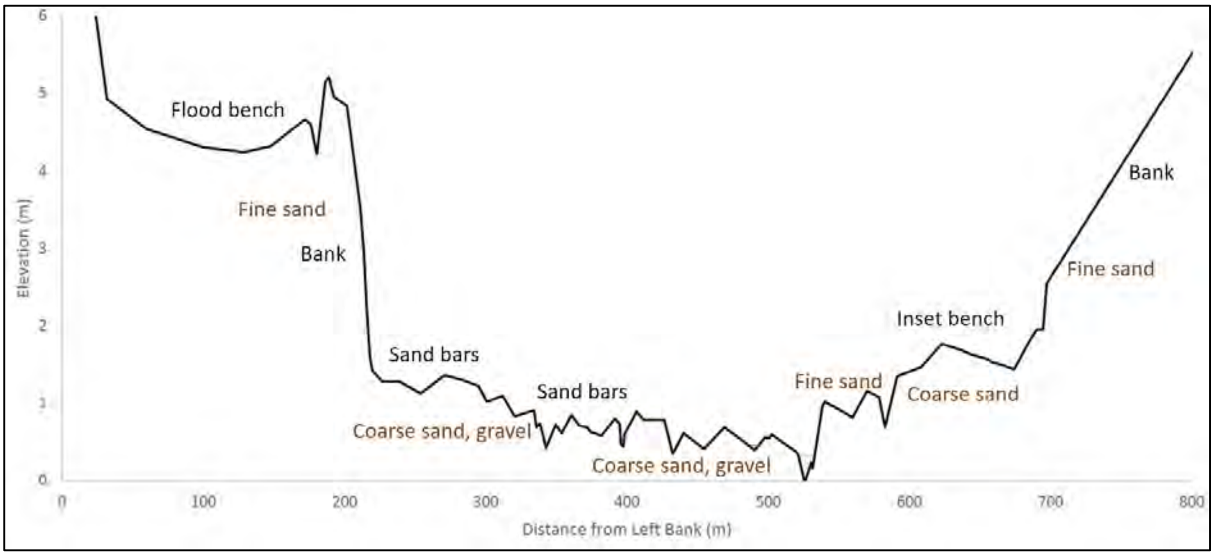


FIGURE 39: CROSS SECTION OF SHAS-Y20B-TULIB (SHASHE RIVER) SHOWING MORPHOLOGICAL FEATURES AND SEDIMENT COMPOSITION.

FIGURE 40: SITE IMAGES SHOWING A) AN UPSTREAM VIEW OF THE WELL VEGETATED CHANNEL; B) FINE GRAVEL FROM THE RIFFLE SECTION; C) SAND BENCH ALONG RIGHT BANK; D) RECENT SAND DEPOSIT ALONG THE CHANNEL MARGIN

The parameters used for developing the rating curve is presented in Table 4.15 and the coefficients for the rating curve are given in Table 4.16. The rating curve is shown in Figure 41 with the velocity depth frequency distribution for a range of depths shown in Figure 42.

No observed flow data above 0 were available to calibrate the velocity depth distributions of the model. This results in low confidence in the modelled output.

TABLE 4.15 OBSERVED AND MODELLED DATA USED TO DERIVE THE RATING CURVE

Date	Depth (m)	Mannings n	Energy gradient	Discharge (m3/s)	Velocity (m/s)	Comment
Flow 1	0.8	0.0300	0.0011	18.5	0.414	Modelled
23-Jul-21	0.36	NA	0.0011	0.00	0.000	Observed
Flood 1	2.5	0.0250	0.0011	1250	1.735	Modelled
Flood 2	4.5	0.0230	0.0011	4951	2.790	Modelled

TABLE 4.16: EQUATION FOR THE RATING CURVE

Power Fit: y=axb + c	
Coefficient Data:	

a =	0.088
b =	0.452
c =	0.36

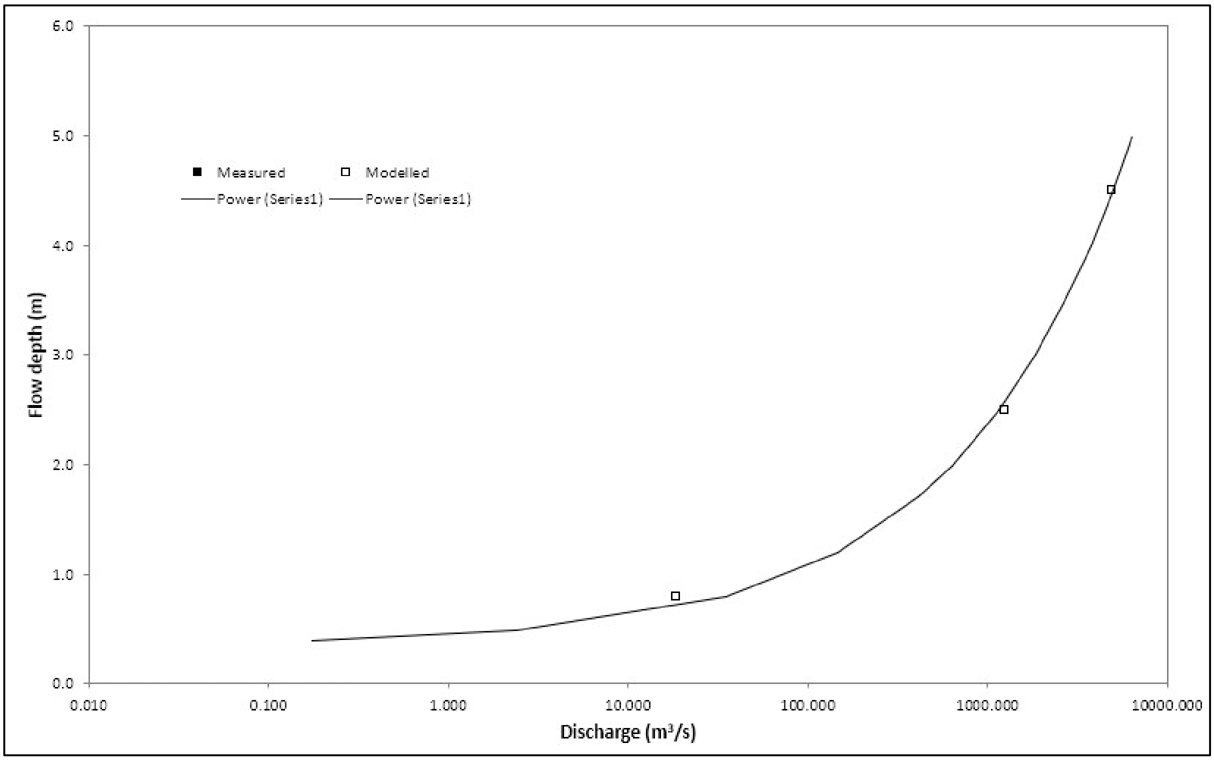


FIGURE 41: RATING CURVE FOR SHAS-Y20B-TULIB (SHASHE RIVER)

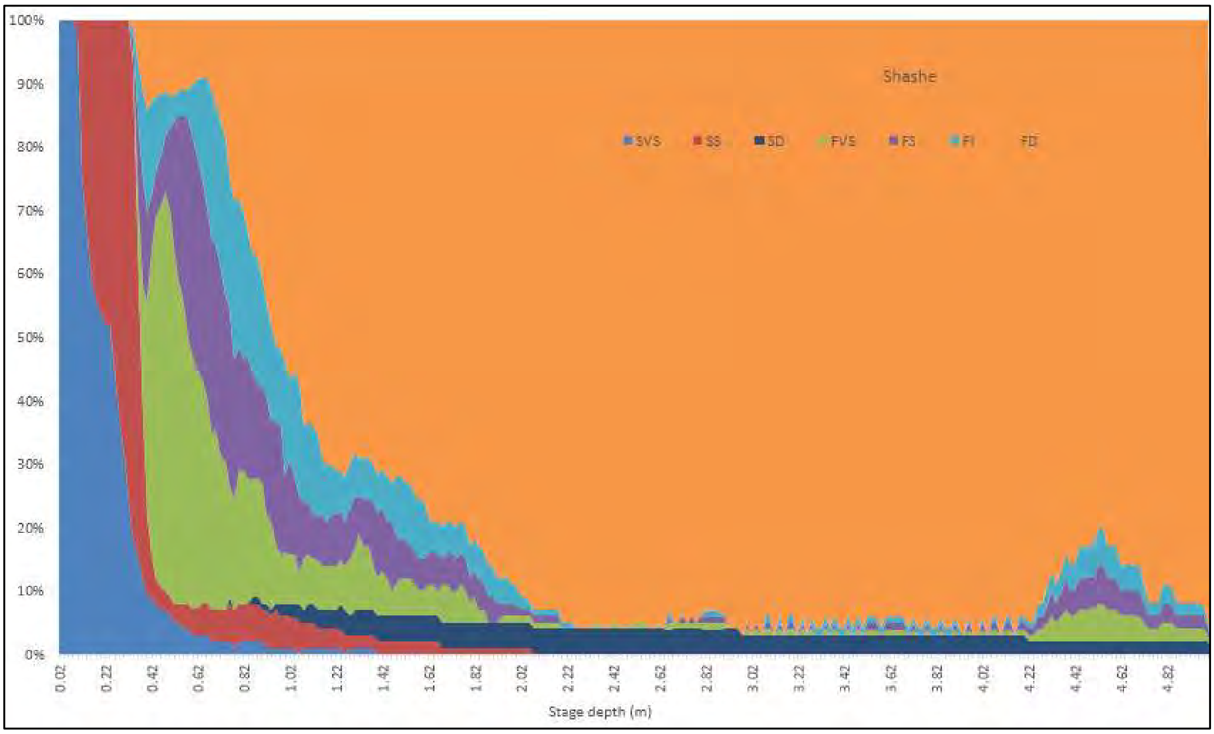


FIGURE 42: MODELLED VELOCITY DEPTH FREQUENCY DISTRIBUTIONS FOR VARIOUS MAXIMUM DEPTH LEVELS FOR SHAS-Y20B-TULIB (SHASHE RIVER)

4.4.8 LIMP-A71L-MAPUN (Limpopo at Poachers Corner)

The Limpopo at Poachers corner has a wide sandy channel with a braided flow pattern during low flow conditions (FIGURE 43). During higher flows it has a single wandering channel alternating between lateral sand bars. A narrow flood bench and floodplain are present along the right bank (FIGURE 44). Large trees grow on the flood bench and floodplain. (FIGURE 45). The low flow braided channel is 10 to 30 cm deep, with localized pools up to 1m in depth. Localised gravel deposits armour the coarse sand underneath. The coarse sand is actively rolling along in water with >0.3m/s and 10cm deep, covering sand covered in algae. These mobile sands advance into slower flowing pools, reducing their volume over time.

Pools and glides dominate the hydraulic habitats. Recent flood debris was surveyed at 4.8m above the thalweg elevation.

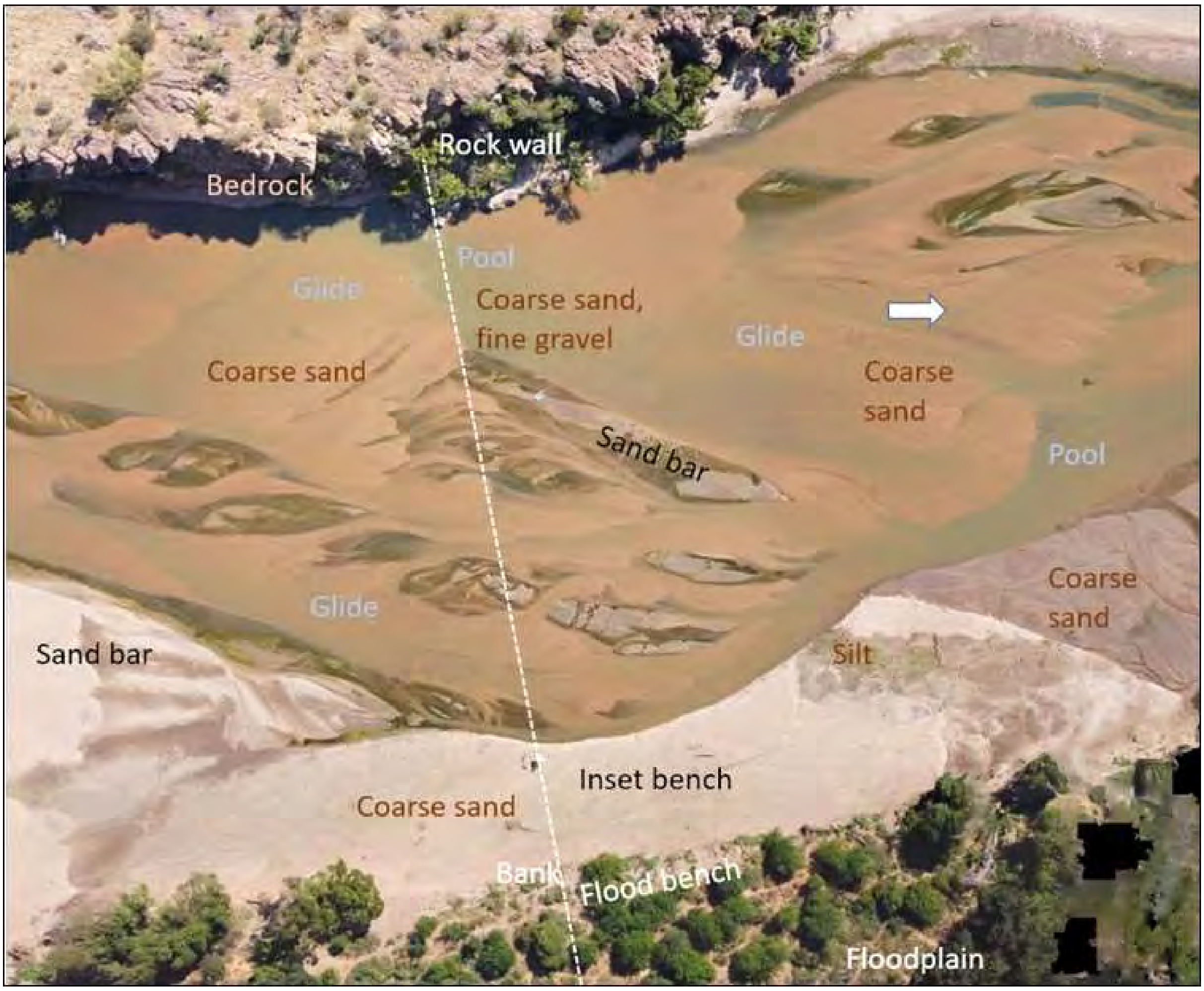


FIGURE 43: ORTHOPHOTO SHOWING MORPHOLOGICAL FEATURES AND SEDIMENT COMPOSITION OF THE LIMPOPO RIVER AT POACHERS CORNER

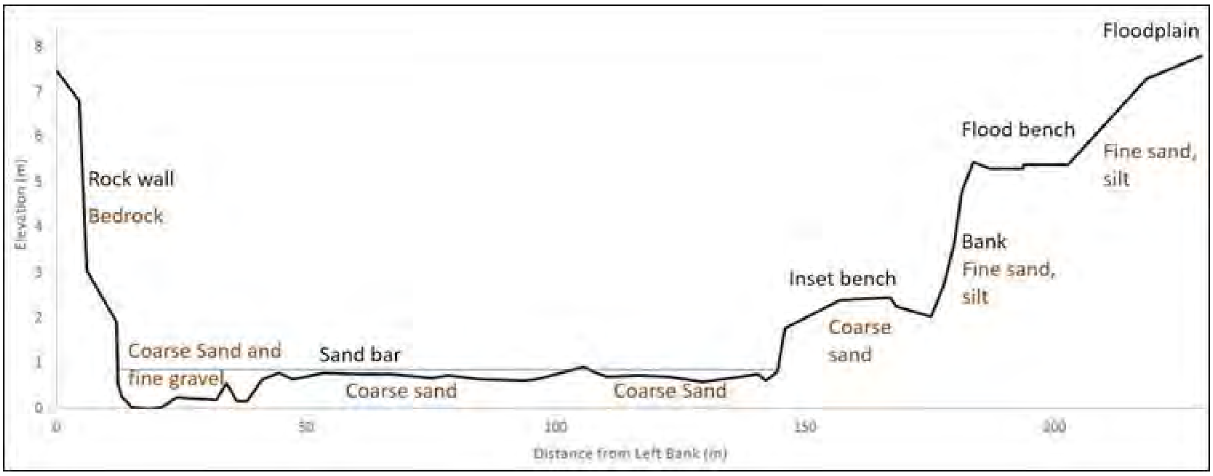


FIGURE 44: CROSS SECTION OF THE LIMPOPO RIVER AT POACHERS CORNER SHOWING MORPHOLOGICAL FEATURES AND SEDIMENT COMPOSITION

FIGURE 45: SITE IMAGES SHOWING A) A PANORAMIC VIEW OF THE CHANNEL FROM THE ROCKY LEFT BANK; B) STEEP FINE SAND AND SILT FLOOD BENCH ALONG THE RIGHT BANK; C) ORGANIC RICH SILT DEPOSIT DOWNSTREAM OF SAND BAR; D) FINE GRAVEL SUBSTRATE IN SHALLOW WATER; AND E) WOODY DEBRIS CREATING LOCAL COVER FOR BIOTA

The observed velocities across the main channel is shown in FIGURE 46.

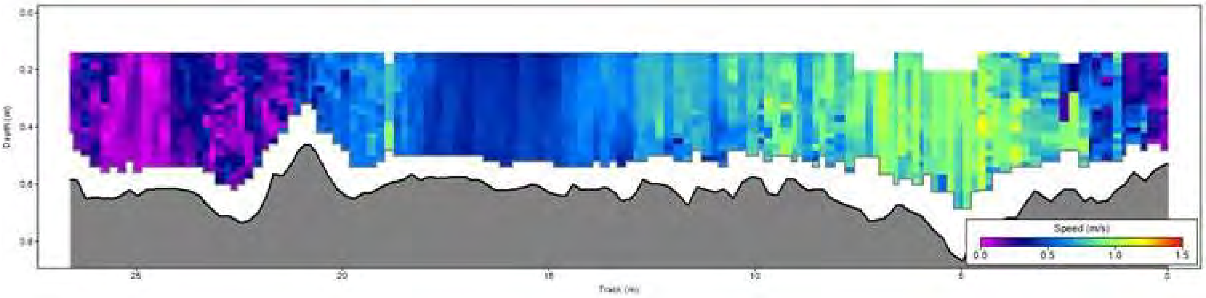


FIGURE 46: VELOCTY AND DEPTH ALONG THE CROSS SECTION

The mobile nature of the bed is shown in

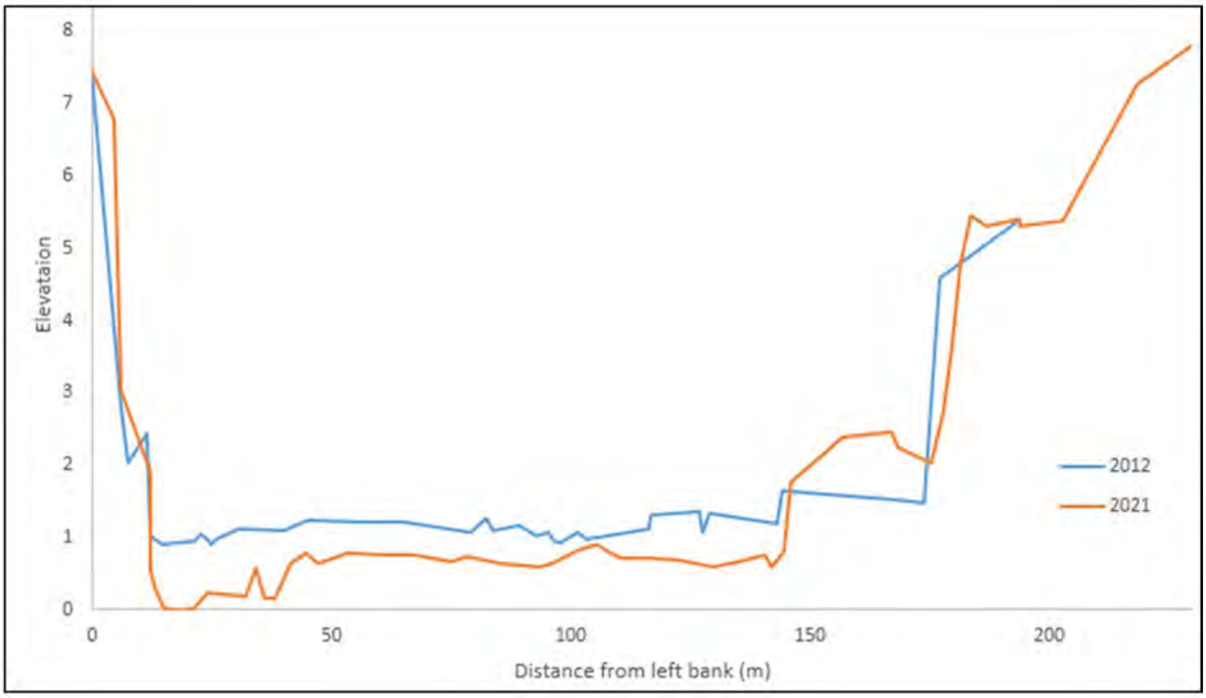


Figure 47 where the channel thalweg differs by 1 metre between the surveys using fixed markers (same datum). This has implications for repeat hydraulic surveys as the rating channel geometry changes frequently. The observed data from 2012 was used for developing the rating curve based on the thalweg depth assuming the low flow channel geometry is similar (Table 4.17). The rating parameters and rating curve for the geometry measured in 2021 are shown in

Table 4.18 and

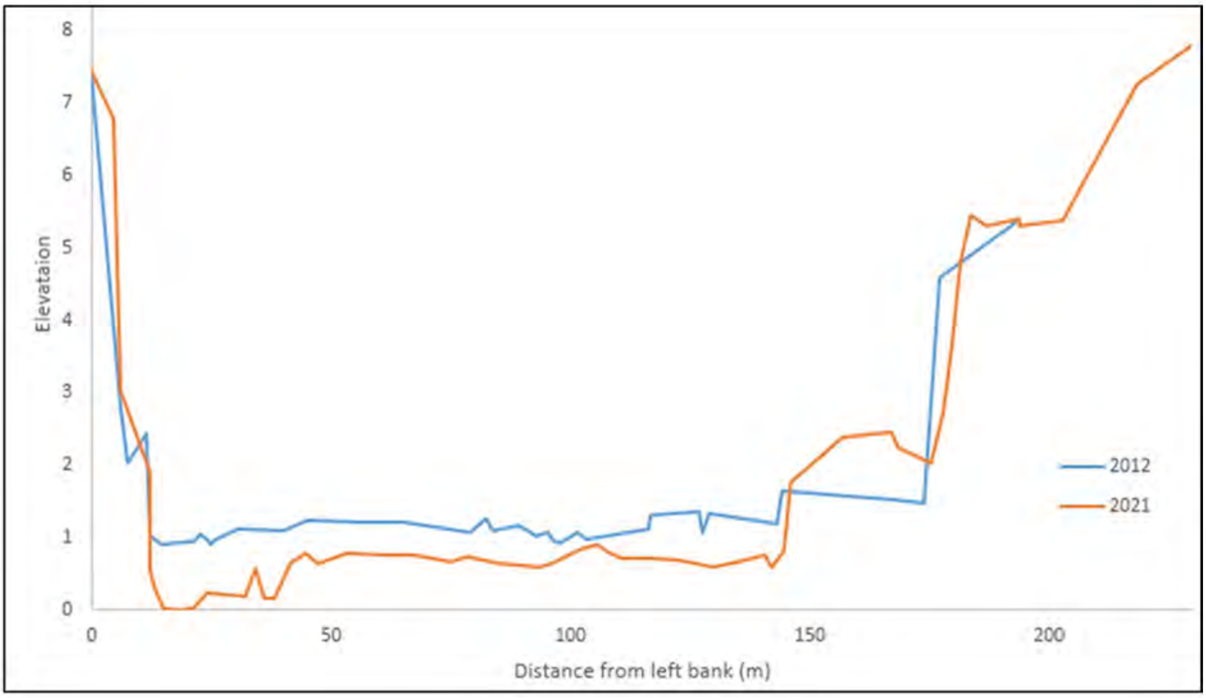


FIGURE 47: COMPARISON OF THE CHANNEL CROSS SECTION OF 2012 AND 2021 USING THE SAME LOCAL DATUM

TABLE 4.17: 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	0.0	N/A	N/A	0.000	0.000	Modelled
7-June-2012	0.06	0.008	0.00152	0.081	0.395	Observed
27-Apr-2021	0.82	0.037	0.00102	9.74	0.326	Observed
Flood 1	3	0.028	0.00102	631.5	1.812	Modelled

TABLE 4.18: EQUATION FOR THE RATING CURVE

Power Fit: y=axb + c	
Coefficient Data:	
a =	0.37
b =	0.33
c =	0

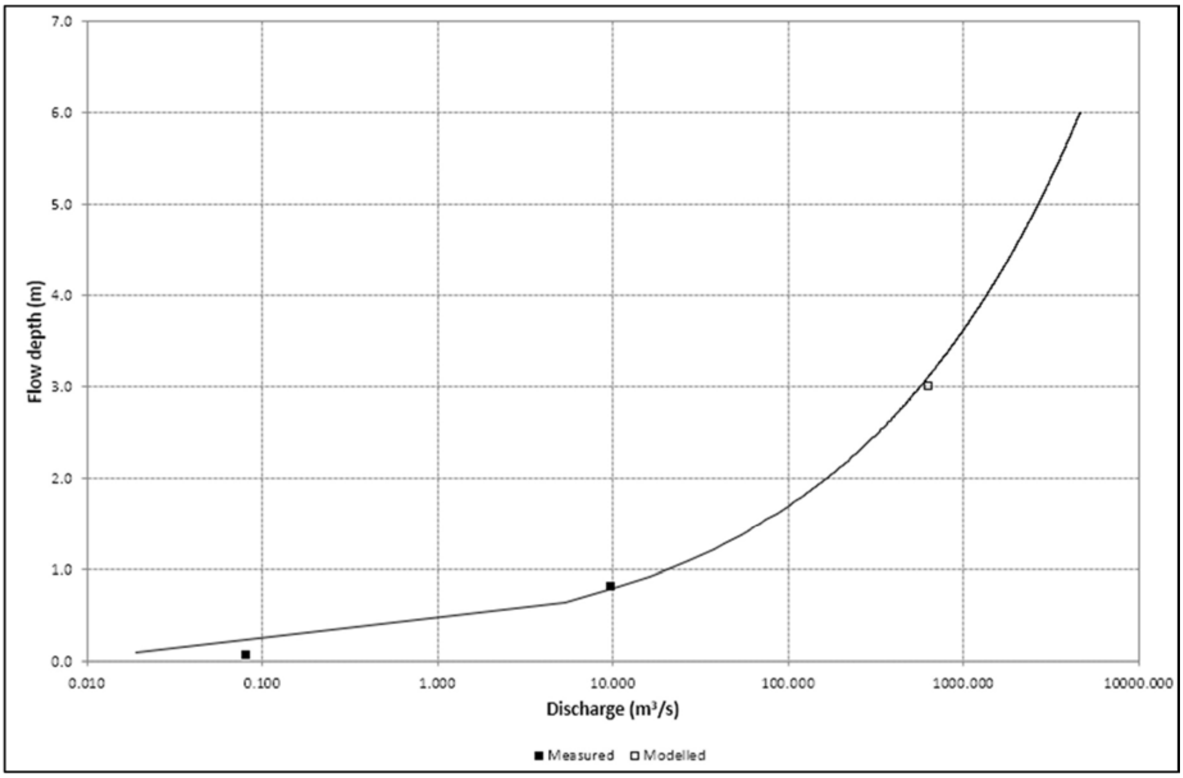


FIGURE 48: RATING CURVE FOR THE LIMPOPO RIVER AT THE POACHERS CORNER SITE

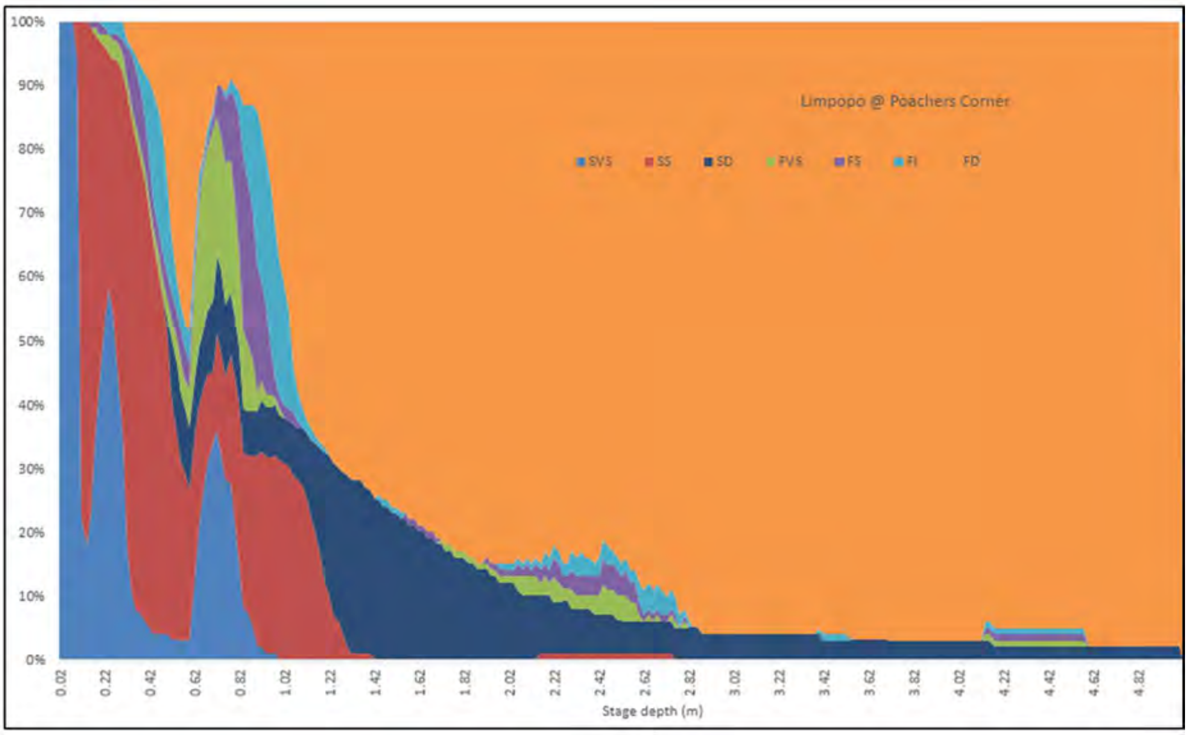


FIGURE 49: MODELLED VELOCITY DEPTH FREQUENCY DISTRIBUTIONS FOR VARIOUS MAXIMUM DEPTH LEVELS AT THE LIMPOPO RIVER POACHERS CORNER SITE

4.4.9 UMZI-Y20C-BEITB (Umzingwani)

The Umzingwani River is a mixed bed sand river set in a gently undulating landscape. The site falls in the lower foothill geomorphic zone and has a very narrow floodplain and wide sandy bed approximately 100m wide (Figure 50, Figure 51). Bedrock forms the left bank and fine sand and silt the right bank. Trees and shrubs grow along both banks with low grass cover due to overgrazing (Figure 52). The plane sand bed has low topographic variation longitudinally, resulting in very shallow pools. The bed and bar substrate are dominated by coarse sand and fine gravels. Some larger gravels were forming an armour layer over the coarse sand along the right channel margin (Figure 52).

During the field visit no surface flow was observed with shallow pools present along low point along the bed. Flood debris from the 2021 wet season was surveyed at 5.5 to 5.8m above the channel thalweg.

The site is located ~40 km downstream of a dam, that will trap bedload, but larger tributaries seems to balance the sediment trapping. Large areas of the lower catchment is used for subsistence farming, with slash and burn practices visible throughout the landscape. The upper and middle catchment has small orchard and centre pivot development, with large areas used for game and livestock grazing. Erosion potential is likely to be high due to the low vegetation cover.

FIGURE 50: ORTHOPHOTO SHOWING MORPHOLOGICAL FEATURES AND SEDIMENT COMPOSITION OF UMZI-Y20C-BEITB (UMZINGWANI RIVER; GOOGLE EARTH IMAGE DECEMBER 2020).

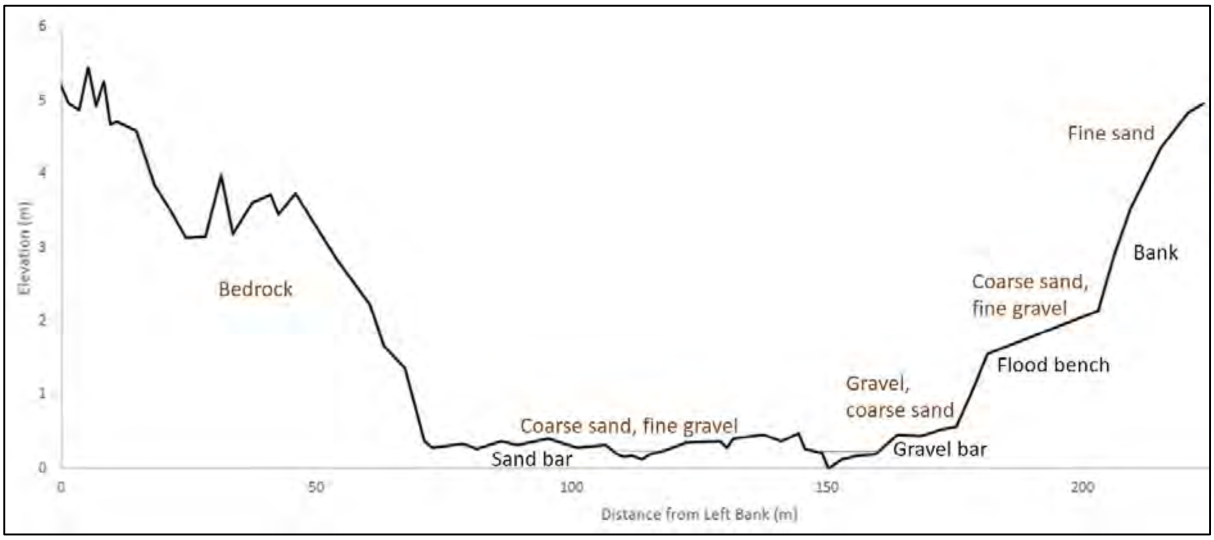


FIGURE 51: CROSS SECTION OF UMZI-Y20C-BEITB (UMZINGWANI RIVER) SHOWING MORPHOLOGICAL FEATURES AND SEDIMENT COMPOSITION.

FIGURE 52: SITE IMAGES SHOWING A) THE SANDY CHANNEL FROM THE ROCKY LEFT BANK; B) COARSE SAND AND FINE GRAVEL IN THE CHANNEL; C) MEDIUM GRAVEL ARMOURING COARSE SAND ALONG THE RIGHT CHANNEL MARGIN D) SHALLOW POOL HABITAT WITH WOODY DEBRIS; AND E) BEDROCK POOL HABITAT ALONG THE LEFT BANK

The observed and modelled data points are shown in Table 4.19 with the rating curve coefficients presented in Table 4.20. The rating curve is presented in Figure 41 and the velocity depth frequency distributions shown in Figure 42. No observed flow data was available to calibrate the model resulting in low confidence in the output.

TABLE 4.19: OBSERVED AND MODELLED DATA USED TO DERIVE THE RATING CURVE

Date	Depth (m)	Mannings n	Energy gradient	Discharge (m3/s)	Velocity (m/s)	Comment
Flow 1	0.8	0.0300	0.001257	36.206	0.714	Modelled
26-Jul-21	0.19	NA	0.00125	0.00	0.000	Observed
Flood 1	2.5	0.0250	0.0012	535.184	2.037	Modelled
Flood 2	4.5	0.0230	0.0011	1843.609	3.012	Modelled

TABLE 4.20: EQUATION FOR THE RATING CURVE

Power Fit: y=axb + c	
Coefficient Data:	
a =	0.0986
b =	0.502
c =	0.19

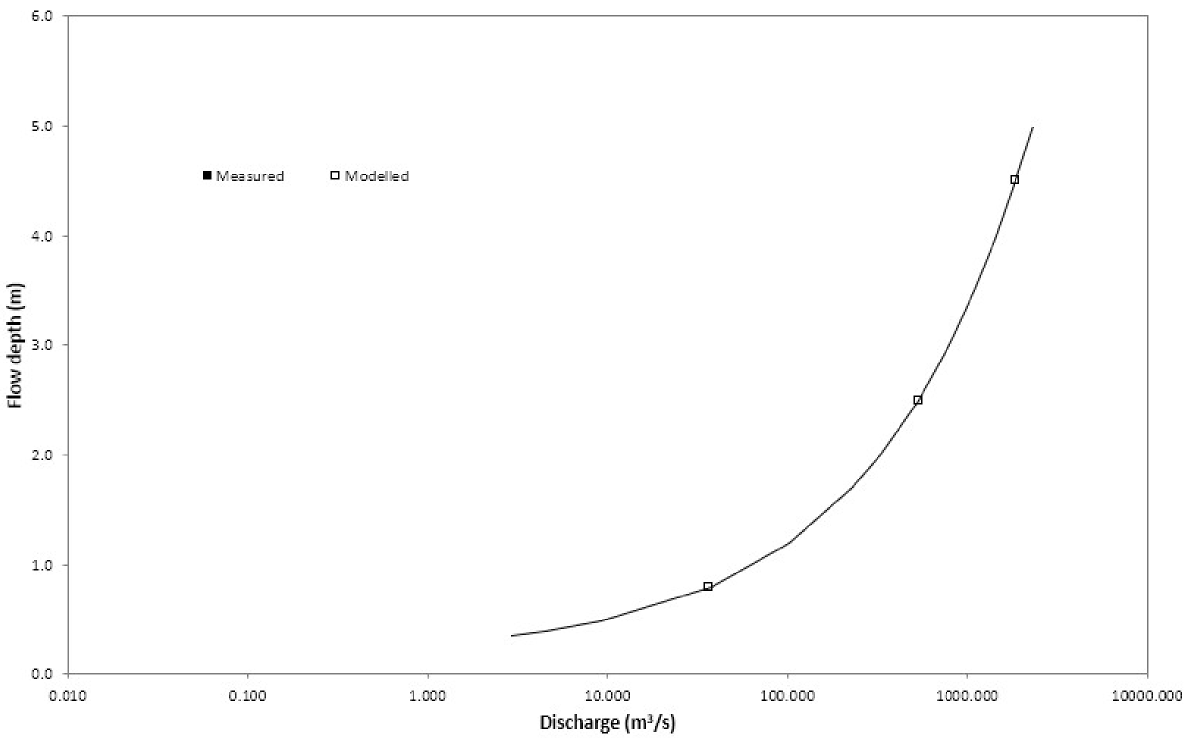


FIGURE 53: RATING CURVE FOR UMZI-Y20C-BEITB (UMZINGWANI RIVER)

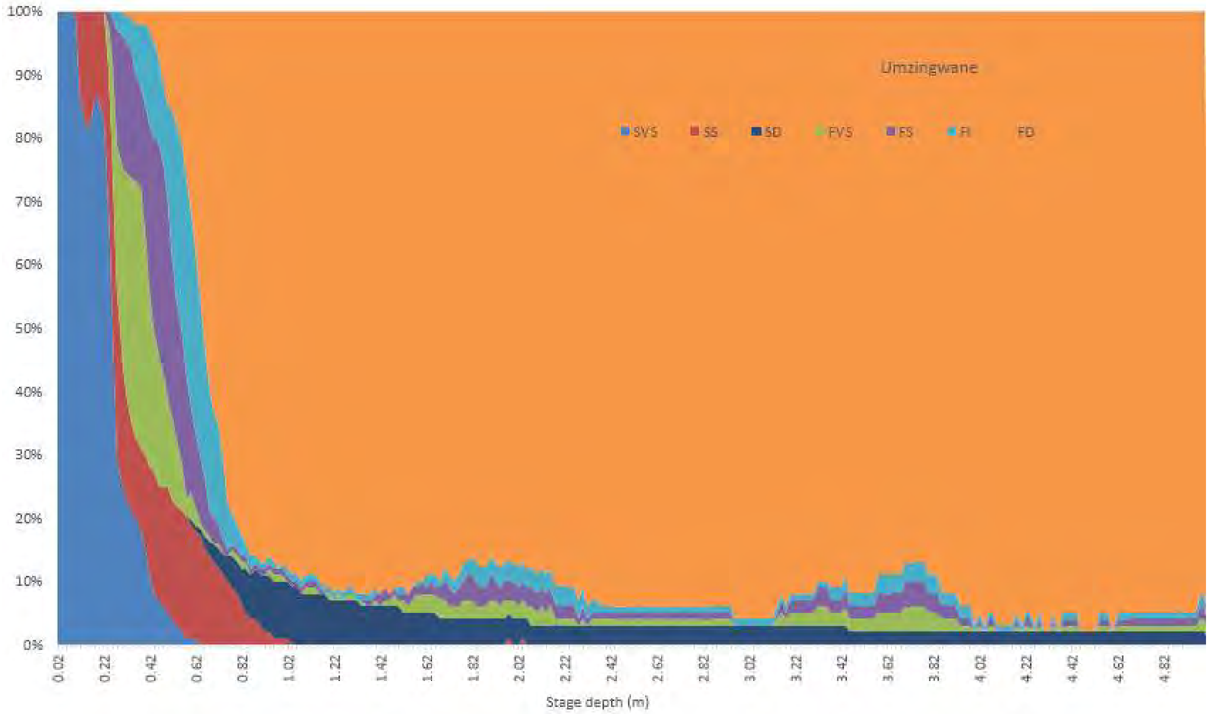


FIGURE 54: MODELLED VELOCITY DEPTH FREQUENCY DISTRIBUTIONS FOR VARIOUS MAXIMUM DEPTH LEVELS FOR UMZI-Y20C-BEITB (UMZINGWANI RIVER)

4.4.10 SAND-A71K-R508B (Sand River)

This section of the Sand River is a bedrock-controlled reach with a mixed load channel (

FIGURE 55,

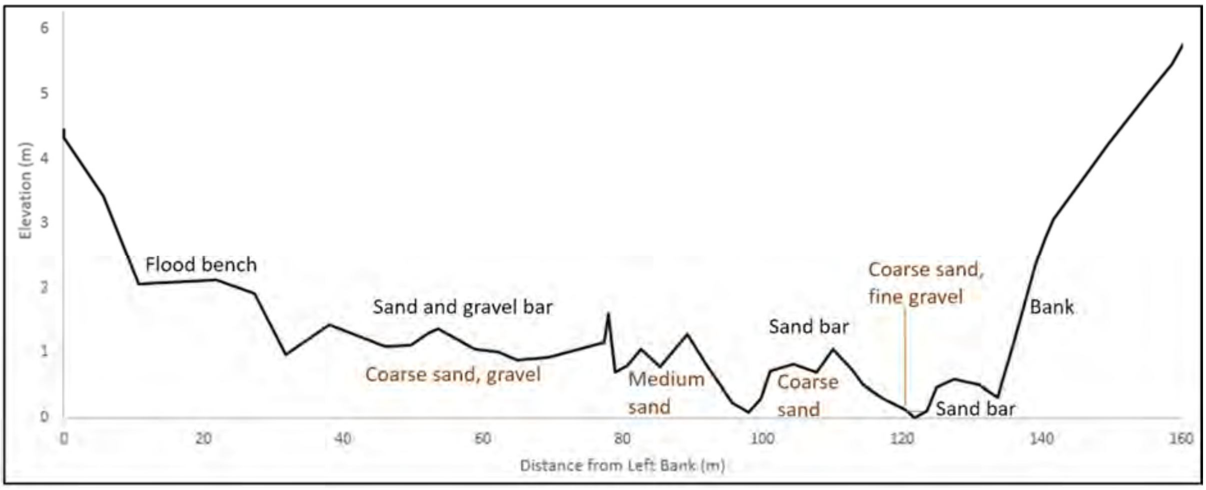


FIGURE 56,

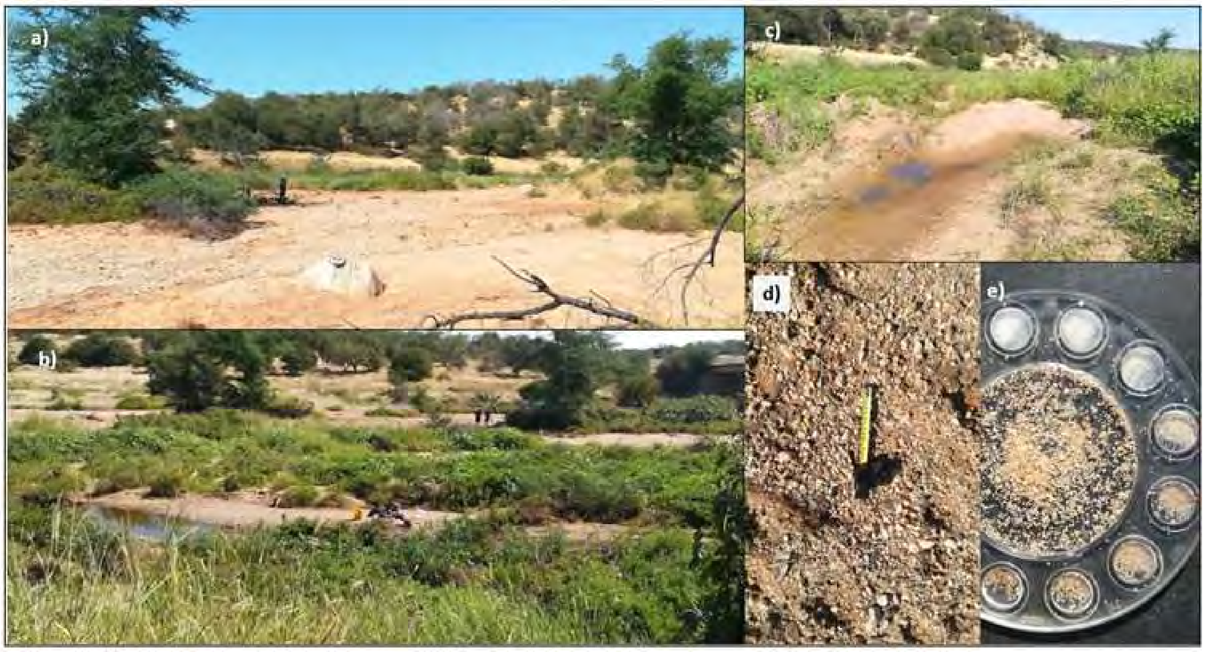


FIGURE 57). The complex channel morphology is composed of a single wandering low-flow channel, with several high flow channels. Sand bars form small well vegetated islands between the high flow channels and a narrow flood bench is present along the left bank. Gravel bars form in the channel and on flood features in an otherwise coarse sand dominated channel

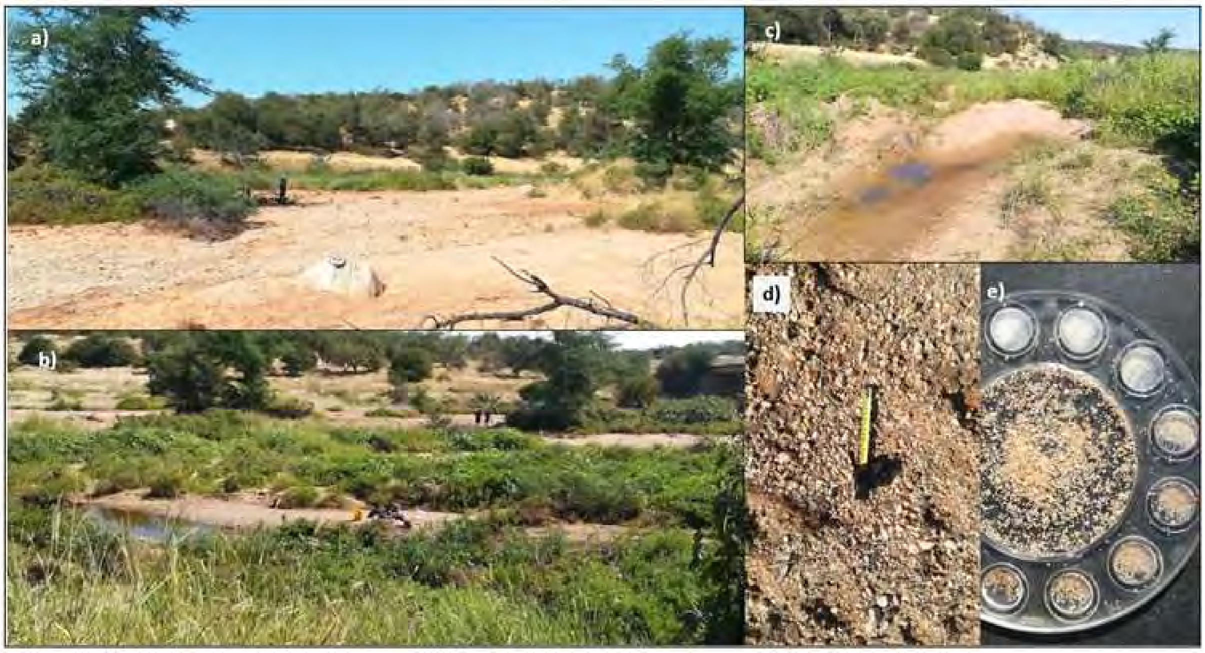


FIGURE 57).

A recent flood level was surveyed at 1.6m above the thalweg elevation.

FIGURE 55: ORTHOPHOTO SHOWING MORPHOLOGICAL FEATURES AND SEDIMENT COMPOSITION OF THE SAND RIVER.

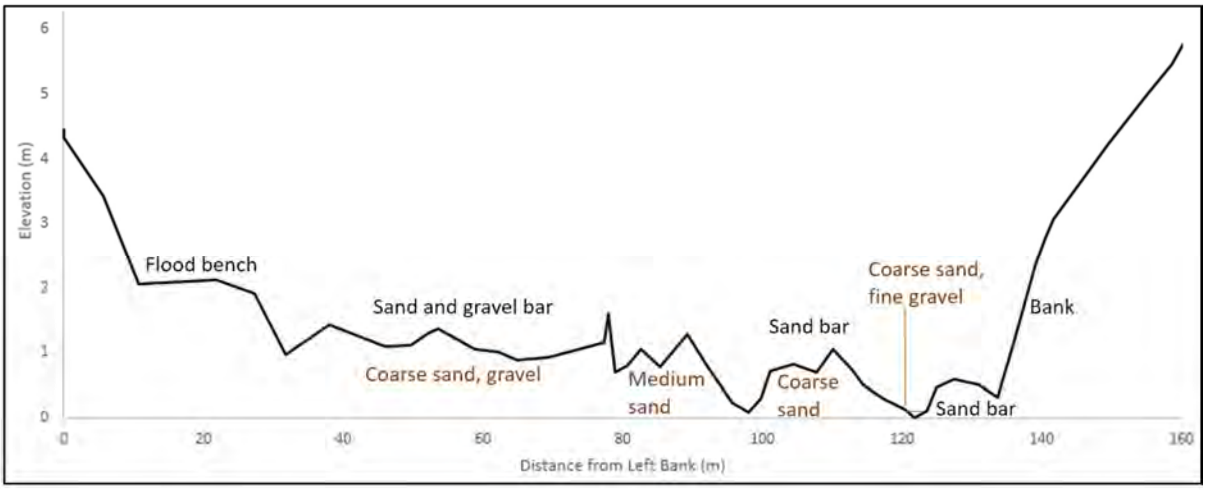


FIGURE 56: CROSS SECTION OF THE SAND RIVER SHOWING MORPHOLOGICAL FEATURES AND SEDIMENT COMPOSITION.

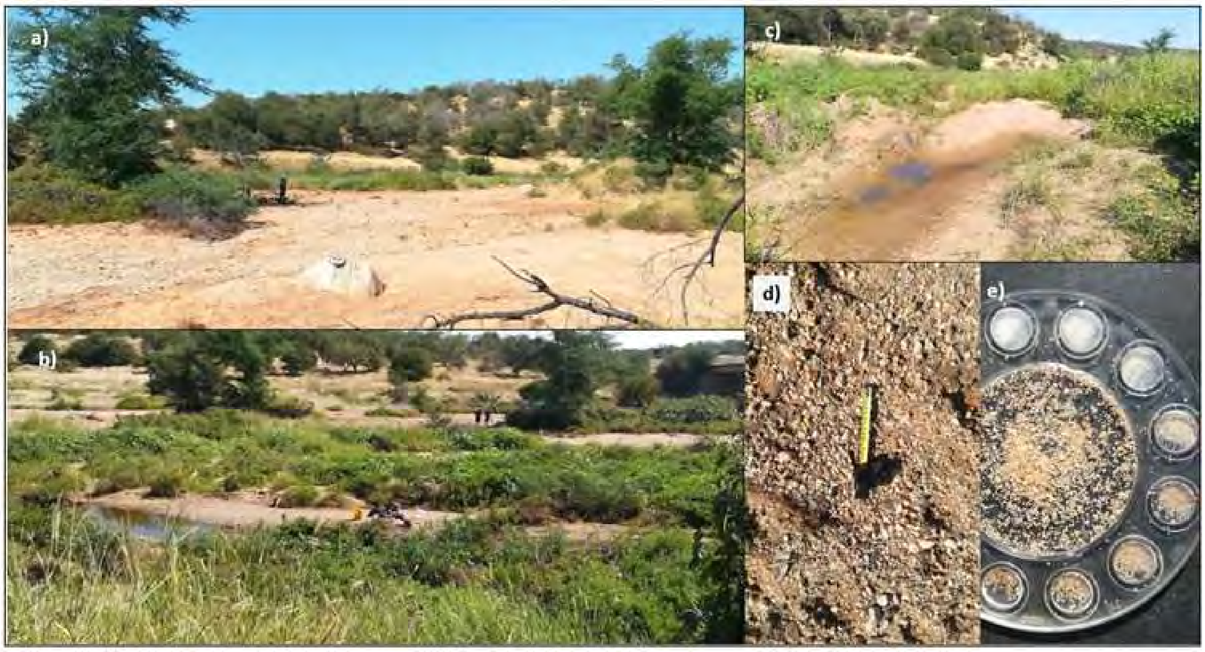


FIGURE 57: SITE IMAGES SHOWING A) VIEW LEFT BANK WITH GRAVEL AND SAND BAR IN FOREGROUND; B) VIEW FROM RIGHT BANK; C) HIGH FLOW CHANNEL AND VEGETATED SAND BARS; D) GRAVEL BAR; AND E) COARSE SAND FROM CHANNEL

The observed and modelled hydraulic parameters are presented in Table 4.21 and the rating equation in Table 4.22. The rating curve is shown in FIGURE 58 and the velocity depth modelled data in

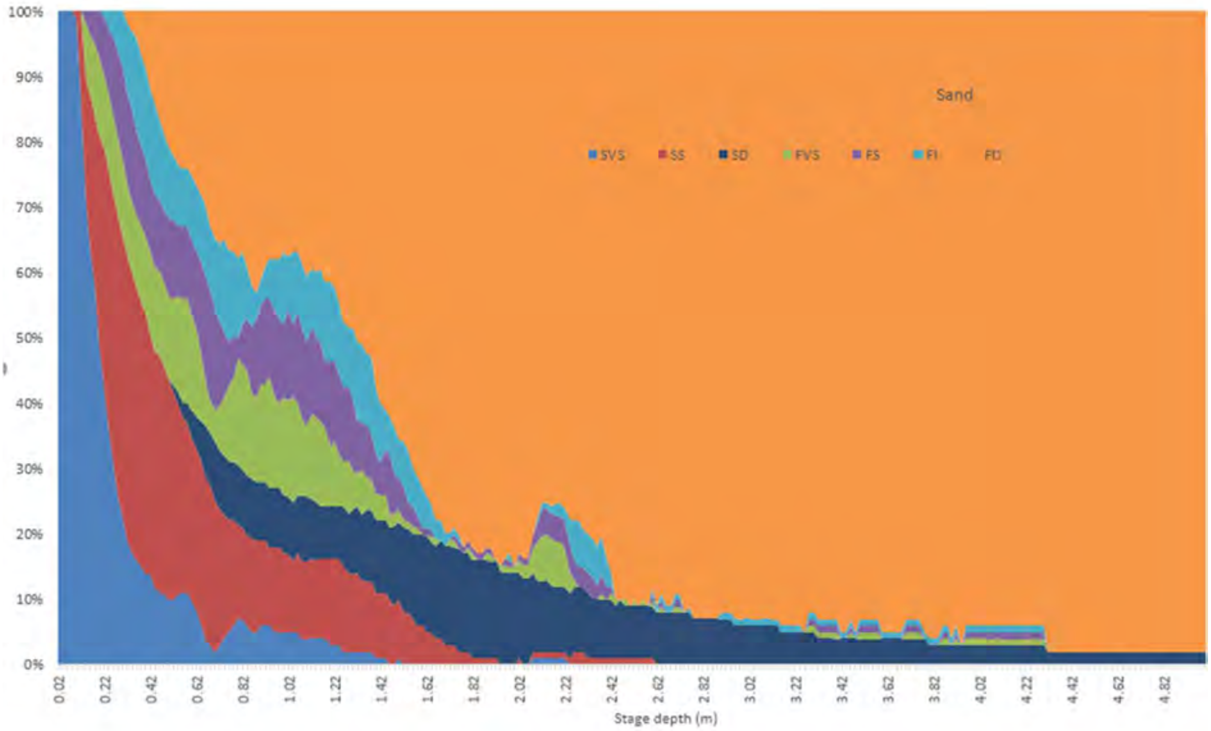


FIGURE 59.

TABLE 4.21: 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	0.001	NA	0.0017601	0.000	0.001	Modelled
28-Apr-21	0.12	0.126784	0.0017601	0.01	0.045	Observed
Flood 1	1.5	0.0450	0.0017601	47.564	0.689	Observed
Flood 2	3.5	0.0400	0.0017601	557.895	1.784	Modelled

TABLE 4.22: EQUATION FOR THE RATING CURVE

Power Fit: y=axb + c	
Coefficient Data:	
a =	0.404
b =	0.34
c =	0

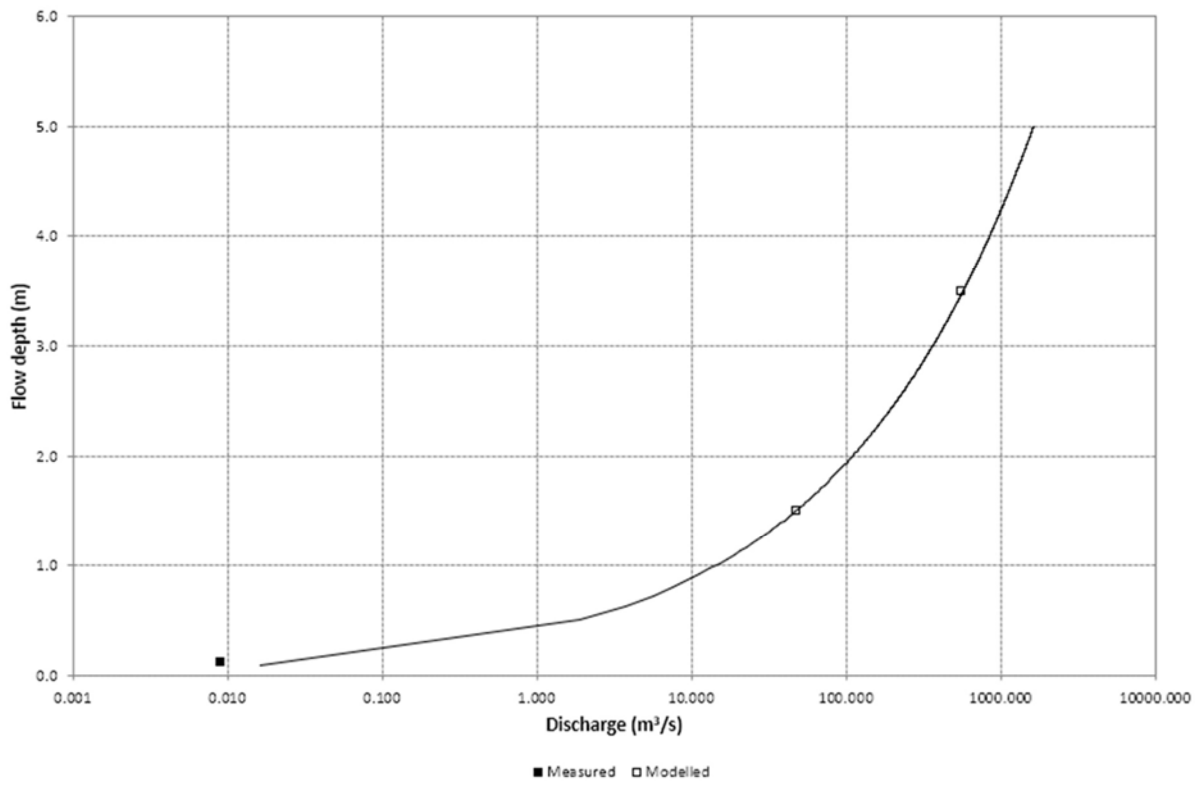


FIGURE 58: RATING CURVE FOR THE LIMPOPO RIVER AT THE POACHERS CORNER SITE

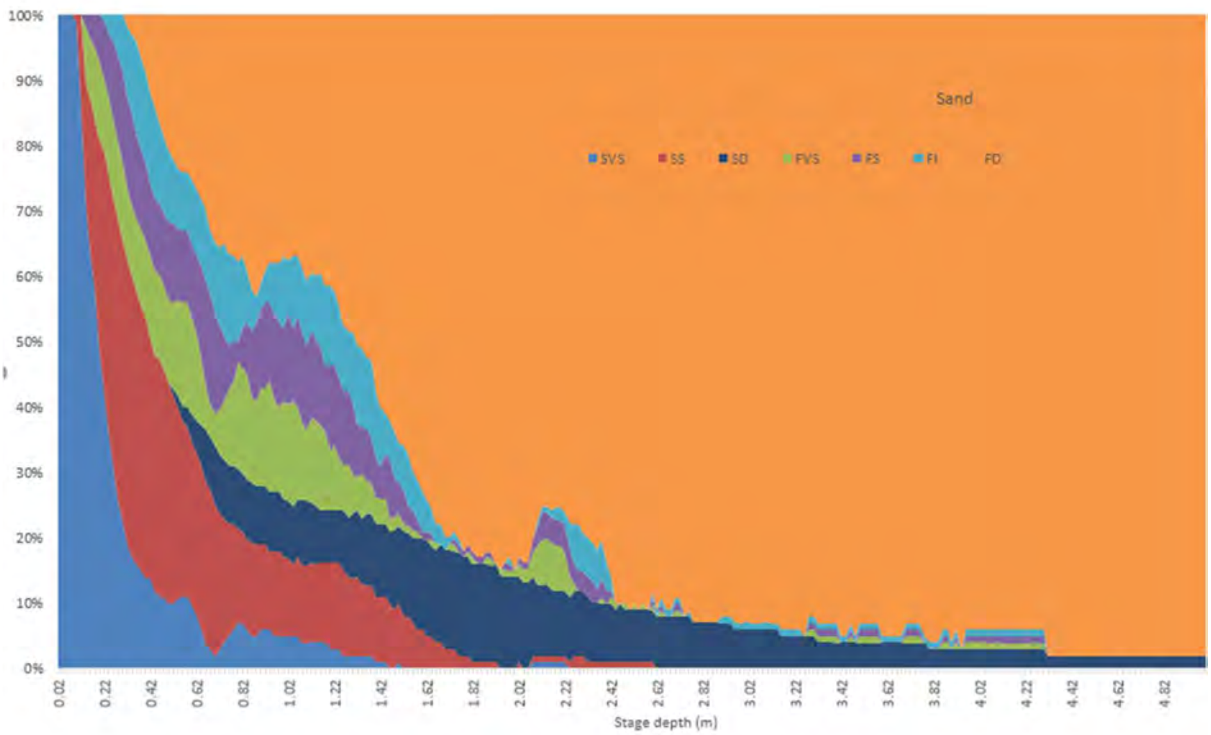


FIGURE 59: MODELLED VELOCITY DEPTH FREQUENCY DISTRIBUTIONS FOR VARIOUS MAXIMUM DEPTH LEVELS AT THE LIMPOPO RIVER POACHERS CORNER SITE

4.4.11 LUVU-A91K-OUTPO (Luvuvhu)

This section of the Luvuvhu River is characterised by a pool riffle sequence with cobble and boulder sized material along the riffle (

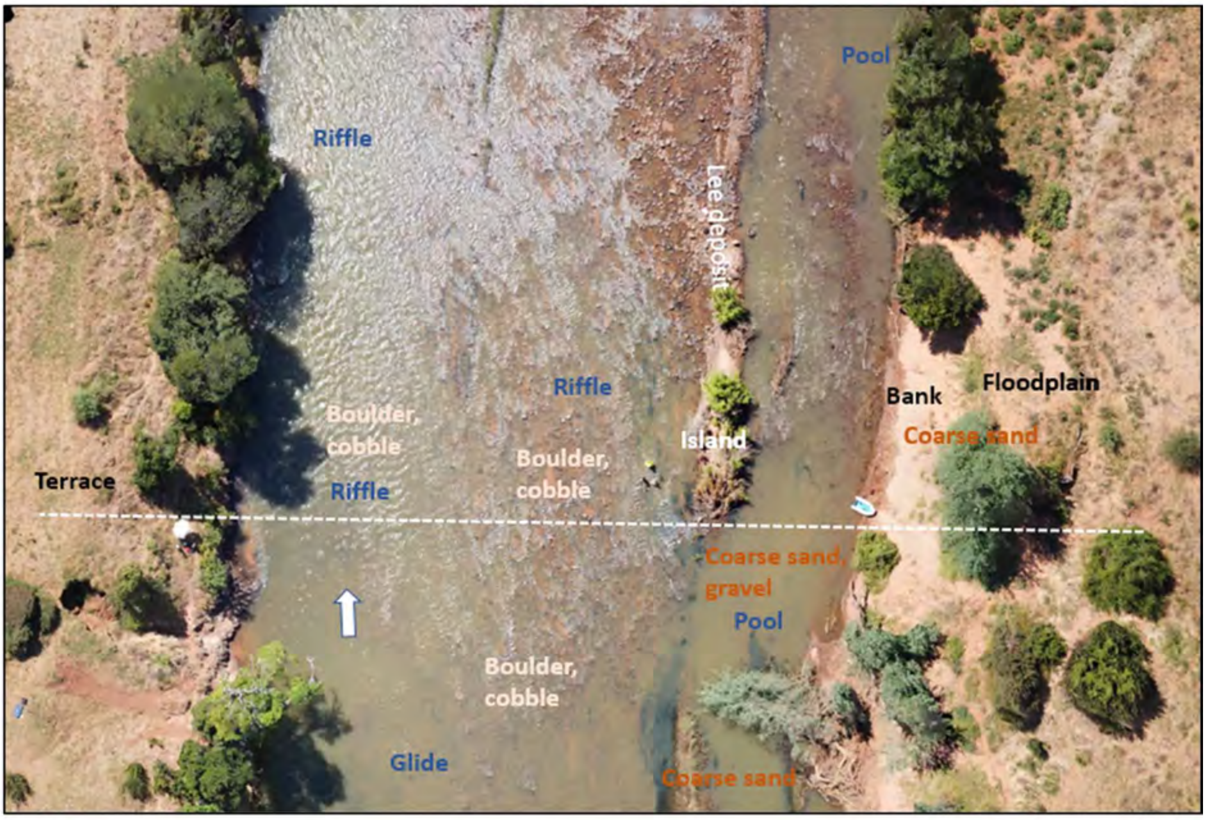


FIGURE 60,

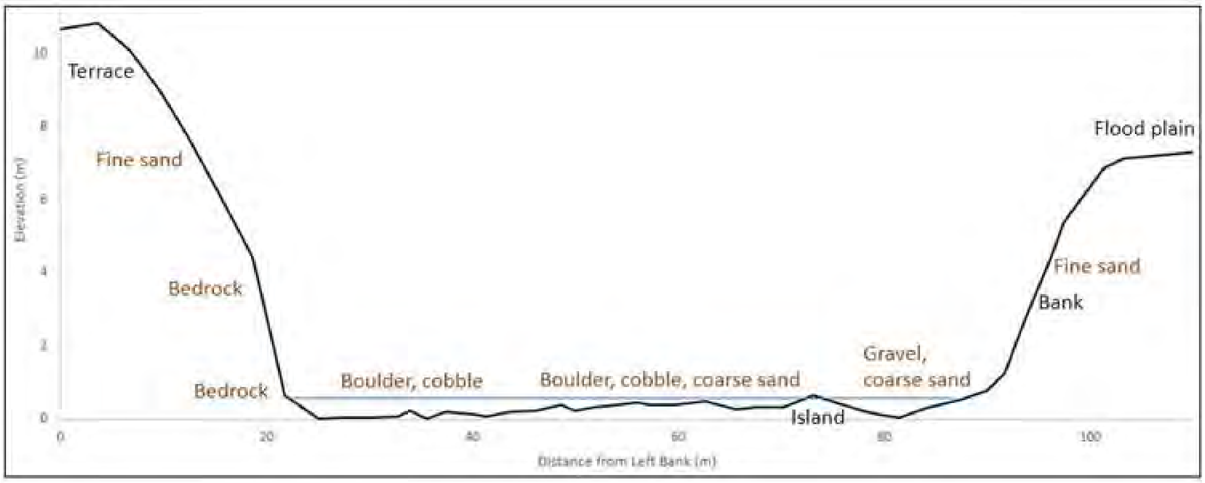


FIGURE 61,

FIGURE 62). The velocity distributions across the riffle and pool are presented in FIGURE 63. Sandy lee bars develop downstream of boulder high points. Small coarse sand and fine gravel deposits are found between the cobble and boulder high points in the slower flow of the riffle. The gravels and cobles are moderately loose and mobile where not embedded in sand or gravel. Very low embeddedness and imbrication in the flowing water of the riffle. Higher levels of imbrication and embeddedness out of the main flow zone. Bedrock is present along the left bank. The steep right bank is composed of loose medium to coarse sand and show erosion and deposition from the last food. The pools are lined with sand and silt over coble and gravel. Sandy inset benches develop and are covered by reeds.

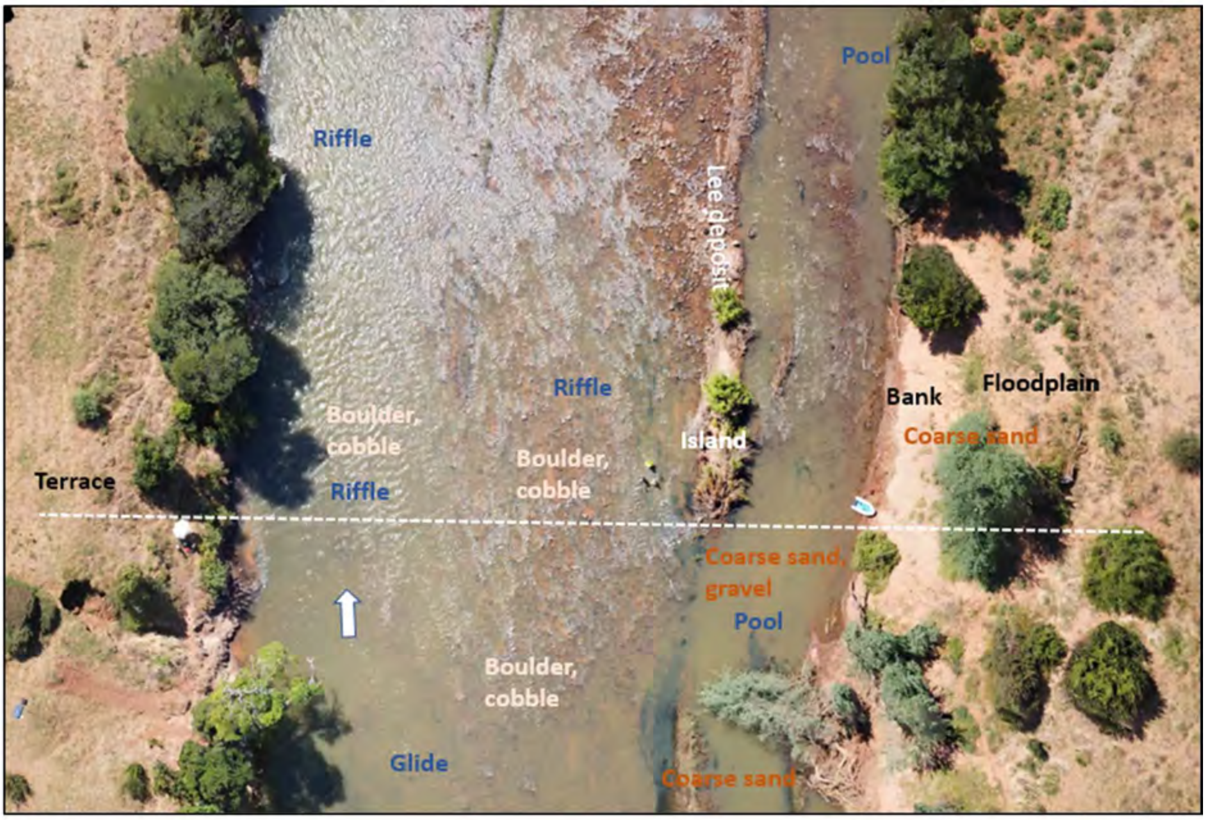


FIGURE 60: ORTHOPHOTO SHOWING MORPHOLOGICAL FEATURES AND SEDIMENT COMPOSITION OF THE LUVUVHU RIVER.

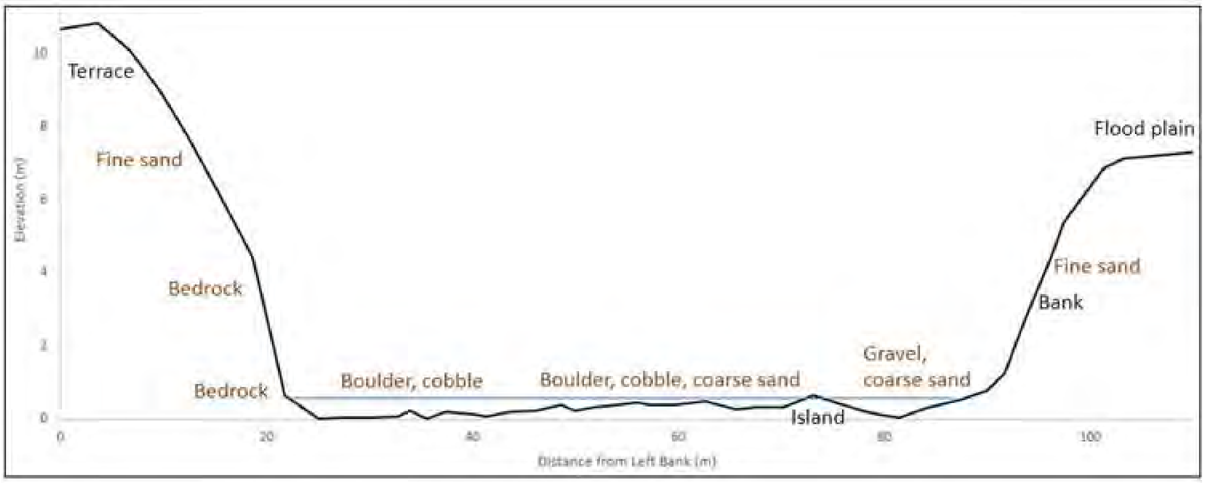


FIGURE 61: CROSS SECTION OF THE LUVUVHU RIVER SHOWING MORPHOLOGICAL FEATURES AND SEDIMENT COMPOSITION.

FIGURE 62: SITE IMAGES SHOWING A) THE VIEW FROM THE LEFT BANK; B) BOULDER AND COBBLE ALONG THE EDGE OF THE RIFFLE WITH SLOW FLOW; C) REEDS GROWING ON ELONGATED BOULDER AND COBBLE HIGH POINTS; D) RCOBBLE AND SAND MATRIC OUT OF CURRENT; E) COARSE SAND TRAPPED INBETWEEN COBBLES IN RIFFLE

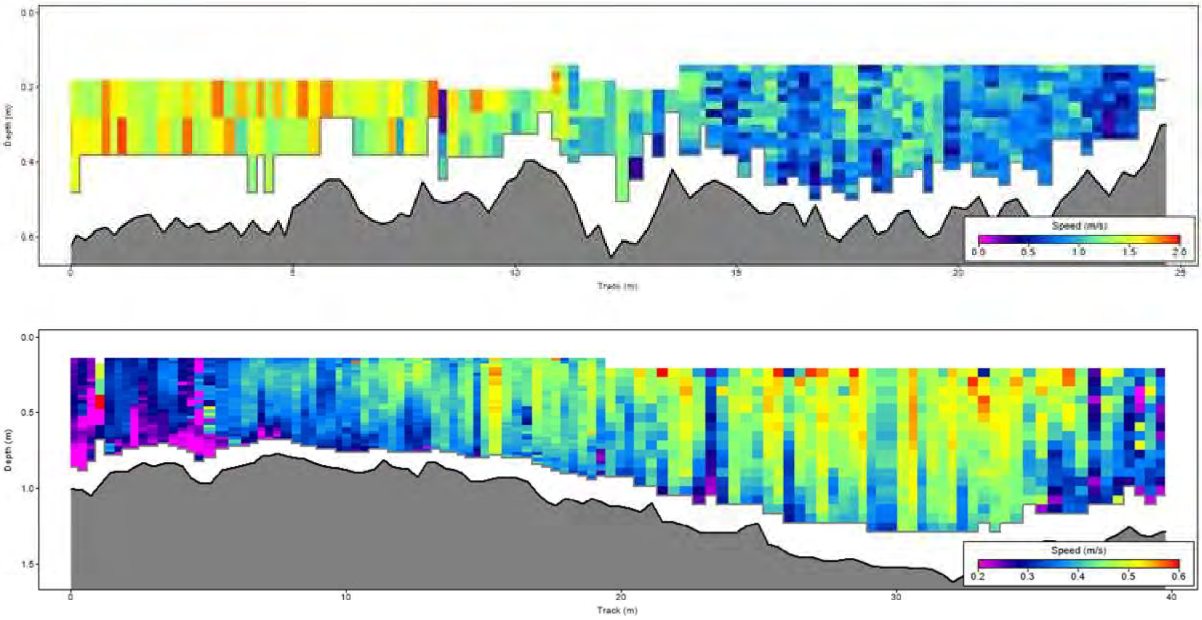


FIGURE 63: OBSERVED VELOCITY AND DEPTH ALONG THE RIFFLE (TOP) AND POOL (BOTTOM)

The observed and modelled hydraulic parameters are presented in Table 4.23 and the rating equation in Table 4.24. The rating curve is shown in FIGURE 64 with the modelled velocity depth frequency distribution presented in

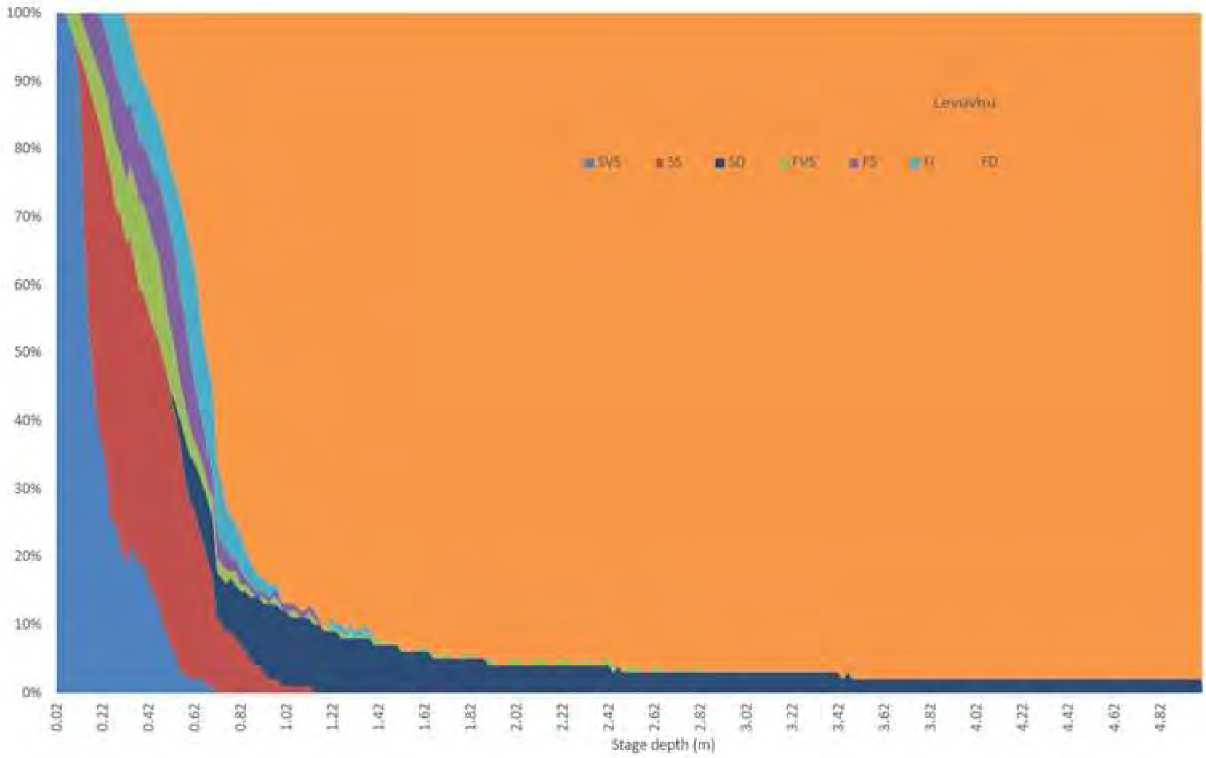


FIGURE 65.

TABLE 4.23: 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	0.0	N/A	N/A	0.000	0.000	Modelled
29-Apr-2021	0.7	0.059	0.004	17.43	0.607	Observed
Flood 1	3	0.045	0.004	502	2.610	Modelled
Flood II	4.5	0.040	0.004	1106	3.613	Modelled

TABLE 4.24: EQUATION FOR THE RATING CURVE

Power Fit: y=axb + c	
Coefficient Data:	
a =	0.164
b =	0.471
c =	0

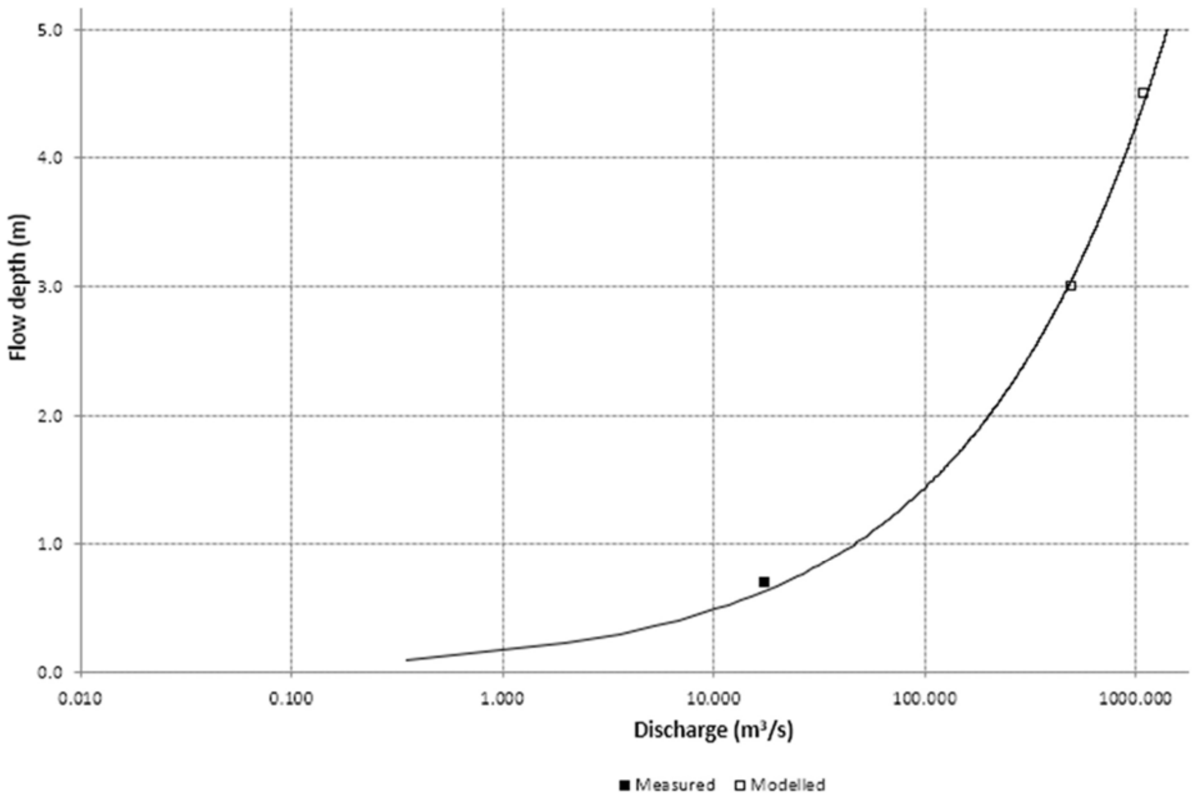


FIGURE 64: RATING CURVE FOR THE LEVUVHU RIVER SITE

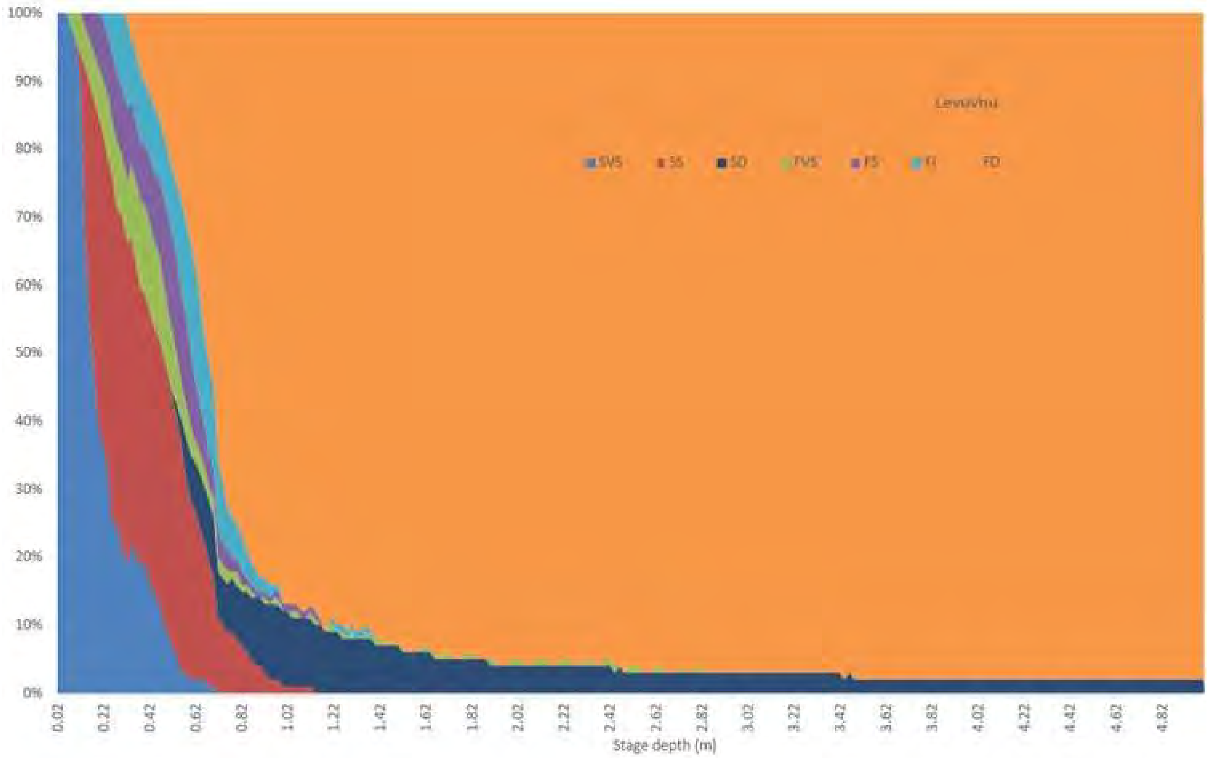


FIGURE 65: MODELLED VELOCITY DEPTH FREQUENCY DISTRIBUTIONS FOR VARIOUS MAXIMUM DEPTH LEVELS AT THE LEVUVHU RIVER SITE

4.4.12 SHIN-B90H-POACH (Shingwedzi)

The Shingwedzi River is incised into the surrounding landscape with a very narrow floodplain (

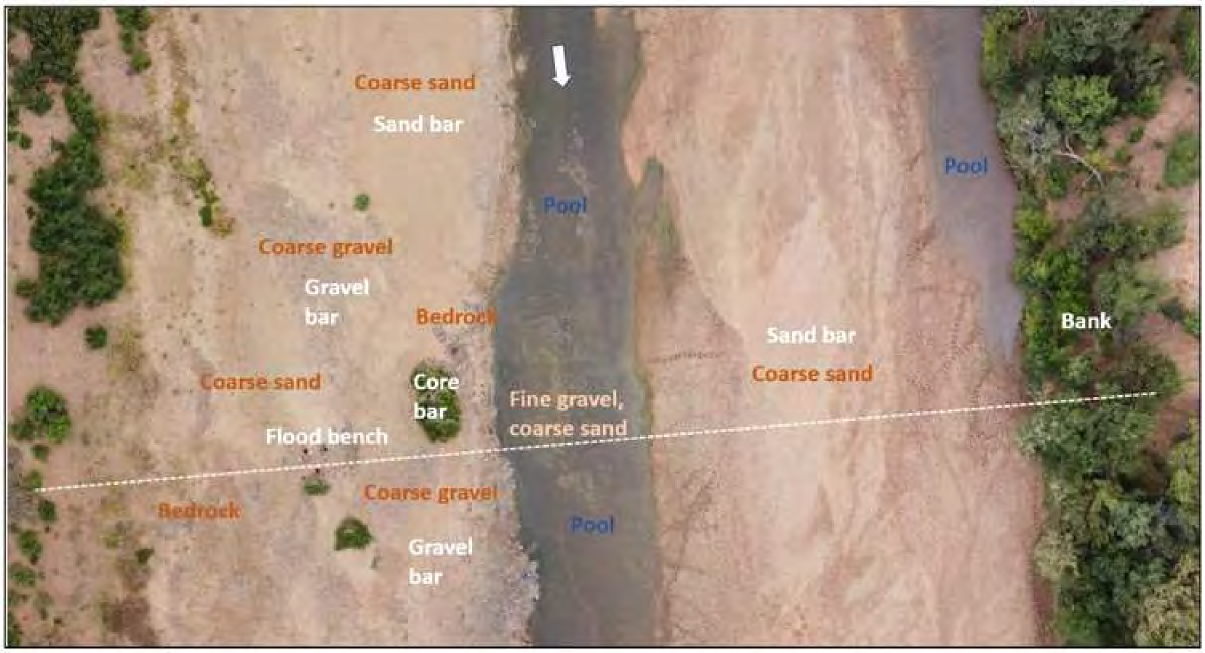


FIGURE 66). Pools form along the gentler gradients with wide shallow slow flowing water. Coarse sand and fine gravel dominate the bed material. The left bank is steep with good tree cover and composed of fine sand and silt. The right bank is composed of various levels of sand and gravel bars forming various flood levels.

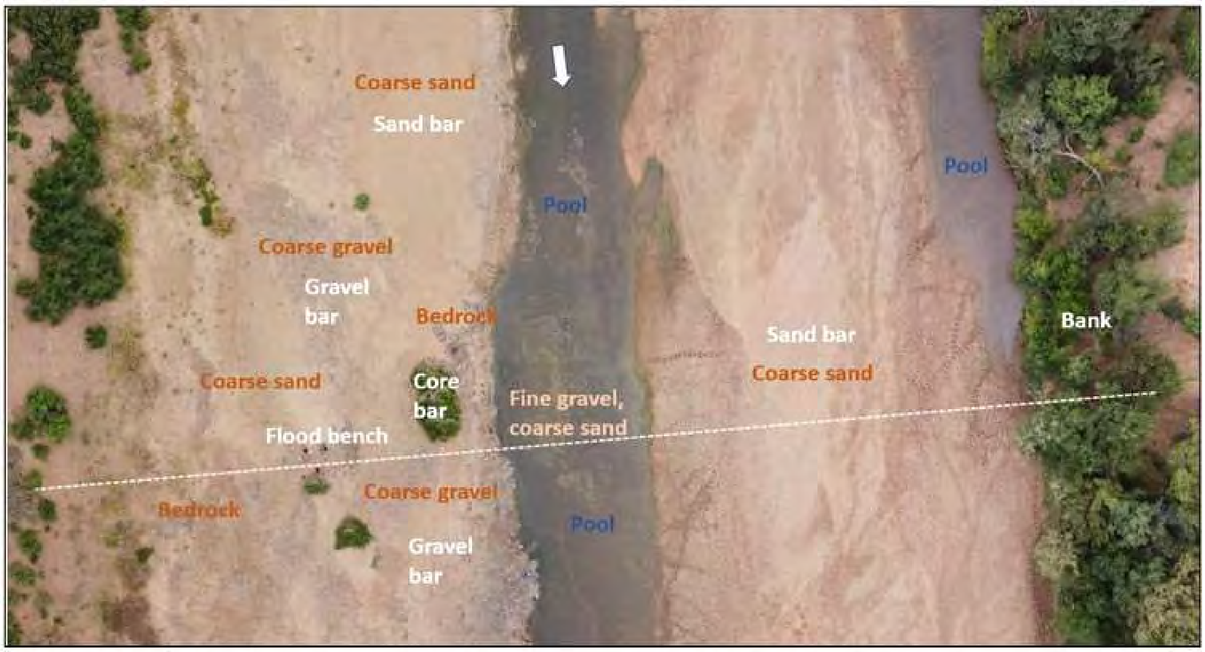


FIGURE 66: ORTHOPHOTO SHOWING MORPHOLOGICAL FEATURES AND SEDIMENT COMPOSITION OF THE SHINGWEDZI RIVER.

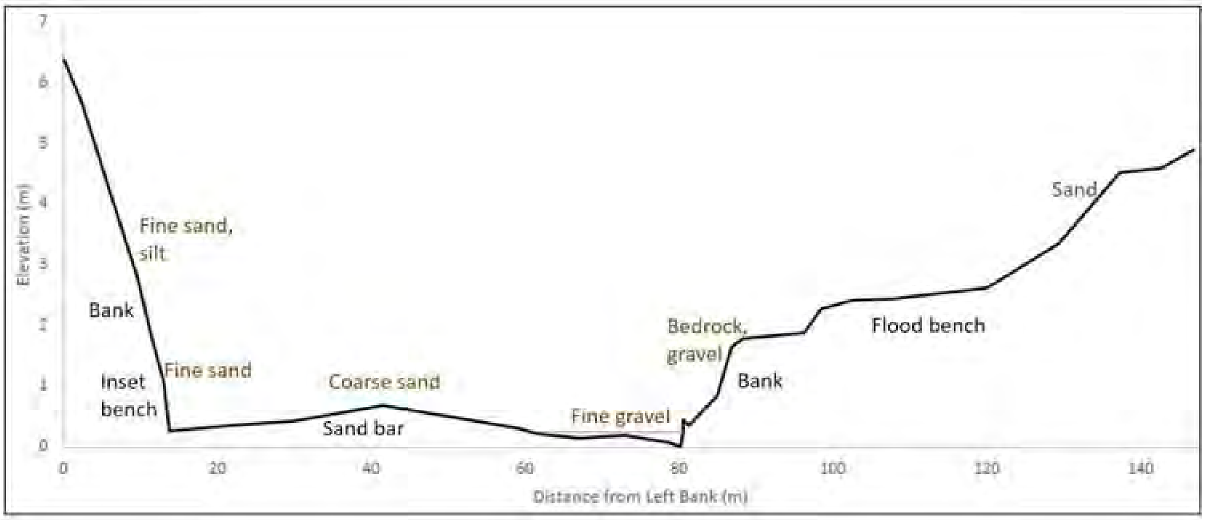


FIGURE 67: CROSS SECTION OF THE SHINGWEDZI RIVER SHOWING MORPHOLOGICAL FEATURES AND SEDIMENT COMPOSITION.

FIGURE 68: SITE IMAGES SHOWING A) A VIEW FROM THE RIGHT BANK (GRAVEL ON THE FLOOD BENCH IN FOREGROUND); B) WELL VEGETATED BANKS AND SANDY CHANNEL; C) FIEW OF THE SANDY CHANNEL FROM THE LEFT BANK; D) SANDY LEE DEPOSIT BEHIND BEDROCK CORE ISLAND

The observed and modelled hydraulic parameters are presented in Table 4.25 and the rating equation in Table 4.26. The rating curve is presented in FIGURE 69 and the modelled velocity depth frequency distributions are presented in

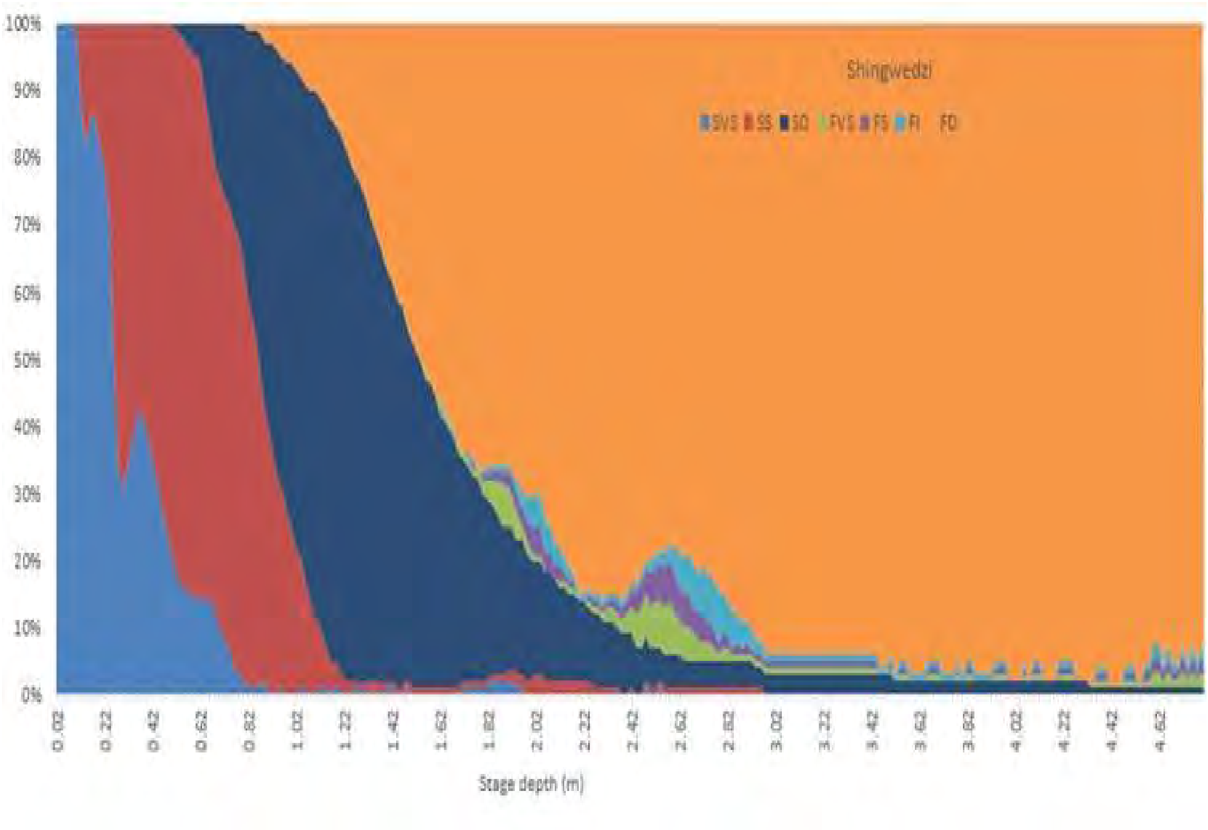


FIGURE 70.

TABLE 4.25: 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	0.0	N/A	N/A	0.000	0.000	Modelled
1-May-2021	0.22	0.38	0.00035	17.43	0.009	Observed
Flood 1	2	0.035	0.00035	81	0.67	Modelled

TABLE 4.26: EQUATION FOR THE RATING CURVE

Power Fit: y=axb + c

Coefficient Data:	
a =	0.665
b =	0.25
c =	0

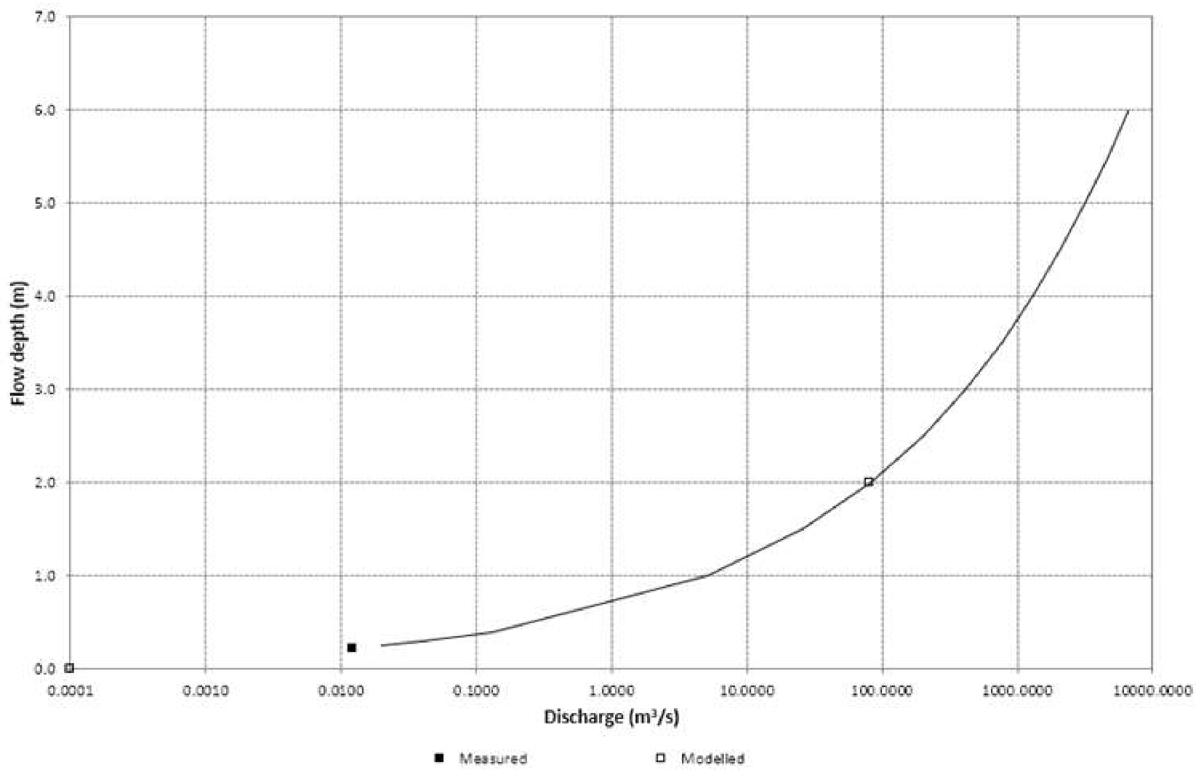


FIGURE 69: RATING CURVE FOR THE SHINGWEDZI RIVER SITE

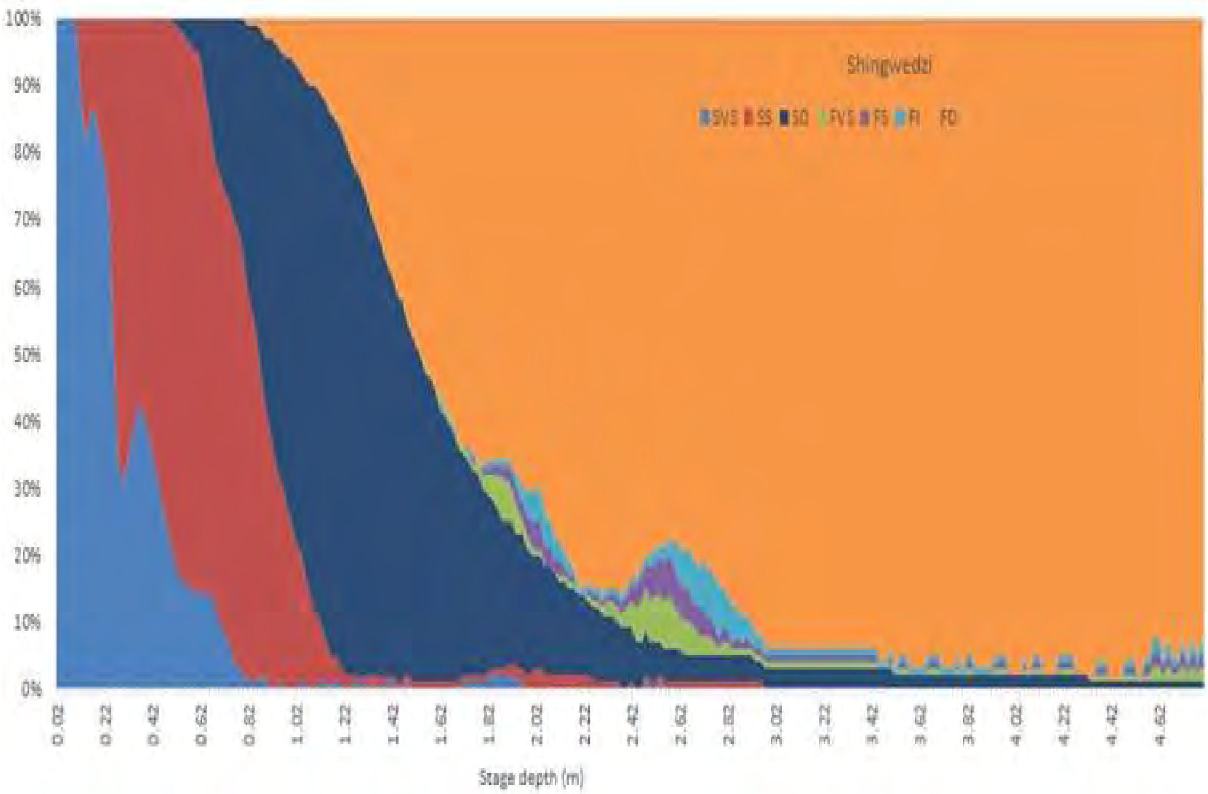


FIGURE 70: MODELLED VELOCITY DEPTH FREQUENCY DISTRIBUTIONS FOR VARIOUS MAXIMUM DEPTH LEVELS AT THE SHINGWEDZI RIVER SITE

4.4.13 LETA-B83A-LONEB (Letaba at Lone Bull)

This Letaba River reach is a mixed bed section with steeper bedrock sections interspersed wilt longer lower angle sandy and gravel sections. It follows a pool riffle sequence along the steeper bedrock sections (

FIGURE 71). Large gravel bars form with smaller sand bars as lee deposits or along the active channel margins (

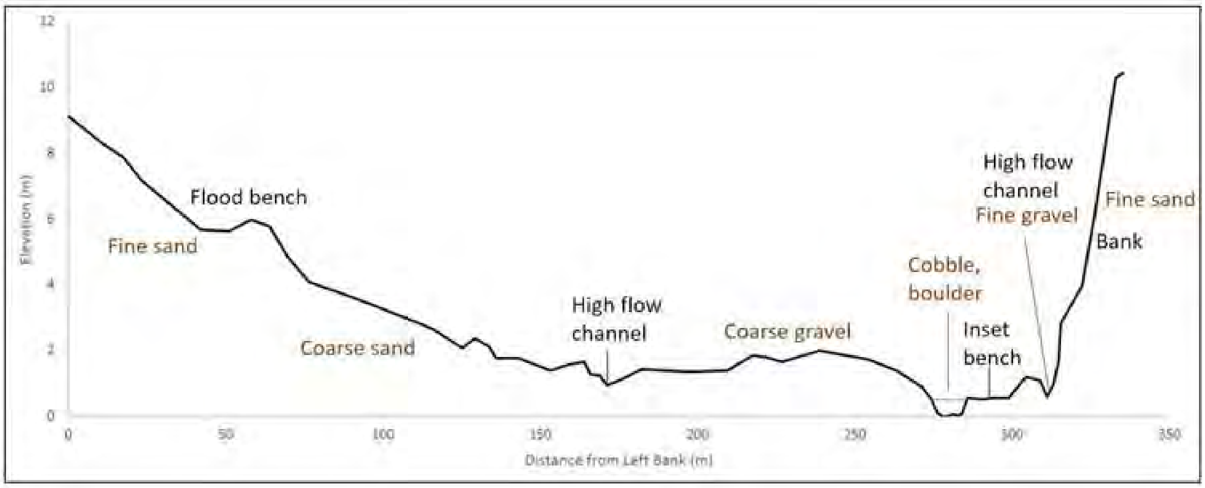


FIGURE 72,). Bedrock core bars have grass and reed cover and trap finer sand. Woody debris in the channel causes local scour and useful cover for biota. Small secondary channels with gravel bottoms are present along the right bank. The steep right bank shows signs of local erosion and deposition. Silt drapes form in slack water, with low siltation in flowing water. The wide extensive gravel bars are cemented and embedded with sand, giving the impression that they were covered by sediment and was recently uncovered. Some grazing is taking place on the vegetated bars at low elevation.

The boulders and cobble in the riffle are loose and mobile, with increased sand embeddedness along the channel edges. Low flows are concentrated in relatively rough cobble and boulder lined channels, where higher flows overtop gravel and sand bars. Flood flows will make vegetated flood benches available.

FIGURE 71: ORTHOPHOTO SHOWING MORPHOLOGICAL FEATURES AND SEDIMENT COMPOSITION OF THE LETABA RIVER.

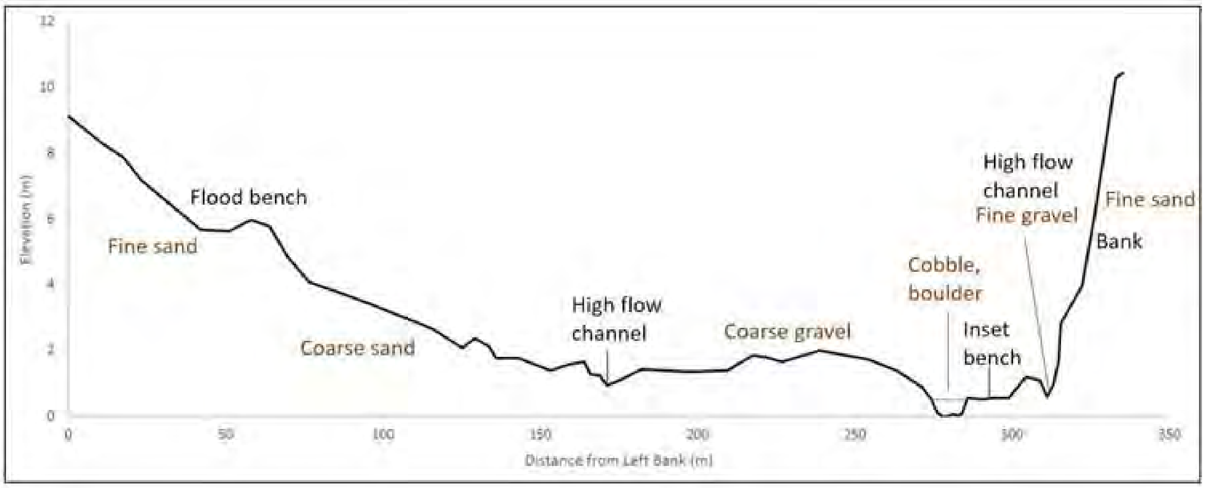


FIGURE 72: CROSS SECTION OF THE LETABA RIVER SHOWING MORPHOLOGICAL FEATURES AND SEDIMENT COMPOSITION.

FIGURE 73: SITE IMAGES SHOWING A) A VIEW OF THE CHANNEL FROM THE RIGHT BANK; B) BOULDERS AND COBBLE IN THE RIFFLE; C) VEGETATED INSET BENCHES ALONG THE RIGHT BANK; D) SAND BAR MATERIAL; AND E) GRAVEL BAR MATERIAL

The observed and modelled hydraulic parameters are presented in Table 4.27 and the rating equation in Table 4.28. The Rating curve is shown in FIGURE 74: RATING CURVE FOR THE LETABA RIVER SITE.

TABLE 4.27: 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	0.001	0.1	0.0071	0.0	0.001	Modelled
4-May-2021 	 0.3	 0.042	 0.0071	 1.66	 0.753	Observed
Flood 1	2.5	0.038	0.0035	357	1.651	Modelled
Flood 2	4.5	0.035	0.0035	2158	3.235	Modelled

TABLE 4.28: EQUATION FOR THE RATING CURVE

Power Fit: y=axb + c	
Coefficient Data:	
a =	0.34
b =	0.336
c =	0

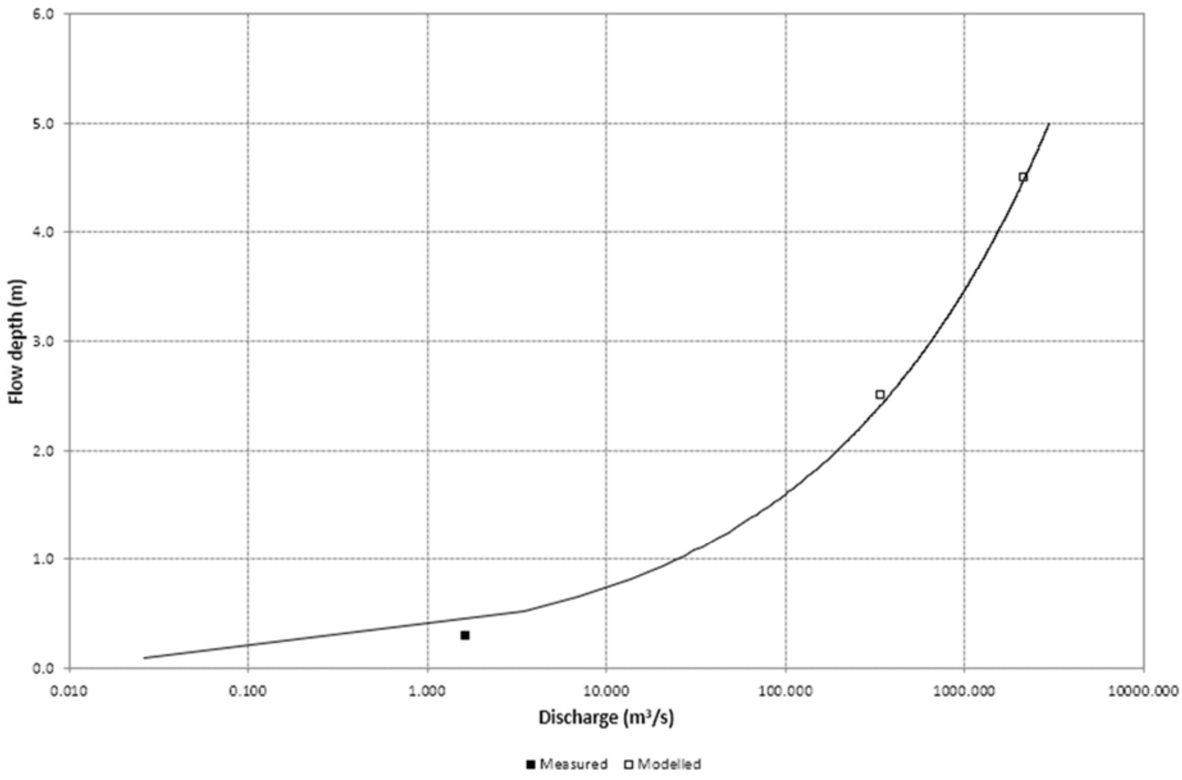


FIGURE 74: RATING CURVE FOR THE LETABA RIVER SITE

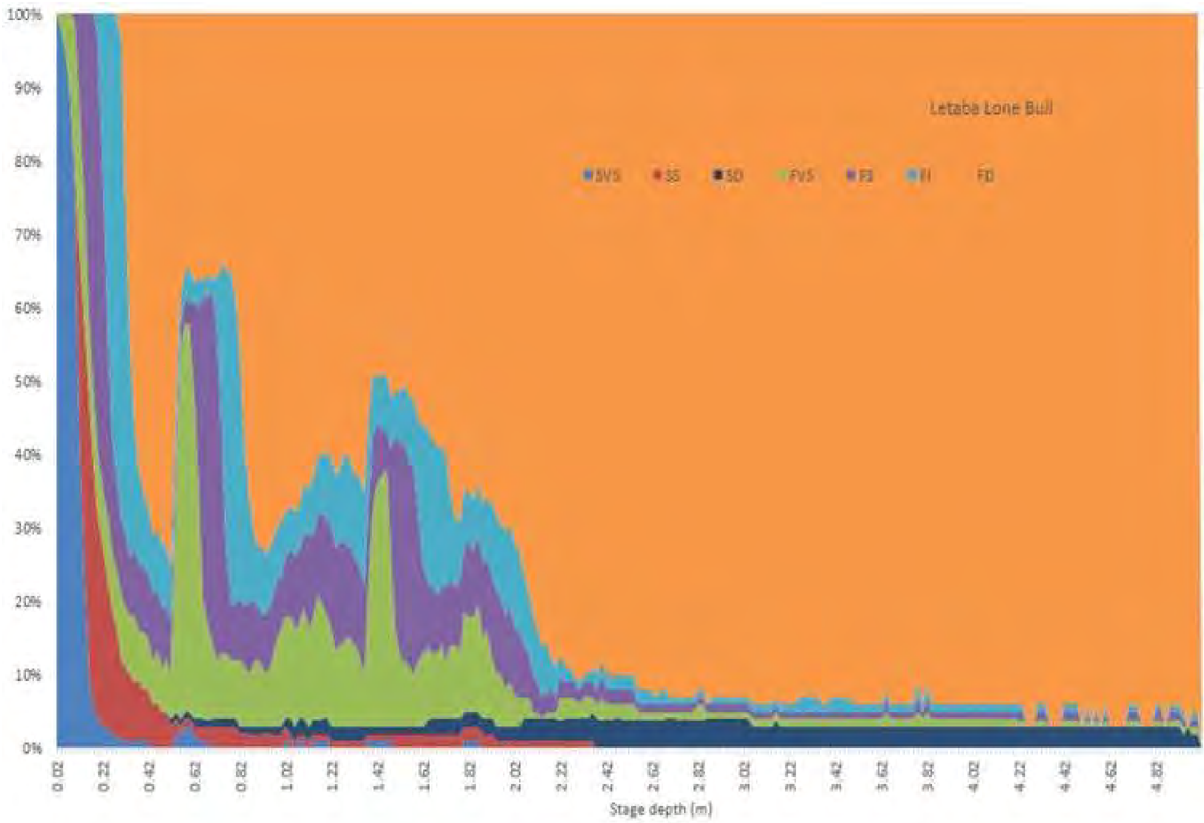


FIGURE 75: MODELLED VELOCITY DEPTH FREQUENCY DISTRIBUTIONS FOR VARIOUS MAXIMUM DEPTH LEVELS AT THE LETABA RIVER SITE

4.4.14 GLET-B81J-LRANC (Groot Letaba)

The Letaba River is incised into the surrounding relatively flat landscape. It has a narrow flood zone with well grassed flood benches composed of fine sand (

FIGURE 76, FIGURE 77). The bedrock sections are steeper, providing riffle type habitats. It follows a pool riffle sequence, except for steeper bedrock sections where rapids form. Glides and runs were observed. In between the bedrock sections the channel is wider and less steep, resulting in the formation of sand bars. The sand bars create a braided low flow pattern. Cobble and gravel are deposited in between the protruding bedrock. Coarse sand is deposited behind higher bedrock features, forming lee bars. Reeds are present along the low flow channel margin, with grass growing on smaller inset benches. Game grazing and trampling evident at the site.

The cross section is located along a gradual glide/riffle run transition just upstream of a pool. The local bedrock protrusions cause significant flow resistance with a downstream dyke controlling the energy gradient. Low to moderate confidence in the model output.

FIGURE 76: ORTHOPHOTO SHOWING MORPHOLOGICAL FEATURES AND SEDIMENT COMPOSITION OF THE GROOT LETABA RIVER.

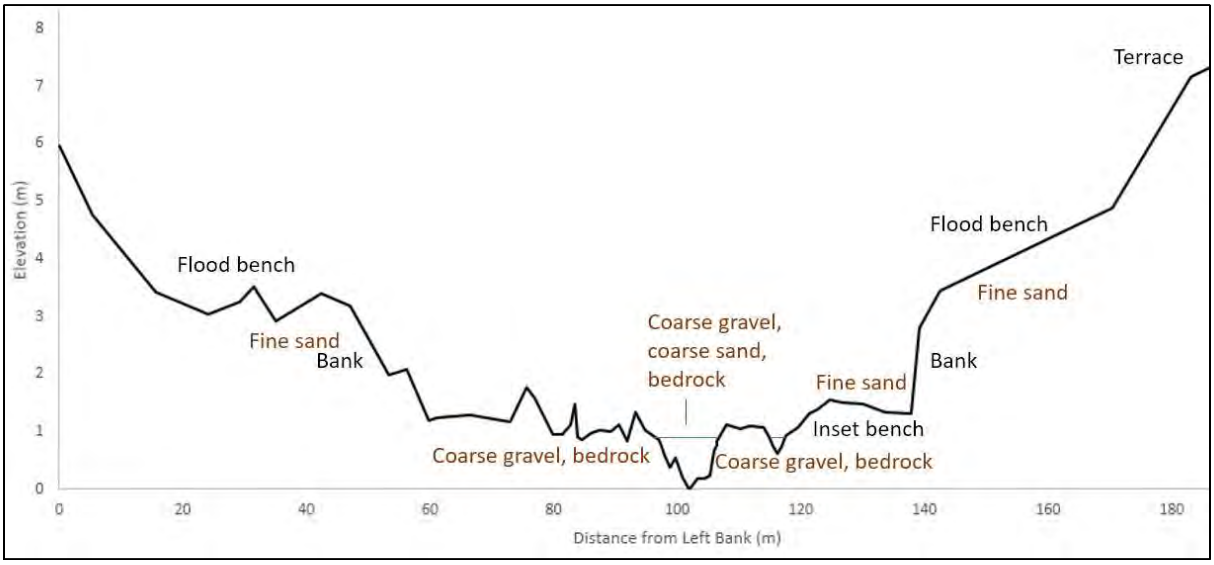


FIGURE 77: CROSS SECTION OF THE GROOT LETABA RIVER SHOWING MORPHOLOGICAL FEATURES AND SEDIMENT COMPOSITION.

FIGURE 78: SITE IMAGES SHOWING A) A DOWNSTREAM VIEW OF THE CHANNEL; B) SANDY LEE DEPOSITS BEHIND BEDROCK; C) SAND BARS IN THE CHANNEL; D) COARSE SAND DEPOSIT; E) SPARSELY VEGETATAED GRAVEL BAR; AND F) EMBEDDED COBBLES AND BEDROCK

The observed and modelled hydraulic parameters are presented in Table 4.29 with the resultant rating equation in Table 4.30. The rating curve is shown in

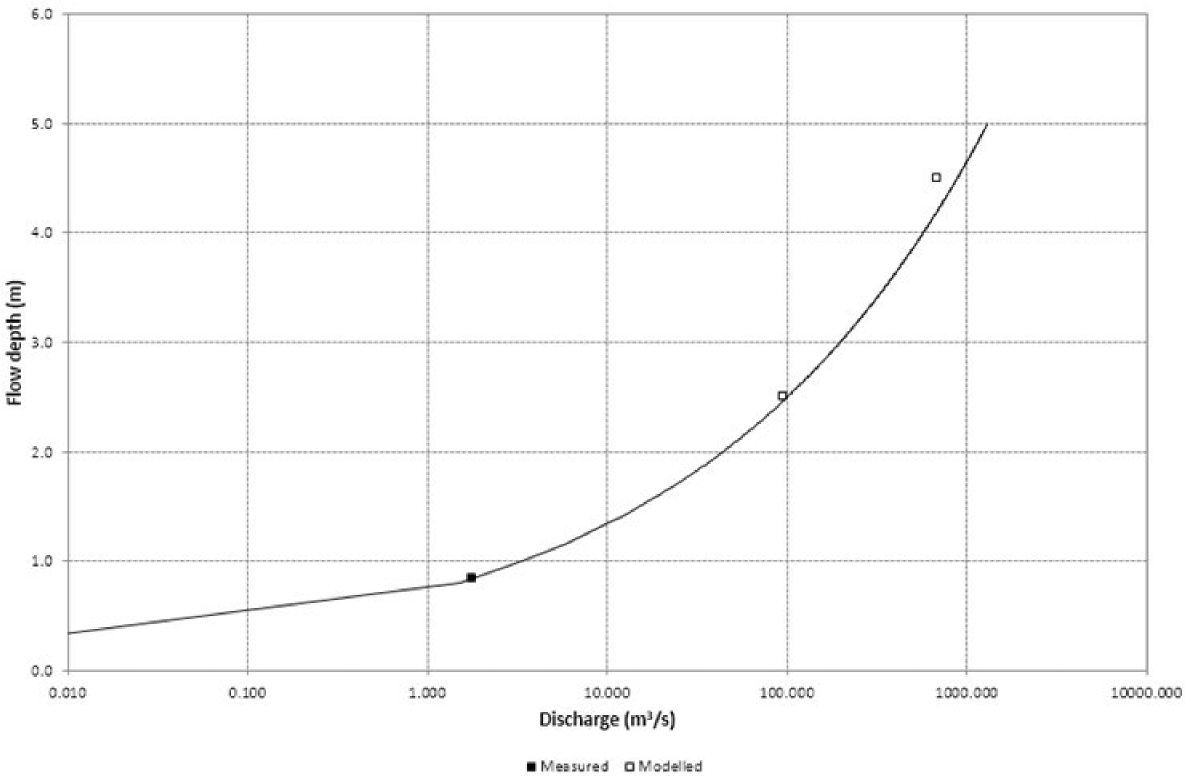


FIGURE 79 and the modelled velocity depth frequency distribution presented in

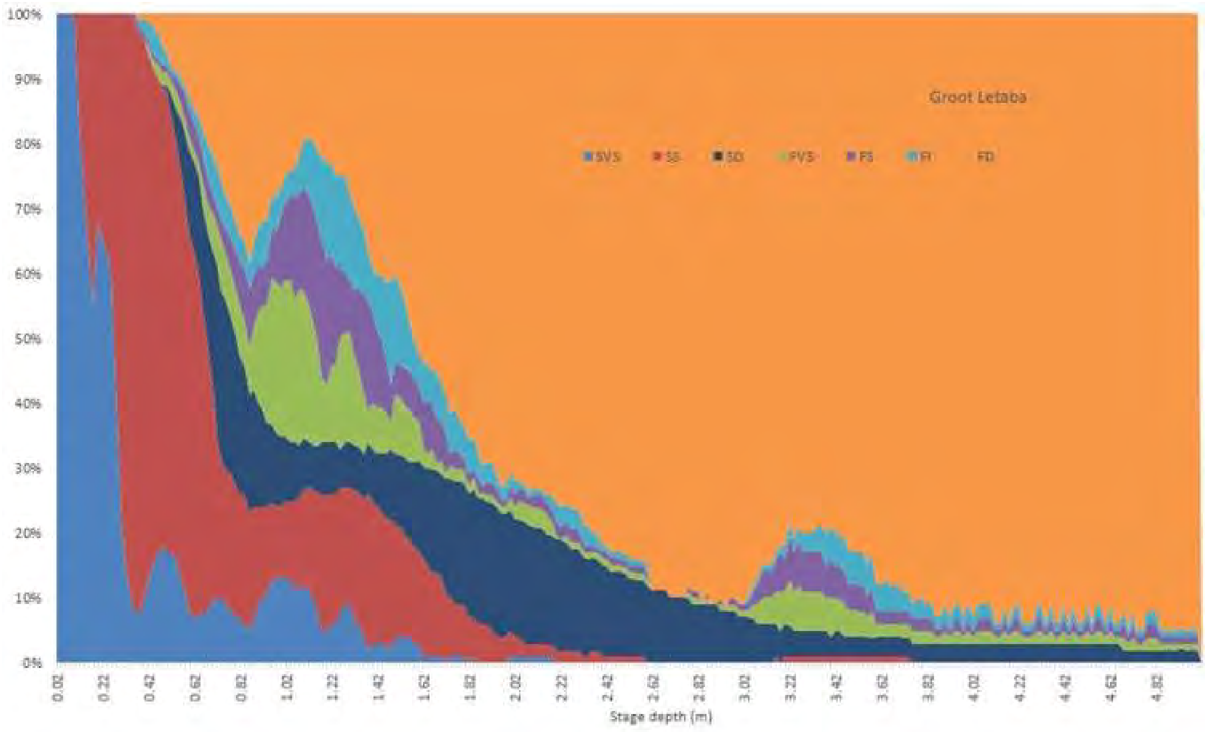


FIGURE 80.

TABLE 4.29: 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	0.001	0.1	0.00152	0.000	0.001	Modelled
6-May-2021	0.85	0.061	0.00152	1.79	0.358	Observed
Flood 1	2.5	0.055	0.00152	96	0.835	Modelled
Flood 2	4.5	0.035	0.00152	688	1.923	Modelled

TABLE 4.30: EQUATION FOR THE RATING CURVE

Power Fit: y=axb + c	
Coefficient Data:	

a =	0.72
b =	0.27
c =	0

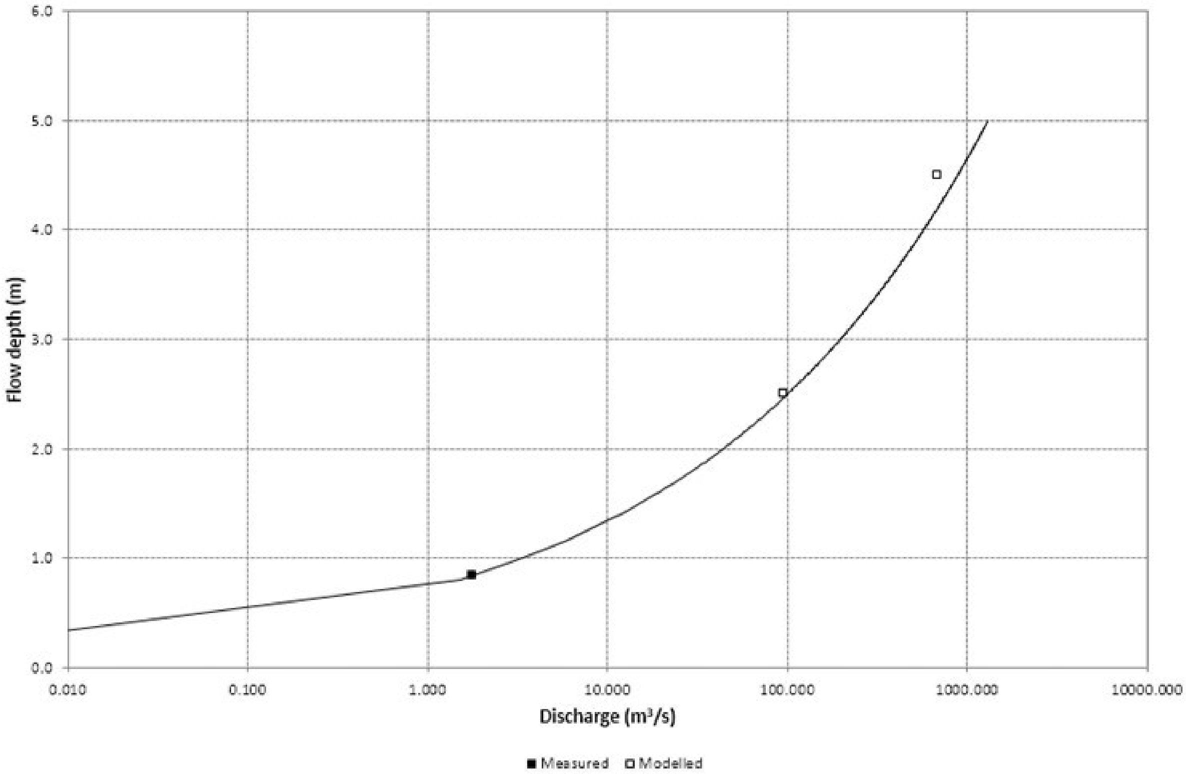


FIGURE 79: RATING CURVE FOR THE LETABA RIVER SITE

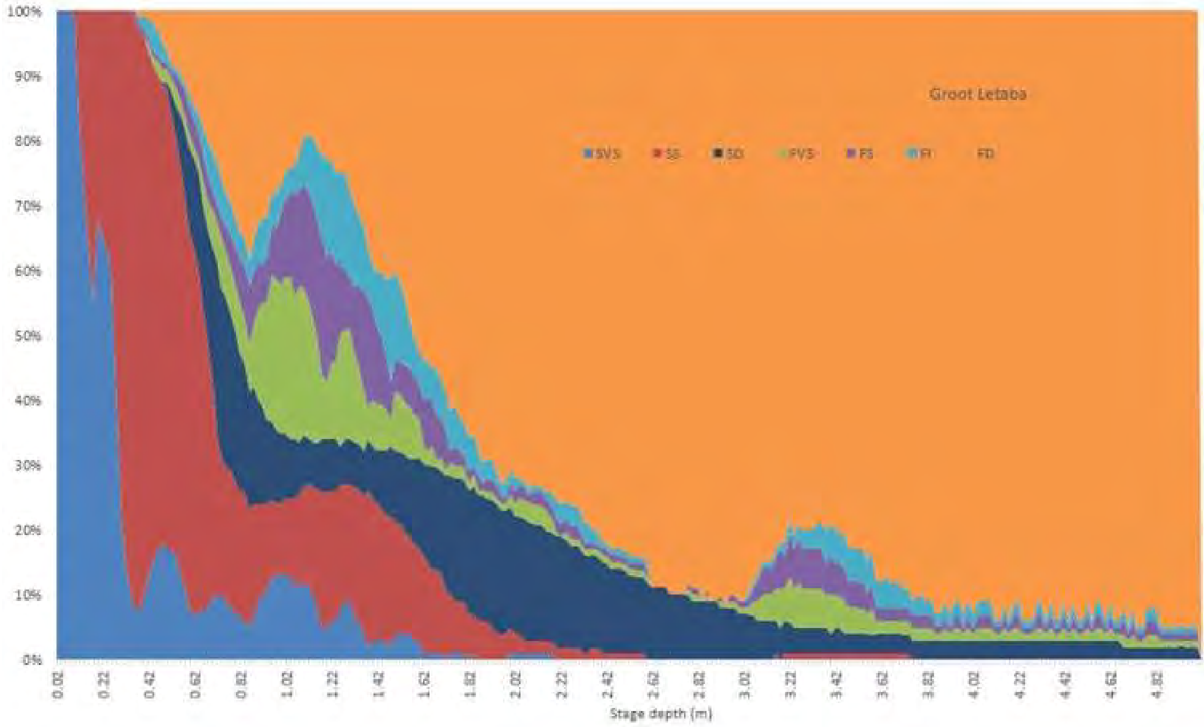


FIGURE 80: MODELLED VELOCITY DEPTH FREQUENCY DISTRIBUTIONS FOR VARIOUS MAXIMUM DEPTH LEVELS AT THE GROOT LETABA RIVER SITE

4.4.15 OLIF-B73C-MAMBA (Olifants at Mamba)

Locally steepened bedrock site immediately downstream of the Klaserie River confluence with the Olifants River. The site is located on a dolerite dyke that crosses the river at 45 degrees (

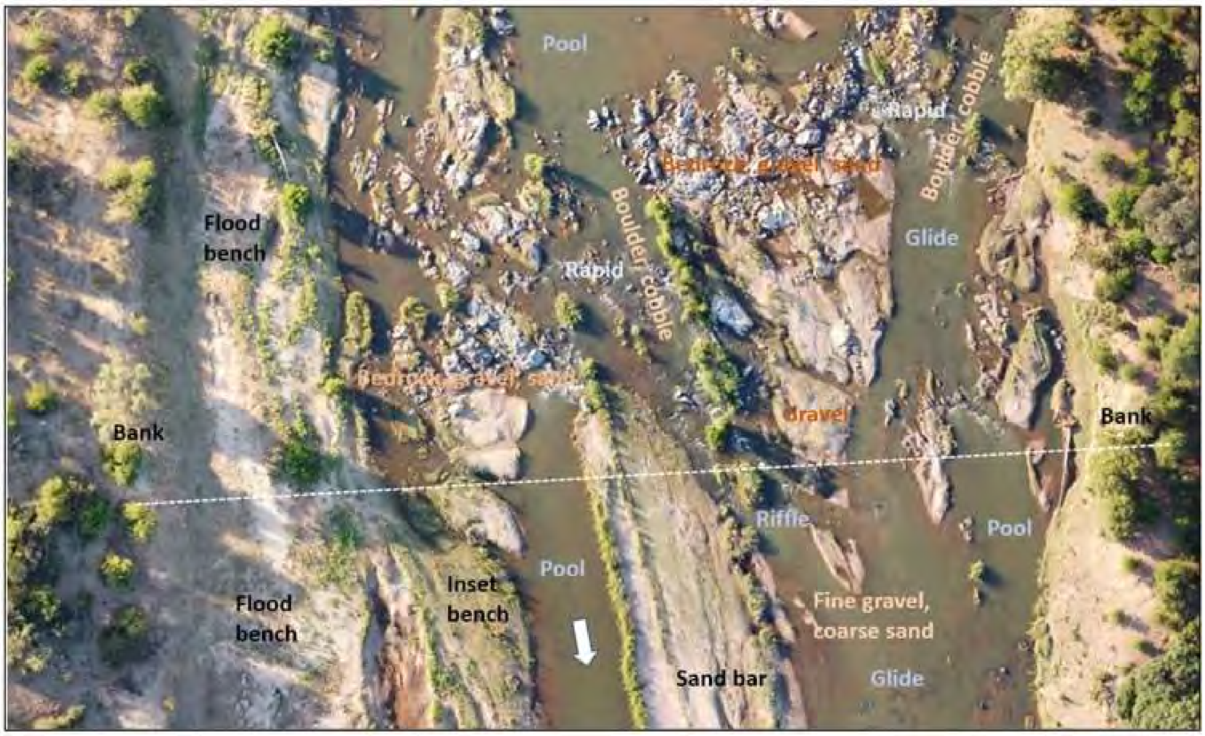


FIGURE 81). An anatomising channel pattern developed through the bedrock, with bedrock core bars

forming islands and a number of low flow channels with bedrock, boulder, cobble, gravel and sand habitat types. Reeds and trees grow on the core bars. Rapid habitats are associated with bedrock and boulders, riffles and runs are mostly over cobble and gravels. Glides are associated with gravel and coarse sand substrates.

Sandy low gradient reaches are common between bedrock sections. The river follows a wandering single channel or braided pattern where sand bars form in the channel.

The gradient flattens out at T2 with a run type of habitat over gravel and some bedrock. Flow is still turbulent and gradients steepen for higher discharges. Unfortunately, the channels are at different elevations, thus 1D hydraulics are not representative of the site for low flows. T1 is an order of magnitude worse (over 1m elevation difference between the channels).

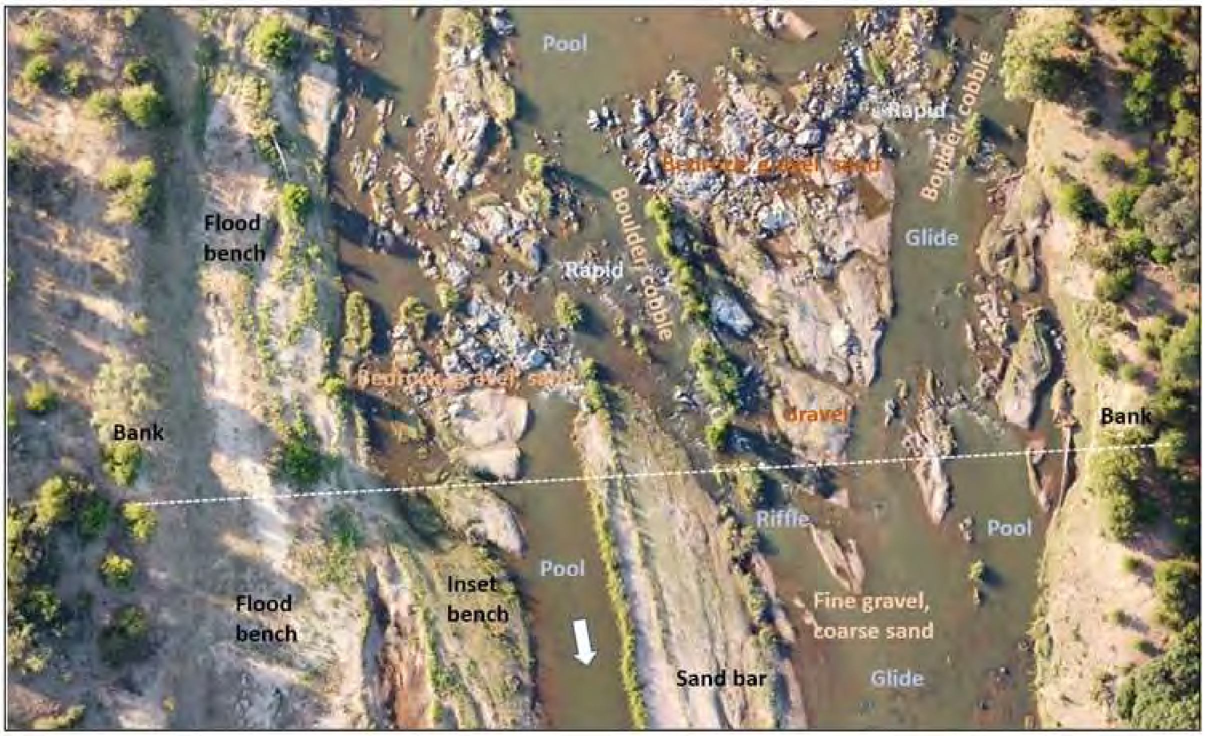


FIGURE 81: ORTHOPHOTO SHOWING MORPHOLOGICAL FEATURES AND SEDIMENT COMPOSITION OF THE OLIFANTS RIVER AT MAMBA.

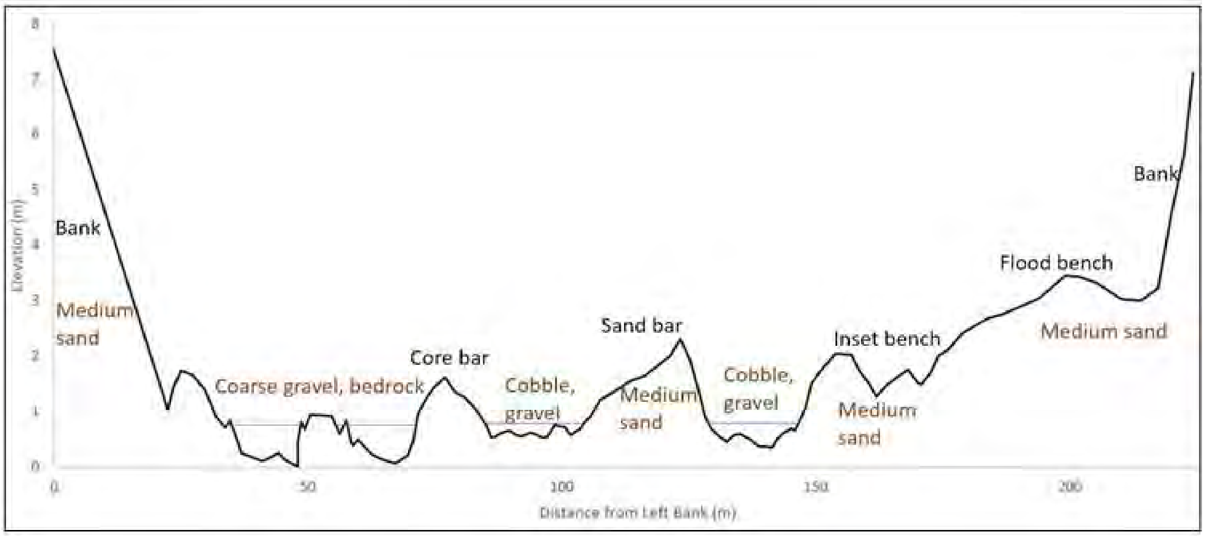


FIGURE 82: CROSS SECTION OF THE OLIFANTS RIVER AT MAMBA SHOWING MORPHOLOGICAL FEATURES AND SEDIMENT COMPOSITION.

FIGURE 83: SITE IMAGES SHOWING A) A DOWNSTREAM VIEW OF THE ANASTOMOSING CHANNEL; B) VIEW DOWNSTREAM OF THE ANASTOMOSING SECTION; C) GRAVEL RIFFLE IMMEDIATELY DOWNSTREAM OF BEDROCK SECTION; D) CORE BAR WITH REED AND TREE COVER

The observed and modelled hydraulic parameters are presented in TABLE 4.31 with the rating equation in Table 4.32. The rating curve is presented in

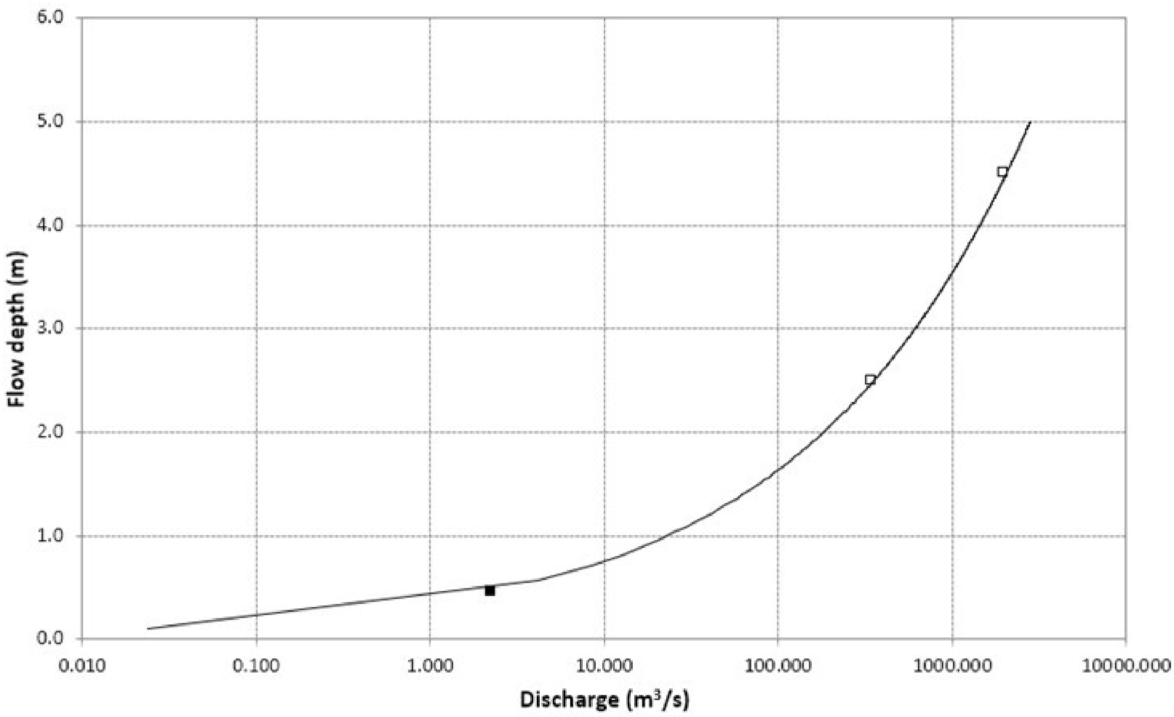


FIGURE **84** and the modelled velocity depth frequency distributions in

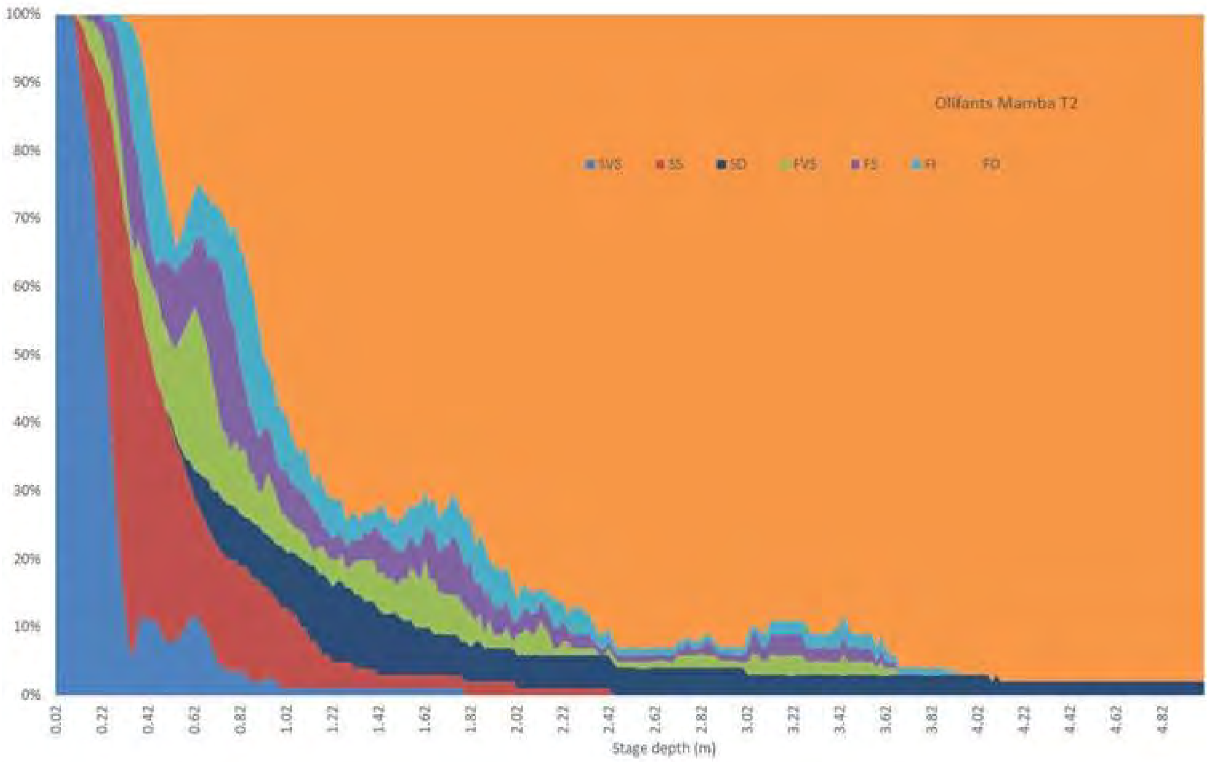


FIGURE **85**.

TABLE 4.31: 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	0.001	0.1000	0.0014	0.000	0.001	Modelled
30 Feb 2020	0.46	0.04	0.0014	2.27	0.347	Observed
Flood 1	2.5	0.0380	0.002	343	1.477	Modelled
Flood 2	4.5	0.0350	0.003	1985	3.201	Modelled

TABLE 4.32: EQUATION FOR THE RATING CURVE

Power Fit: y=axb + c	
Coefficient Data:	
a =	0.35
b =	0.335
c =	0

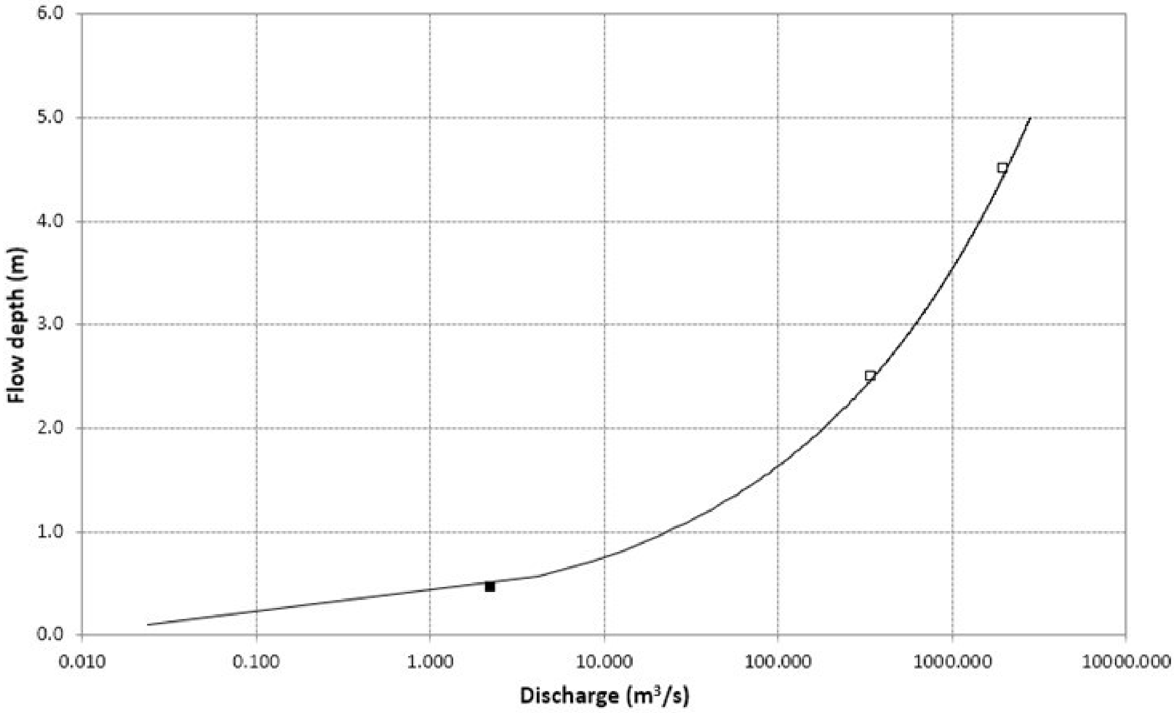


FIGURE 84: RATING CURVE FOR THE OLIFANTS RIVER AT MAMBA

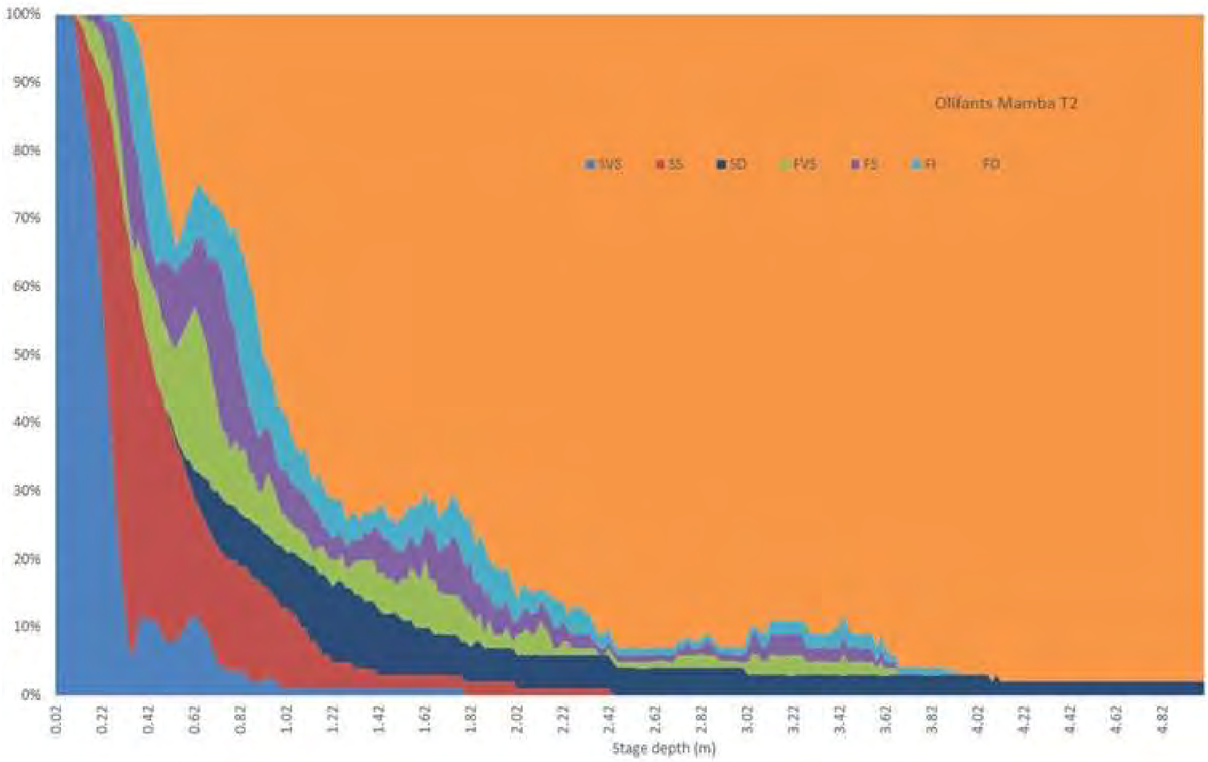


FIGURE 85: MODELLED VELOCITY DEPTH FREQUENCY DISTRIBUTIONS FOR VARIOUS MAXIMUM DEPTH LEVELS FOR THE OLIFANTS RIVER AT MAMBA

4.4.16 OLIF-B73H-BALUL (Olifants at Balule)

Balule is a bedrock controlled site at a dolerite dyke (Figure 86, Figure 87, Figure 88). The river follows an anastomosing flow pattern along the steeper bedrock sections and a wandering channel or braided low flow channel for the gentle gradient sections between bedrock sections. Several of the high flow channels become stagnant pool type habitats under low flow conditions. Silt deposits in these stagnant water during lower flows. Rapids, riffles, runs, glides and pools are associated with the bedrock sections, with glides and pools associated with the sandy sections. Bedrock core bars are common and are well vegetated with reeds, forbs and grasses. Inset benches are narrow and poorly defined and composed of fine to medium sand. A flood bench is located along the right bank. The river is incised into the surrounding plain, with no active floodplain.

There is downstream fining of sediment from the rapids (boulder), riffle (cobble and gravel) to pools (sand and silt). Sand is largely stored as sand bars along the gentler gradient sections. The sand is moving in a single layer in water as shallow as 20cm.

Flood debris was observed at 3 to 3.9m above the channel bed for 2021.

The upper and middle catchment has moderate to low densities of natural grassland and woodland that is used for grazing, with moderate densities of dryland agriculture, fallow fields, subsistence agriculture and urban development and low densities of mining. The lower catchment is largely natural grassland and woodland used for grazing purposes in conservation areas, with low to moderate densities of dryland agriculture, fallow fields, subsistence agriculture, urban development and mining. High to moderate sediment yield was predicted for most of the catchment, with lower values along the fringes of the catchment.

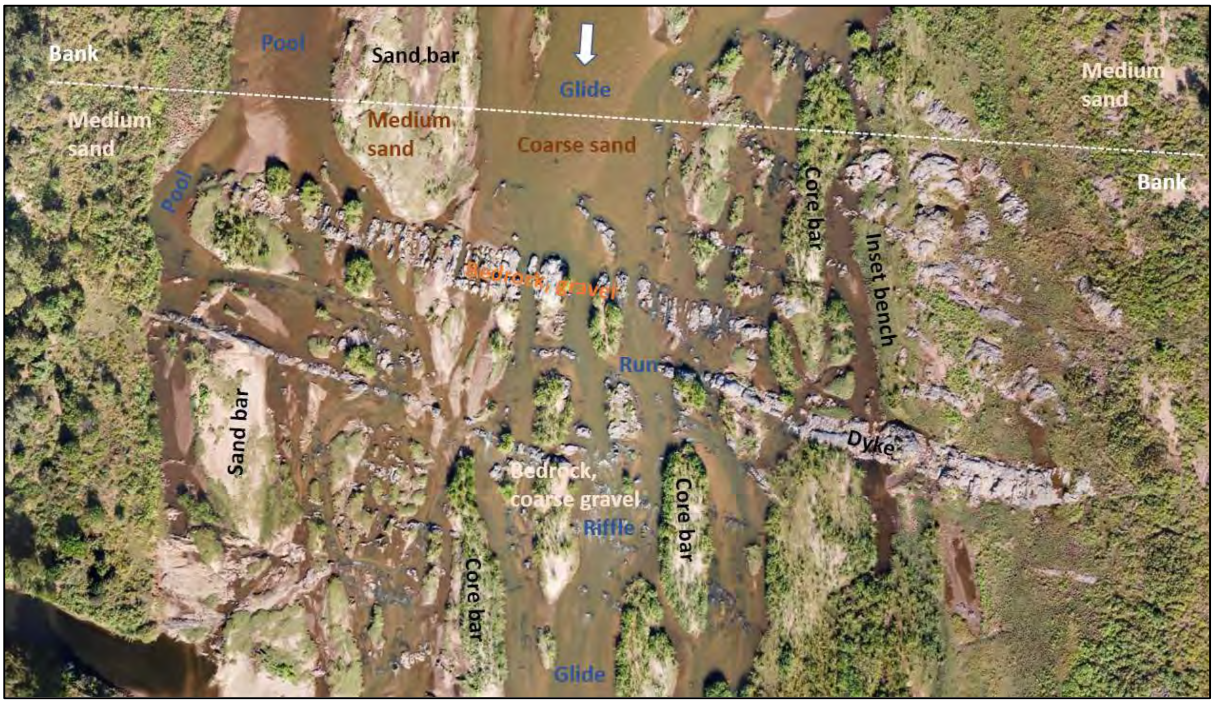


FIGURE 86 ORTHOPHOTO SHOWING MORPHOLOGICAL FEATURES AND SEDIMENT COMPOSITION OF OLIF-B73H-BALUL (OLIFANTS RIVER AT BALULE).

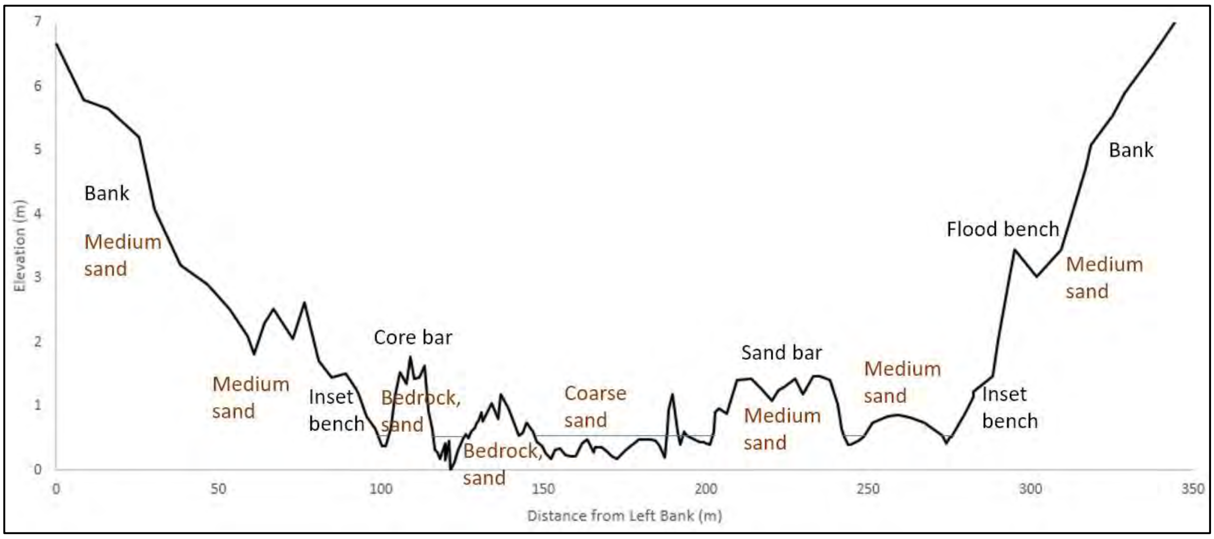


FIGURE 87: CROSS SECTION OF OLIF-B73H-BALUL (OLIFANTS RIVER AT BALULE) SHOWING MORPHOLOGICAL FEATURES AND SEDIMENT COMPOSITION.

Figure 88: Site images showing a) a view from the right bank of the anastomosing bedrock channels; b) Silt drapes over sandy bed material; c) vegetated bars and stagnant high flow channels; d) gravel deposits in and around bedrock chutes

The observed and modelled hydraulic parameters are presented in Table 4.33. The rating equation and curve are presented in Table 4.34 and Figure 89 respectively. Figure 90 shows the modelled velocity depth frequency distributions for various water levels.

Table 4.33: 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	0.001	0.1000	0.002	0.000	0.001	Modelled
30 Feb 2020	0.53	0.031	0.002	4.47	0.410	Observed
3 May 2021	0.7	0.0338	0.0011	10.67	0.410	Observed
Flood I	4.5	0.0300	0.003	3439.268	3.860	Modelled

Table 4.34: Equation for the rating curve

Power Fit: y=axb + c	
Coefficient Data:	
a =	0.327
b =	0.322
c =	0

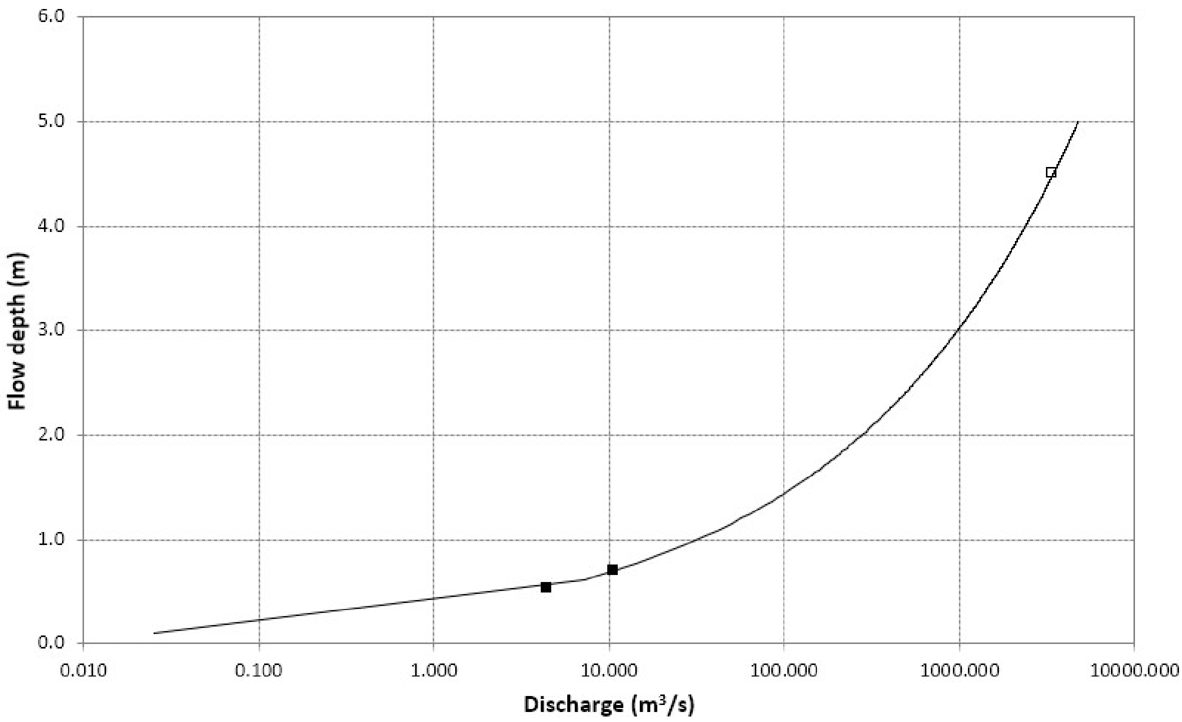


FIGURE 89: RATING CURVE FOR OLIF-B73H-BALUL (OLIFANTS RIVER AT BALULE)

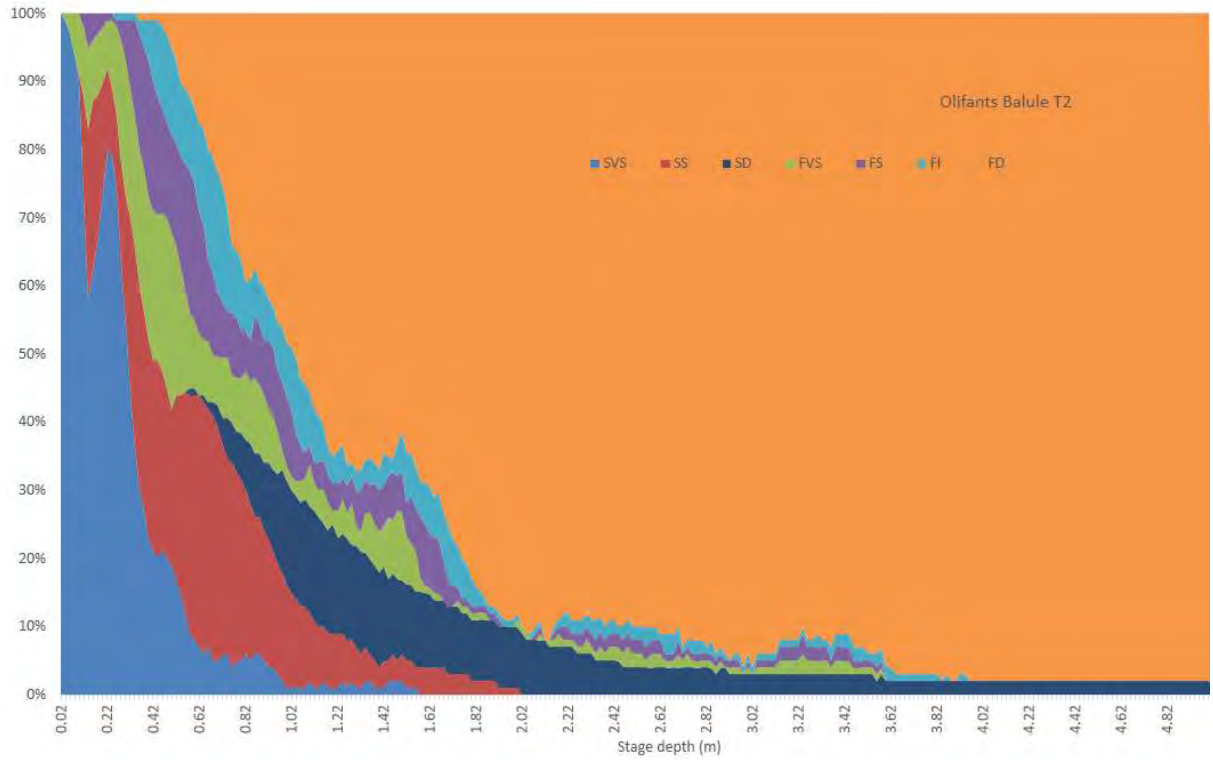


FIGURE 90: MODELLED VELOCITY DEPTH FREQUENCY DISTRIBUTIONS FOR VARIOUS MAXIMUM DEPTH LEVELS FOR OLIF-B73H-BALUL (OLIFANTS RIVER AT BALULE)

4.4.17 ELEP-Y30C-SINGU (Elephantes)

The Elephantes River is an alluvial channel with sand dominating the bed, morphological features and finer sand the floodplain (Figure 91). It is located 8km downstream of the Masingir Dam (constructed before 1984 based on LandSat images), with associated sediment and flow regulation. There are no signs of sediment starvation of channel incision or widening at the site yet (Figure 92). The floodplain is 3km wide at the site, with a gentle fall in elevation away from the channel banks and levees. The low-flow channel has a braided pattern, becoming a wandering channel pattern during higher flows (Figure 93). The active channel has various bars and benches that are transient as they are composed of non-cohesive sandy material and non-vegetated. The majority of the bars along the fringes are well vegetated and stable, effectively forming islands. Small dunes can be seen on the river bed, indicating slow ongoing sand movement during the observed flows.

Cultivation is taking place along the right bank and the margin of the floodplain closest to the channel. The remainder of the floodplain is extensively used for grazing, with smaller fenced farms along the river margin.

Unfortunately, the benchmarks for the 2020 survey could not be located, thus the 2021 field data could not be merged to increase the confidence of the modelling.

The observed flow velocities observed across the channel are presented in Figure 94.

The upper and middle catchment has moderate to low densities of natural grassland and woodland that is used for grazing, with moderate densities of dryland agriculture, fallow fields, subsistence agriculture and urban development and low densities of mining. The lower catchment is largely natural grassland and woodland used for grazing purposes in conservation areas, with low to moderate densities of dryland agriculture, fallow fields, subsistence agriculture, urban development and mining. A high to moderate sediment yield is predicted for most of the catchment, with lower values along the fringes of the catchment.

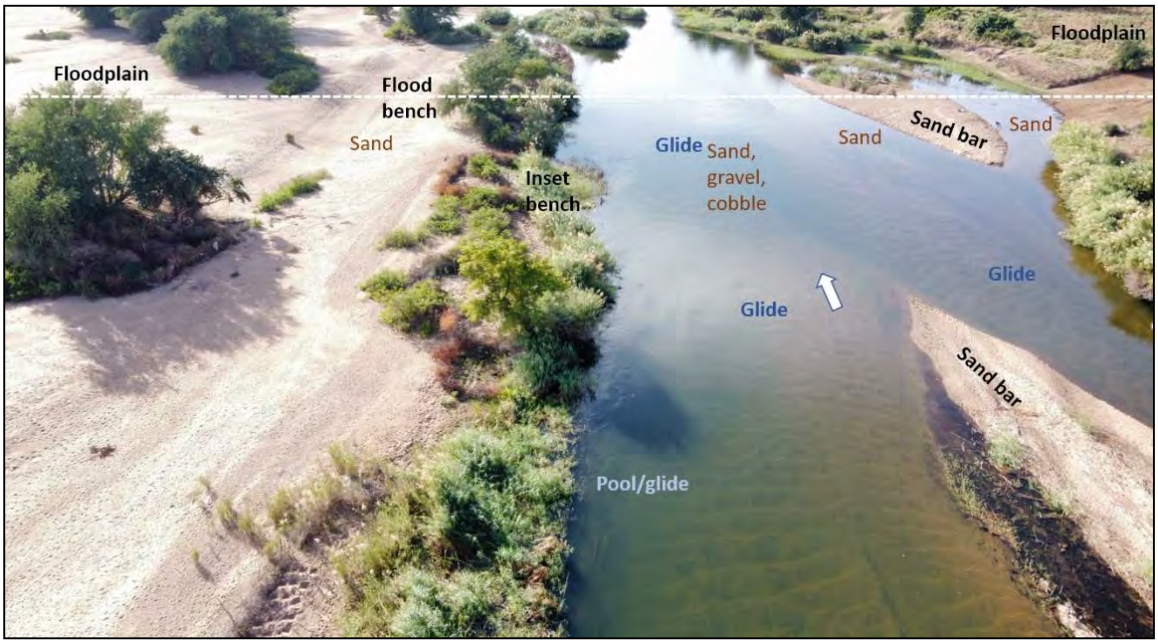


FIGURE 91: OBLIQUE PHOTO SHOWING MORPHOLOGICAL FEATURES AND SEDIMENT COMPOSITION OF ELEP-Y30C-SINGU (ELEPHANTES RIVER). THE DASHED LINE INDICATE THE LOCATION OF THE TRANSECT.

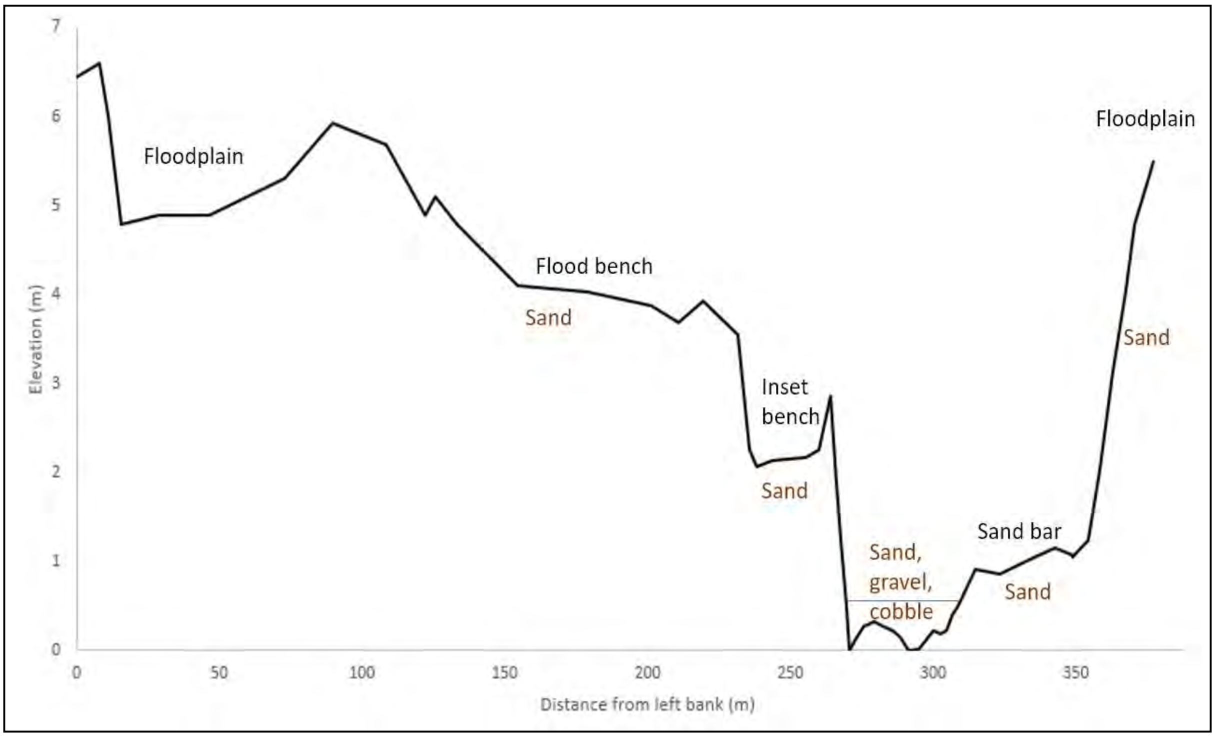


FIGURE 92: CROSS SECTION (DATED 2020) OF ELEP-Y30C-SINGU (ELEPHANTES RIVER) SHOWING MORPHOLOGICAL FEATURES AND SEDIMENT COMPOSITION.

FIGURE 93: SITE IMAGES SHOWING A) AN UPSTREAM VIEW OF THE WELL VEGETATED CHANNEL MARGIN; B) UNVEGETATED BANK AND SAND BAR WHERE LIVESTOCK ACCESS THE RIVER; C) OBLIQUE UPSTREAM VIEW OF THE SITE SHOWING SAND BARS AND CULTIVATION ALONG THE RIGHT BANK

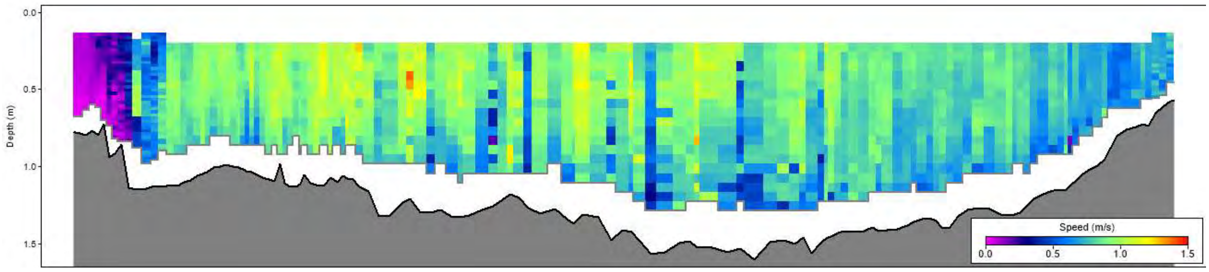


FIGURE 94: ADCP PROFILE SHOWING VELOCITY AND DEPTH ALONG THE CROSS SECTION

The observed and modelled hydraulic parameters are presented in Table 4.35. The rating equation and curve are presented in Table 4.36 and Figure 89 respectively. Figure 96 shows the modelled velocity depth frequency distributions for various water levels.

TABLE 4.35: 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	0.001	0.1000	0.00047	0.000	0.001	Modelled
2020	0.495	0.0285	0.00047	3.90	0.339	Observed
Flood I	2.5	0.025	0.0005	202	1.140	Modelled
Flood 2	4.5	0.025	0.0005	728	1.486	Modelled

TABLE 4.36: EQUATION FOR THE RATING CURVE

Power Fit: y=axb + c	
Coefficient Data:	
a =	0.283
b =	0.41
c =	0

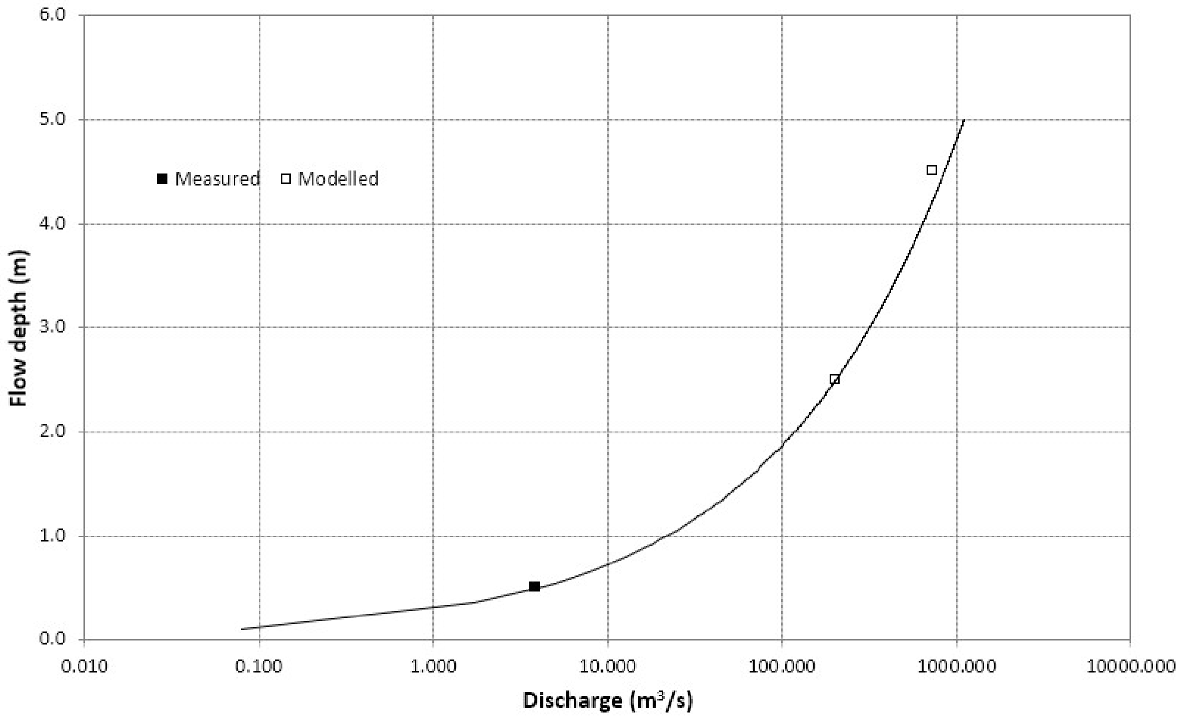


FIGURE 95: RATING CURVE FOR ELEP-Y30C-SINGU (ELEPHANTES RIVER)

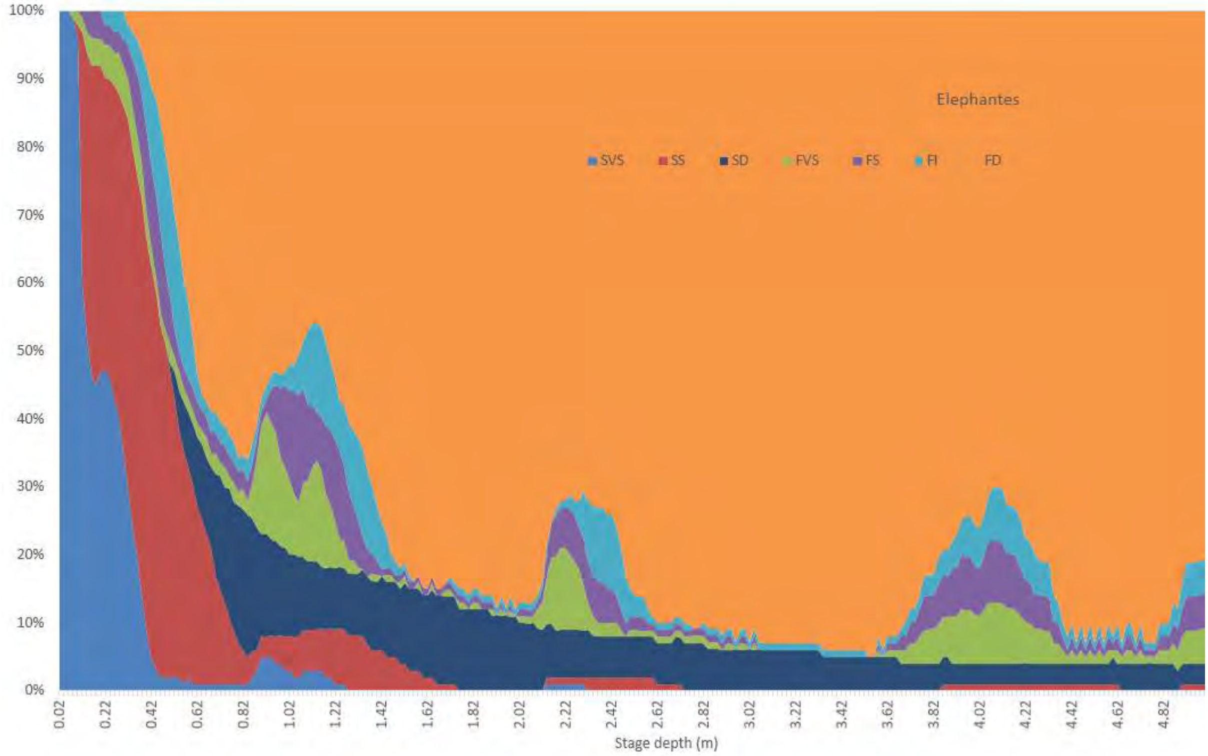


FIGURE 96: MODELLED VELOCITY DEPTH FREQUENCY DISTRIBUTIONS FOR VARIOUS MAXIMUM DEPTH LEVELS FOR ELEP-Y30C-SINGU (ELEPHANTES RIVER)

4.4.18 LIMP-Y30F-CHOKW (Limpopo at Chokwe)

The floodplain at Chockwe is used for housing and agriculture **(**

Figure 97). The low-flow channel has a braided pattern that becomes a wandering channel pattern during higher flows (FIGURE 98;

FIGURE 99**).** Within the macro channel, the sandy flood benches along the right bank are used for agriculture. The sand bars are reworked frequently, thus not well vegetated unless protected during higher flows (out of the main current). The deeper part of the active channel is composed mainly of coarse sand, with patches of gravel.

The hydraulic habitats range from pools to riffle/glides. Smaller well vegetated secondary channels are presented along the steeper braided sections in-between the longer pool sections. The observed velocities across the main channel are presented in Figure 100.

FIGURE 97: SATELLITE IMAGE SHOWING MORPHOLOGICAL FEATURES AND SEDIMENT COMPOSITION OF THE LIMPOPO RIVER AT CHOKWE.

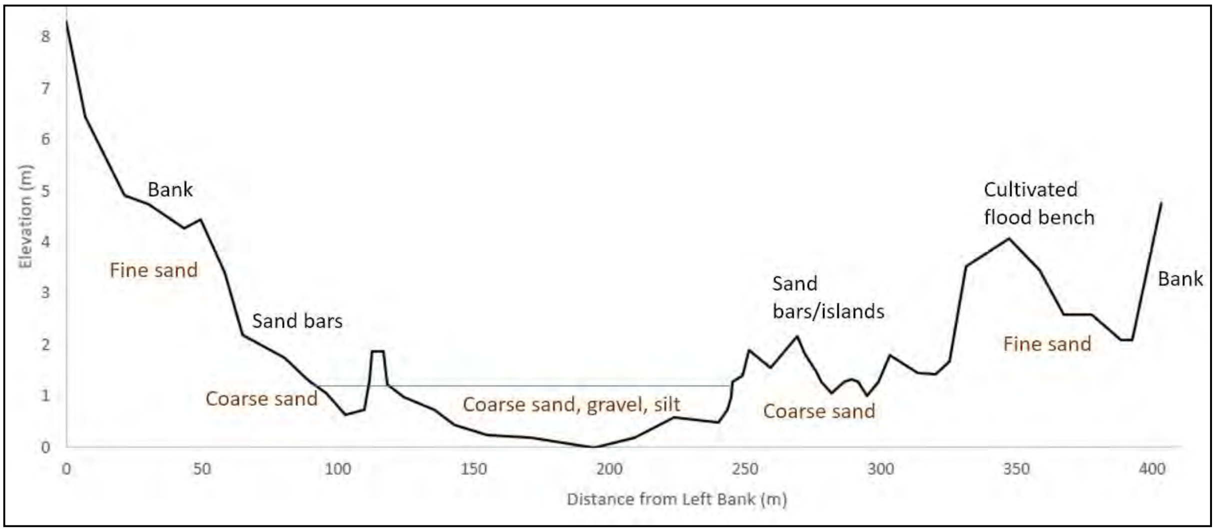


FIGURE 98: CROSS SECTION OF THE LIMPOPO RIVER AT CHOCKWE SHOWING MORPHOLOGICAL FEATURES AND SEDIMENT COMPOSITION.

FIGURE 99: SITE IMAGES SHOWING A) A DOWNSTREAM VIEW OF THE CHANNEL WITH EXTENSIVE SAND BARS AONG THE LEFT BANK AND CULTIVATION ON THE FLOOD BENCH ALONG THE RIGHT BANK; B) BRAID CHANNELS BETWEEN SAND BARS

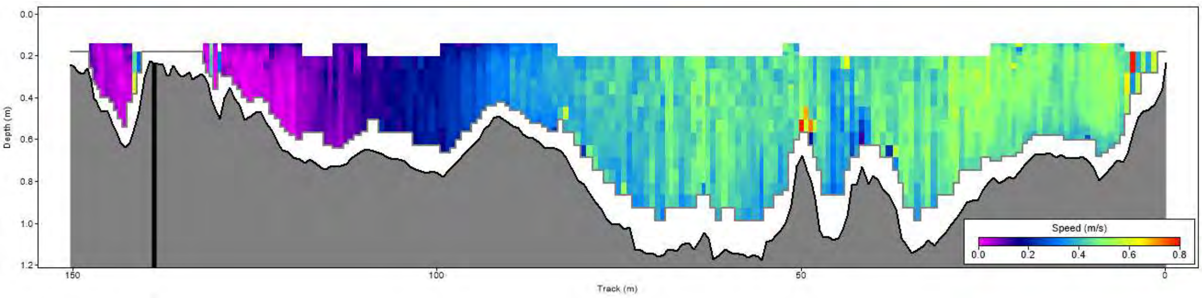


Figure 100: Velocity and depth data along the cross section.

The rating data from the 2012 study could not be used as the channel shape has changed dramatically with a much wider channel for 2021 (

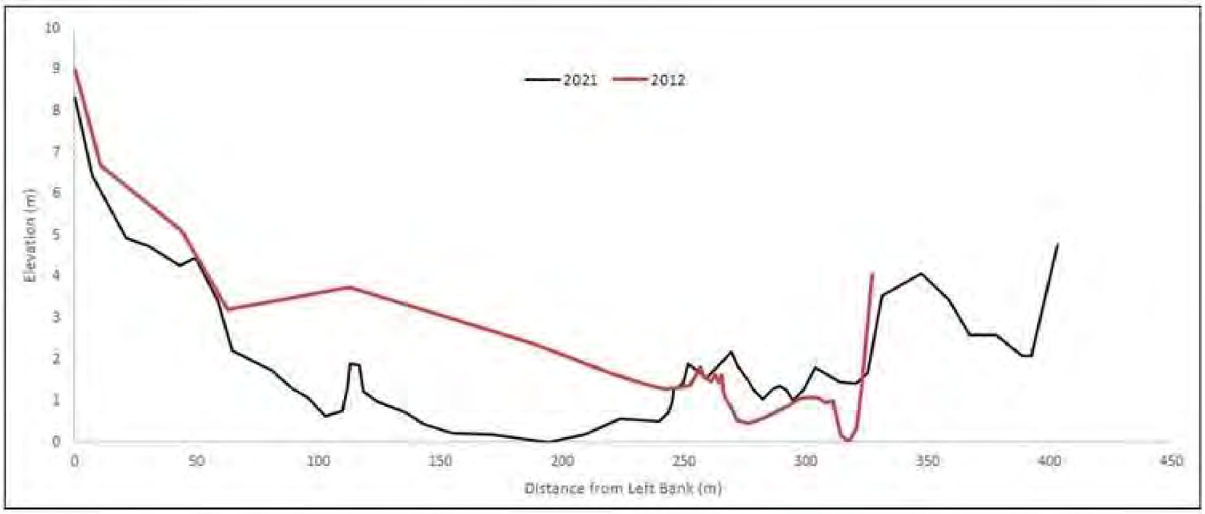


FIGURE 101: the observed and modelled hydraulic parameters are presented in Table 4.37: Observed and modelled data used to derive the rating curve. the rating equation and curve are presented in Table 4.38: Equation for the rating curve and FIGURE 102 respectively. FIGURE 103 shows the modelled velocity depth frequency distributions for various water levels.

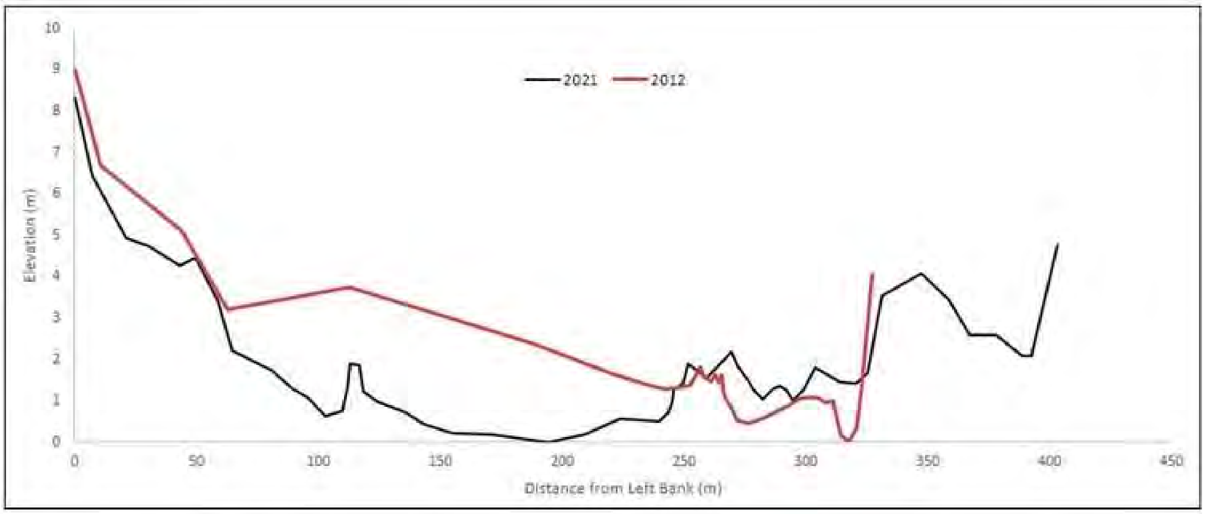


FIGURE 101: CROSS SECTIONS ALONG THE SAME TRANSECT FOR 2012 AND 2021 SHOWING THE DYNAMIC NATURE OF THE SAND BED CHANNEL

TABLE 4.37: OBSERVED AND MODELLED DATA USED TO DERIVE THE RATING CURVE

Date	Depth (m)	Manning s n	Energy gradient	Discharge (m3/s)	Velocity (m/s)	Comment
Zero flow	0.001	0.1000	0.000264	0.000	0.001	Modelled
2020	1.25	0.0446	0.000264	35.06	0.296	Observed
Flood 1	2.5	0.0300	0.00025	276.982	0.678	Modelled
Flood 2	4.5	0.0250	0.00024	1386.338	1.322	Modelled

TABLE 4.38: EQUATION FOR THE RATING CURVE

Power Fit: y=axb + c	
Coefficient Data:	
a =	0.345
b =	0.355
c =	0

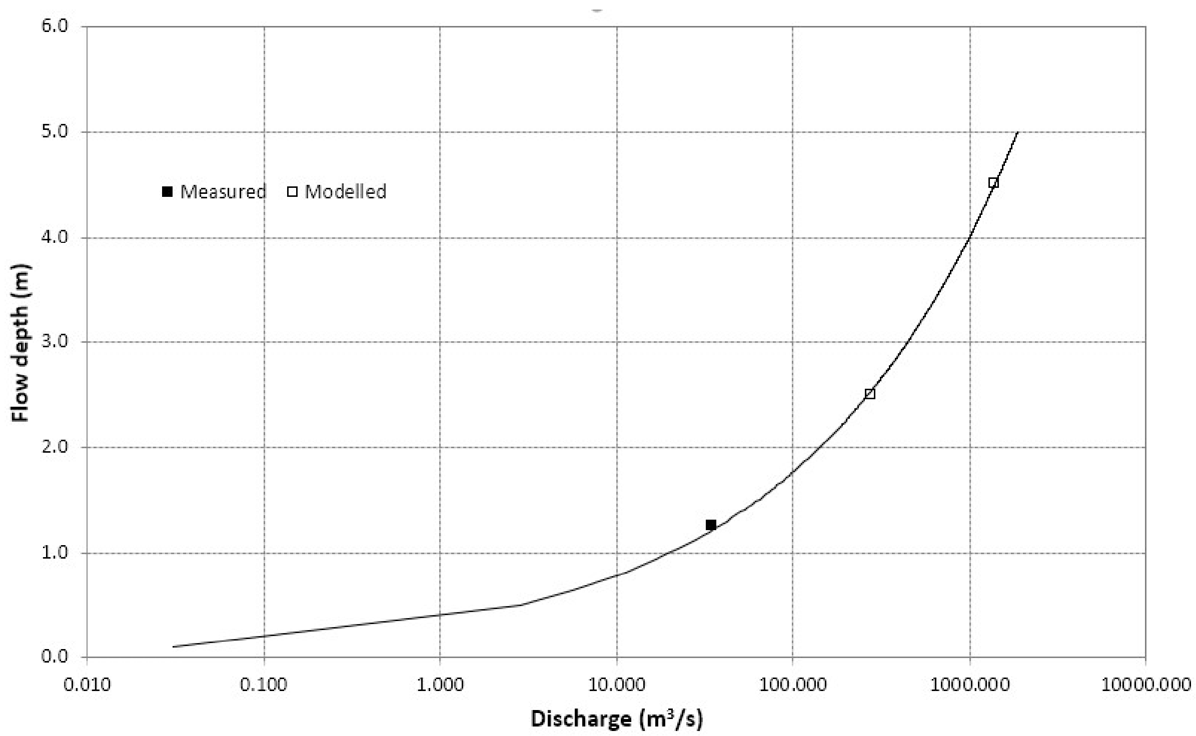


FIGURE 102: RATING CURVE FOR THE LIMPOPO RIVER AT CHOKWE

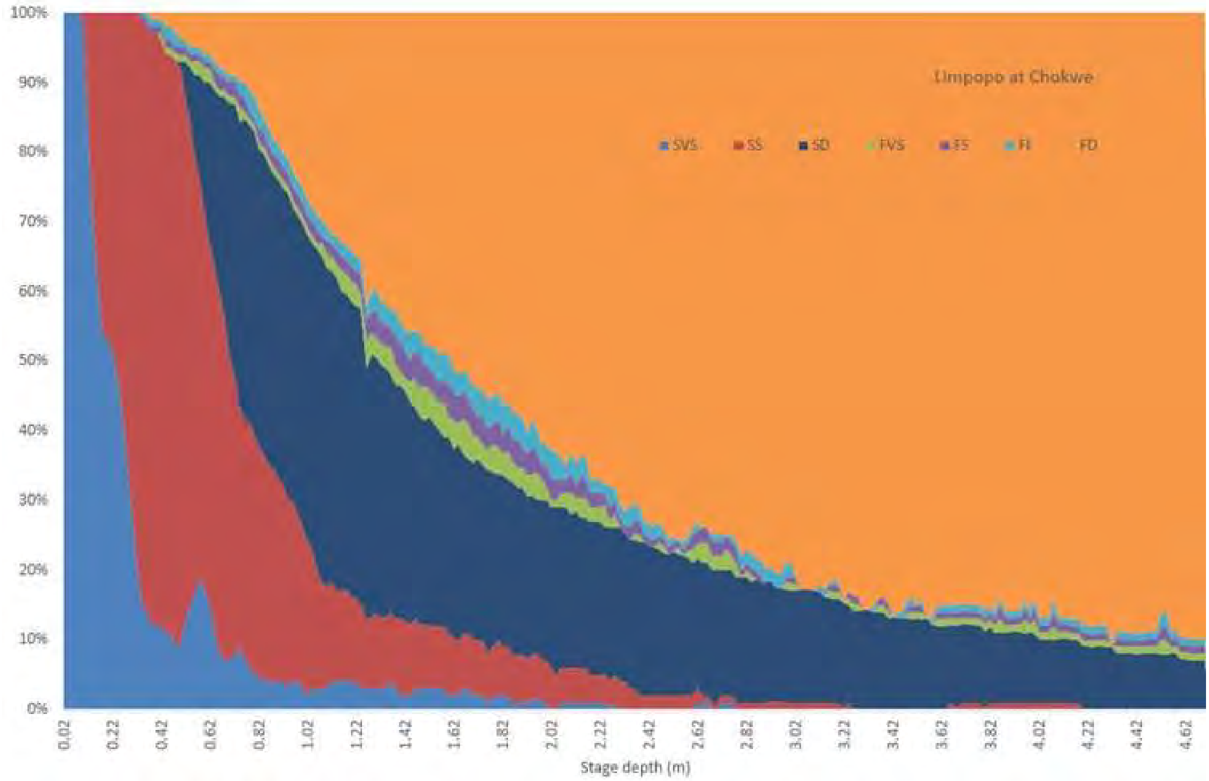


FIGURE 103: MODELLED VELOCITY DEPTH FREQUENCY DISTRIBUTIONS FOR VARIOUS MAXIMUM DEPTH LEVELS FOR THE LIMPOPO RIVER AT CHOKWE

4.5 HYDRAULICS APPENDICES

Appendix A (cross sectional data) and B (velocity depth frequency tables) contain much of the raw data on which the above figures are based.

4.6 HYDRAULIC and GEOMORPHOLOGY REFERENCES

Birkhead, A., 2010. The role of ecohydraulics in the South African Reserve, in: James, C., King, J. (Eds.), Ecohydraulics for South African Rivers - a Review and Guide. Water Research Commission TT453/10, Pretoria, South Africa, pp. 159–218.

Gordon, N., McMahon, T., Finlayson, B., Gippel, C., Nathan, R., 2004. Stream Hydrology: An Introduction for Ecologists, 2nd ed. John Wiley & Sons Ltd, Chichester.

Hirschowitz, P., Birkhead, A., James, C., 2007. Hydraulic Modelling for Ecological Studies for South African Rivers (No. WRC Report No. 1508/1/07). Pretoria, South Africa.

Lamouroux, N., Souchon, Y., Herouin, E., 1995. Predicting Velocity Frequency Distributions in Stream Reaches. Water Resources Research 31, 2367–2375.

Msadala, V., Gibson, L., Le Roux, J., Rooseboom, A., Basson, G., 2010. Sediment Yield Prediction for South Africa: 2010 Edition (Water Research Commission Report No. 1765/1/10). Pretoria, South Africa.

Rowlston, B., Jordanova, A., Birkhead, A., 2008. , in: King, J., Tharme, R., De Villiers, M. (Eds.), Environmental Flow Assessments for Rivers: Manual for the Building Block Methodology. Pretoria, South Africa.

Rowntree, K.M., 2013. Geomorphological Driver Assessment Index in River EcoClassification: Manual for EcoStatus Determination (version 2) (Water Research Commission Report No. TT 551/13). Pretoria, South Africa.

Rowntree, K.M., Wadeson, R.A., 1999. A hierarchical geomorphological model for the classification of selected South African rivers (Water Research Commission Report No. WRC Report 497/1/99). Water Research Commission, Pretoria, South Africa.

5 WATER QUALITY

Contributors: Victor Wepener, Hannes Erasmus, Shaun Herselman

5.1 WATER QUALITY REPORT OBJECTIVES

The objective of this report is present the water quality data that were collected at selected sites from April to June 2021. A summary of the data is presented as well as a comparison of the data with historical data contained in the previous Water Quality Specialist Report. The data are also assessed using the fitness for use categories proposed by Wepener (2020).

5.2 WATER QUALITY SURVEY

5.2.1 Sites

Water samples for analyse were collected from 16 sites on the main stem of the Limpopo River and its main tributaries (see TABLE 5.1).

5.2.2 Water Quality Analysis

In situ water quality variables were measured at each site. Duplicate readings were taken in current and out of current. Dissolved oxygen (DO; mg/L), total dissolved solids (TDS; mg/L), pH, temperature (°C) and conductivity (µS/cm) were measured at each site during the surveys with the aid of an Extech EC500 pH/Conductivity and Extech D0600 Dissolved Oxygen meter.

Sub-surface water samples were collected in triplicate in 250 mL acid-washed polypropylene bottles. Samples were frozen and kept at -20°C until further analyses. In the laboratory water samples were thawed and analysed using Merck photometric test kits. Samples were tested for nitrates (NO32- as N) (09713), nitrite (NO2- as N) (14776), sulphate (SO42-) (14791), turbidity (measured in NTU), chemical oxygen demand (COD) (01796), chloride (Cl-) (14897), ammonium (NH4+ as N) (14752) and inorganic phosphate (PO42- as P) (14848) using a Merck Pharo 100 Spectro quant.

Defrosted water samples (50 mL) were filtered through pre-weighed cellulose nitrate filter paper (0.45 µm pore size). Filtered samples were transferred to 50 mL volumetric flasks and then acidified to 1% nitric acid using 50 µL of 65% nitric acid. Metal concentrations were determined using Inductively coupled plasma mass spectrometry (ICP-MS) (Agilent technologies, 7500CE) for the following metals Ag, Al, As, B, Ba, Ca, Cd, Co, Cu, Fe, K, Mg, Mn, Mo, Ni, Pb, Ti, Se, Sr, U, V and Zn. Chromium concentrations were measured with a PerkinElmer AAnalyst 900 graphite furnace atomic adsorption spectrophotometer (GF-AAS) equipped with Zeeman-effect background correction. All metal concentrations are expressed as mg/L and µg/L.

TABLE 5.1 SELECTED SITES SAMPLED DURING THE 2021 LOW FLOW SURVEYS IN THE LIMPOPO RIVER AND ITS MAIN TRIBUTARIES WITH ASSOCIATED RISK REGIONS, SITE CODES AND POSITION COORDINATES

RISK REGIONS	RIVER	SITE CODE	SITE COORDINATES	
RR1	Crocodile	CROC-A24J-ROOIB	-24.314167	27.046139
RR1	Limpopo@ Spanwerk	LIMP-A41D-SPANW	-23.945556	26.932028
RR2	Matlabas	MATL-A41D-WDRAAI	-24.051861	27.359639
RR2	Lephalala	LEPH-A50H-SEEKO	-23.141278	27.885028
RR2	Limpopo@Limpokwena	LIMP-A36C-LIMPK	-22.455194	28.901750
RR2	Mogalakwena	MOGA-A36D-LIMPK	-22.473444	28.919500
RR3	Shashe	SHAS-Y20B-TULIB	-21.91624	29.19836
RR3	Limpopo@Poachers Corner	LIMP-A71L-MAPUN	-22.183833	29.405194
RR4	Umzingwani	UMZI-Y20C-BEITB	-22.13590	29.93020
RR4	Sand	SAND-A71K-R508B	-22.399278	30.099417
RR5	Luvuvhu	LUVU-A91K-OUTPO	-22.444444	31.083444
RR7	Olifants@Balule	OLIF-B73H-BALUL	-24.052139	31.728778
RR8	Letaba	LETA-B83E-KNPBR	-23.758333	31.369972
RR8	Groot Letaba	GLET-B81J-LRANC	-23.677083	31.098333
RR10	Elephantes Below Massingir	ELEP-Y30C-SINGU	-23.875120	32.226237
RR9	Shingwedzi	SHIN-B90H-POACH	-23.221944	31.554917
RR11	Limpopo@Chokwe	LIMP-Y30F-CHOKW	-24.500200	33.010400

5.2.3 Assessment of fitness for use of water quality at the different sites

The assessment of the fitness of use of the water quality at the selected sites was undertaken by applying the 2013 Monograph study water quality criteria (Roussouw, 2013) and the Species Sensitivity Distribution (SSD) classification schemes described in the Water Quality Specialist Report (Wepener 2020). In short, the generic classification scheme classifies the water quality as ‘good - blue’, ‘tolerable - green’, ‘poor – amber and ‘unsuitable - red’ (see Table 2 and Table 3).

TABLE 5.2 BOUNDARY VALUES FOR SELECTED 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
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
Inorganic-phosphate	mg/l	0.025	0.075	0.125	>0.125	Aquatic

TABLE 5.3 ASSESSMENT CLASSES FOR THE SELECTED METAL TOXICANTS BASED ON PROBABILITY OF 5% OF THE SPECIES BEING AFFECTED. ALL CONCENTRATIONS ARE IN µG/L.

Metal	Good <HC1 (50)	Tolerable HC5 (5-25)	Poor HC5 (25-50)	Unacceptable >HC5 (50)
Ammonia	<682	683- 1009	1010 - 2097	> 2097
Arsenic	<37.6	37.7 – 76.8	76.9- 159.7	>159.7
Cadmium	<14.8	14.9 - 71.7	71.8 - 141.3	>141.3
Chromium	< 3157	3158- 4543	4544- 6668	>6668
Copper	< 39.6	39.7 - 56.3	56.4 - 64.7	>64.7
Mercury	<11.1	11.2 - 16	16.1 - 19	>19
Zinc	<5	5.1 - 20.1	20.2 - 43.5	>43.5

5.3 WATER QUALITY DATA

5.3.1 Mainstem Limpopo River

During the low-flow survey three sites were sampled on the Limpopo River in South Africa and two sites in Mozambique. The general water quality data and metal concentrations are presented in Table 5.4 and Table 5.5 respectively. Based on the classification schemes the pH at LIMP-A41D-SPANW and LIMP-A71L-MAPUN was poor while the orthophosphates at LIMP-A36C-LIMPK were at unacceptable levels. Metal concentrations were all in the “good” range with Zn at A41D-SPANW and LIMP-A71L-MAPUN being in the “acceptable” range. The current data are compared to historical data at LIMP-A41D-SPANW in Table 5.6. The levels of the current water quality variables are all above the mean at the site and are within the 90 to 95th percentiles.

TABLE 5.4 WATER QUALITY VARIABLES MEASURED AT SELECTED SITES IN THE LIMPOPO RIVER DURING LOW FLOW 2021. VALUES REPRESENT MEAN ± STANDARD DEVIATION.

	LIMP-A41D-SPANW	LIMP-A36C-LIMPK	LIMP-A71L-MAPUN	ELEP-Y30C-SINGU	LIMP-Y30F-CHOKW
Temperature (°C)	22.1±0.8	22.5±0.3	26±0.9	22.6	21.3
pH	8.7±0.01	8.5±0.14	8.8±0.05	8.08	8.13
Dissolved oxygen (mg/L)	11.3±0.6	10.4±0.1	11.4±0.5	12.68	13.71
Oxygen saturation (%)	130.4±8.2	118.3±2.3	131.9±2.3	114	119
Total dissolved solids (mg/L)	554.5±18.5	653±110	288±1	392.1	467.3
Electrical conductivity (µS/cm)	837±58	936±159	422±1	413.6	491.3
Turbidity (NTU)	20±1	9.7±7.1	15.3±4.2	7.5±0.7	15
Chemical oxygen demand (mg/L)	9.9±0.7	11.6±0.8	17.3±20.6	N/A	N/A
Nitrite (N-mg/L)	0.016± 0.001	0.081± 0.103	0.008± 0.001	0.003±0.001	0.003±0.001
Nitrate (N-mg/L)	1.33±0.67	1.77±0.4	0.83±0.4	2.3±0.03	0.08±0.003
Ammonium (N-mg/L)	0.04±0.006	0.06±0.01	0.18±0.006	0.04±0.002	0.035±0.007
Orthophosphate (P-mg/L)	0.04±0.02	0.24±0.28	0.1±0.01	0.006±0.001	0.025±0.013
Chloride (mg/L)	81.3±9.1	53±8.7	48±2	21.25±1.1	35.75±13.1
Sulphate (mg/L)	58	14±1.7	33.3±2.1	41.5±3.5	35.5±3.5
Sodium (mg/L)	65.7±0.7	33.7±1.3	35.2±0.4	27.1±2.3	34.4±2.5
Potassium (mg/L)	8.4±0.1	4.1±0.4	4.7±0.1	4±0.4	3.6±0.3
Calcium (mg/L)	31.1±1.1	16.1±0.8	24±2.1	18.3±2.1	22.5±0.3
Magnesium (mg/L)	23.6±0.4	11.7±0.4	13.6±0.1	13.6±0.8	14.7±0.9

TABLE 5.5 METAL CONCENTRATIONS MEASURED AT SELECTED SITES IN THE LIMPOPO RIVER DURING LOW FLOW 2021. VALUES REPRESENT MEAN ± STANDARD DEVIATION.

	LIMP-A41D-SPANW	LIMP-A63C-LIMPK	LIMP-A71L-MAPUN	LIMP-Y30F-CHOKW	ELEP-Y30C-SINGU
Ag (µg/L)	<0.001				
Al (µg/L)	5.5±1.2	49.6±18.5	17.9±9.8	2.21±0.4	2.9±0.8
As (µg/L)	1.56±0.01	0.5±0.04	0.5±0.03	1.1±0.06	0.5±0.03
B (µg/L)	0.038±0.001	0.023±0.001	0.027±0.002	0.04±0.003	0.043±0.003
Ba (µg/L)	5±0.1	2.4±0.15	1.89±0.02	0.03±0.006	0.05±0.001
Cd (µg/L)	<0.001				
Cr (µg/L)	0.15±0.06	0.41±0.15	0.23±0.05	0.09±0.006	0.08±0.005
Co (µg/L)	0.49±0.01	0.14±0.02	0.18±0.12	0.05±0.008	0.04±0.004
Cu (µg/L)	1.54±0.3	5.61±2.13	1.92±0.35	0.9±0.03	1.7±0.26
Fe (µg/L)	2.6±1.4	31±10.4	36.9±46.7	2.83±1	7.54±5.8
Hg (µg/L)	Waiting for results				
Mn (µg/L)	0.56±0.12	1.36±0.63	18.8±30.9	0.51±0.08	1.24±1.1
Mo (µg/L)	1.52±0.03	0.72±0.04	0.82±0.11	0.78±0.05	0.83±0.03
Ni (µg/L)	3.93±0.1	3.21±0.19	2.60±0.23	0.97±0.05	0.94±0.05
Pb (µg/L)	<0.001				
Ti (µg/L)	<0.001	1.1±0.33	0.26±0.03	0.25±0.05	0.12±0.06
Se (µg/L)	0.42±0.32	0.29±0.18	0.2±0.15	1.55±0.19	1.43±0.11
Sr (µg/L)	106.2±3.3	63.6±3.1	98.2±5.1	94.3±9.3	117.3±3.3
U (µg/L)	<0.001				
V (µg/L)	11.1±0.18	3.15±0.12	4.42±1.26	4.56±0.27	4.56±0.19
Zn (µg/L)	2.68±0.49	17.4±11.1	5.43±3.90	1.7±0.06	2.5±0.74

TABLE 5.6 COMPARISON BETWEEN HISTORICAL AND CURRENT WATER QUALITY AT SITE LIMP-A41D-SPANW.

	Historical	Current
Sampling period	1980 - 2018	2021
TDS (mg/L)	165 (46 - 539)	554.5
EC (µS/cm)	258 (73 – 955)	837
pH	7.71 (6.15 – 8.71)	8.7
Na (mg/L)	20.4 (2.9 – 84.9)	65.7
Mg (mg/L)	9 (1.6 – 32)	23.6
Ca (mg/L)	14.8 (2.84 – 43.8)	31.1
K (mg/L)	3.02 (0.58 – 9.8)	8.4
SO42- (mg/L)	16.6 (2 – 89.7)	58
NO2 + NO3 (mg/L)	0.082 (0.005 – 1.72)	1.35
PO42- (mg/L)	0.015 (0.003 – 0.96)	0.04
NH4+ (mg/L)	0.0253 (0.02 – 0.4)	0.04

5.3.1 Main Tributaries of the Limpopo River

During the low-flow survey nine sites were sampled in major tributaries of the Limpopo River in South Africa. The general water quality data and metal concentrations are presented in Table 5.8 and Table 5.9 respectively. Based on the classification schemes the pH at CROC-A24J-ROOIK, SHAS-Y20B-TULIB, UMZI-Y20C-BEITB, SAND-A71K-R508B and OLIF-B73H-BALUL was regarded as poor. The EC of the Matalabas River (MATL-A41D-WDRAAI) was unacceptable whereas the inorganic phosphates at the CROC-A24J-ROOIK, LEPH-A50H-SEEKO, SHAS-Y20B-TULIB, MOGA-A63D-LIMPK, UMZI-Y20C-BEITB and SAND-A71K-R508B sites were also at unacceptably high levels. Two of the main tributaries in the Kruger National Park also had high inorganic phosphate levels resulting in a "poor" classification. The nitrate levels at MATL-A41D-WDRAAI, SAND-A71K-R508B and OLIF-B73H-BALUL sites were also classified as "poor". The Zn concentrations at five of the nine sites as classified as acceptable.

The current water quality data are compared to historical data in the Crocodile River CROC-A24J-ROOIK in Table 5.7. All the salt levels are within the 50th percentile of the historical data. The current pH, nitrate+nitrate and inorganic phosphate levels exceed the RQOs that were set for this reach of the Crocodile River.

TABLE 5.7 COMPARISON BETWEEN HISTORICAL AND CURRENT WATER QUALITY AT SITE CROC-A24J-ROOIK (CROCODILE RIVER).

Site	Historical	Current	RQOs for the lower reaches of the Crocodile River (A24J)
Sampling period	2004 - 2018	2021	
TDS (mg/L)	525.7 (322.5 – 694.3)	542	
EC (µS/cm)	740 (439 – 975)	781	≤ 850 µS/m mg/l (95th percentile)
pH	8.40 (6.58 – 9.04)	9.2	6.5 (5th percentile) - 8.5 (95th percentile)
Na (mg/L)	68.0 (37.6 – 96.1)	67.4	≤ 80 mg/l (95th percentile)
Mg (mg/L)	26.4 (15.4– 43.2)	23.7	
Ca (mg/L)	43 (26.2 – 70.9)	32.5	
K (mg/L)	8.2 (4.4 – 10.1)	8.4	
Cl (mg/L)	87 (40 – 144.6)	92.7	≤ 100 mg/l (95th percentile)
SO42- (mg/L)	73.1 (41.7 – 167.7)	61	≤ 100 mg/l (95th percentile)
NO2 + NO3 (mg/L)	0.94 (0.025 – 3.87)	1.32	≤ 1.0 mg/l (50th percentile)
PO42- (mg/L)	0.105 (0.005 – 0.442)	0.15	≤ 0.06 mg/l (50th percentile)
NH4+ (mg/L)	0.053 (0.015 – 0.295)	0.08	
Turbidity		35	10% variation from background levels

TABLE 5.8 WATER QUALITY VARIABLES MEASURED AT SELECTED SITES IN MAIN TRIBUTARIES OF THE LIMPOPO RIVER DURING LOW FLOW 2021. VALUES REPRESENT MEAN ± STANDARD DEVIATION. NM REPRESENTS PARAMETERS THAT WERE NOT MEASURED

	CROC-A24J-ROOIK	MATL-A41D-WDRAAI	LEPH-A50H-SEEKO	MOGA-A63D-LIMPK	SHAS-Y20B-TULIB	UMZI-Y20C-BEITB	SAND-A71K-R508B	LUVU-A91K-OUTP	SHIN-B90H-POACH	OLIF-B73H-BALUL	LETA-B83E-KNPBR
Temperature (°C)	22.4±0.8	22.3	21.6±0.1	23.6±1.2	18.9	21.6	27.7±1.3	24.9±0.5	21.5±0.6	20.3±0.5	22.7±1.5
pH	9.2±0.03	7.1	7.6±0.04	7.5±0.27	9.3	9.35	8.6±0.07	8.3±0.04	8.2±0.06	8.6±0.02	8.4±0.44
Dissolved oxygen (mg/L)	10.8±1.8	9.3	9.4±0.4	12.8±4.6	17.1	20.13	16.2±0.4	10±0.2	9±0.7	10.2	9.7±0.4
Oxygen saturation (%)	121.4±17	107.5	106.8±2.1	154±59.7	147.3	185.7	200.9±11.2	118.5±4.2	99.9±6.8	109.5±3.4	113.2±9.
Total dissolved solids (mg/L)	542±10	539	591.5±1.5	1655±155	228.9	476.5	1775±25	262	621.5±26.5	642±255	558.5±29
Electrical conductivity (µS/cm)	781.5±10.5	7380	857±2	2415±255	240.6	501.3	2580	381	900±31	547±4.5	805±427
Turbidity (NTU)	35±3.6	4.7±2.3	7.3±0.6	8±3	8	14	13.7±2.9	8±1.7	17.7±2.1	12±1.7	12.7±2.9
Chemical oxygen demand (mg/L)	13±3.6	8.7±2.5	5.2±2.5	14.8±3.1	NM	NM	18.6±1.5	5.3±3.4	9.9±1.6	4.3±0.7	7±2.7
Nitrite (N-mg/L)	0.015± 0.002	0.013± 0.007	0.005± 0.002	0.005± 0.004	0.006	0.023	0.023± 0.010	0.005± 0.003	0.005± 0.002	0.005± 0.001	0.009 ±0.002
Nitrate (N-mg/L)	1.3±0.78	2.4±0.35	0.9±0.35	0.93±0.12	0.1	2.3	1.63±0.25	0.41±0.1	0.87±0.23	1.97±1.21	0.27±0.2
Ammonium (N-mg/L)	0.08±0.006	0.07±0.012	0.01±0.002	0.14±0.127	0.083	0.153	0.13±0.064	0.10±0.002	0.18±0.000	0.12±0.003	0.02±0.0
Orthophosphate (P-mg/L)	0.15±0.01	0.05±0.04	0.46±0.32	0.16±0.01	5.14	0.4	0.23±0.3	0.1±0.06	0.05±0.04	0.11±0.08	0.02±0.0
Chloride (mg/L)	92.7±2.1	10.4±1.1	10.7±3.8	603±90.1	6	51	444±49.6	13.4±0.3	87.3±0.6	32.7±0.6	28.3±8.4
Sulphate (mg/L)	61±1	8.7±0.6	4.7±1.2	216.7±65.3	9	21	133±3.5	4±1	12±1	62.7±0.6	13±1

Sodium (mg/L)	67.4±0.6	4.1±0.4	9.6±0.3	241.4±51.2	NM	NM	268.8±5.7	8.3±0.4	77.8±1.3	32.7±0.2	29.7±7.7
Potassium (mg/L)	8.4±0.1	1.3±0.4	1±0.01	6±1	NM	NM	9.3±0.5	0.9±0.1	7.5±0.3	6.2±0.03	3.2±0.1
Calcium (mg/L)	32.5±1.6	4.3±0.1	7±0.1	129.1±19.9	NM	NM	43.5±1.6	8.5±0.2	30.1±3.7	21.4±3.9	13.1±1.4
Magnesium (mg/L)	23.7±0.3	1.7±0.02	3.4±0.1	90.8±27.5	NM	NM	96.8±1	5.1±0.1	32±0.4	26.6±0.3	15.7±9.3

TABLE 5.9 METAL CONCENTRATIONS MEASURED AT SELECTED SITES IN MAIN TRIBUTARIES OF THE LIMPOPO RIVER DURING LOW FLOW 2021. VALUES REPRESENT MEAN ± STANDARD DEVIATION.

	CROC-A24J-ROOIK	MATL-A41D-WDRAAI	LEPH-A50H-SEEKO	MOGA-A63D-LIMPK	SAND-A71K-R508B	LUVU-A91K-OUTP	SHIN-B90H-POACH	OLIF-B73H-BALUL	SHIN-B90H-POACH	ELEP-Y30C-SINGU
Ag (µg/L)	<0.001									
Al (µg/L)	6.2±0.5	8.3±1.5	4.8±1.3	4.3±1	6.9±0.7	5.8±1	5.3±2.3	5.2±0.1	5.3±2.3	0.5±0.03
As (µg/L)	1.66±0.003	0.27±0.02	0.14±0.01	0.51±0.01	0.88±0.02	0.08±0.01	0.55±0.01	0.94±0.01	0.55±0.01	0.043±0.003
B (µg/L)	0.039±0.001	0.002±0.001	0.005±0.001	0.098±0.026	0.356±0.002	0.004±0.001	0.092±0.003	0.027±0.001	0.092±0.003	0.05±0.001
Ba (µg/L)	5.23±0.06	1.05±0.37	0.93±0.05	2.69±0.48	1.84±0.22	1.16±0.02	1.94±0.1	3.12±0.06	1.94±0.1	0.08±0.005
Cd (µg/L)					<0.001					
Cr (µg/L)	0.2±0.04	0.29±0.12	0.24±0.04	0.08±0.02	0.16±0.02	5.39±8.84	0.26±0.09	0.26±0.07	0.26±0.09	1.7±0.26
Co (µg/L)	0.59±0.02	0.05±0.01	0.03±0.01	0.22±0.08	0.17±0.01	0.10±0.14	0.18±0.02	0.12±0.01	0.18±0.02	7.54±5.8
Cu (µg/L)	1.98±0.14	1.62±0.11	0.76±0.08	1.49±0.4	1.91±0.11	0.97±0.11	1.75±0.33	1.48±0.18	1.75±0.33	1.24±1.1
Fe (µg/L)	2.1±0.6	15.8±17.5	8±0.4	1.7±0.3	4±0.8	35.1±38.5	6.5±5.3	3.1±1.3	6.5±5.3	0.83±0.03
Hg (µg/L)	Waiting for results									
Mn (µg/L)	0.69±0.08	0.66±0.1	0.53±0.08	124.5±105.9	0.65±0.14	4.32±6.58	0.77±0.28	0.6±0.09	0.77±0.28	<0.001
Mo (µg/L)	1.42±0.03	0.11±0.05	0.11±0.01	1.28±0.24	4.36±0.04	0.32±0.42	0.86±0.02	0.99±0.01	0.86±0.02	0.12±0.06
Ni (µg/L)	4.17±0.21	1.68±0.18	1.16±0.06	3.21±0.2	2.59±0.16	26.1±42.4	2.88±0.04	1.96±0.07	2.88±0.04	1.43±0.11
Pb (µg/L)					<0.001					
Ti (µg/L)	<0.001	0.19±0.08	0.14±0.09	0.21±0.08	0.17±0.11	0.12±0.07	0.11±0.06	<0.001	0.11±0.06	<0.001

Se (µg/L)	0.2±0.16	<0.001	0.37±0.28	2.3±0.17	2.04±0.4	0.3±0.18	0.52±0.25	<0.001	0.52±0.25	4.56±0.19
Sr (µg/L)	102±3.7	14.3±0.3	24.5±1.2	580.8±159.5	303.3±8.4	32.8±0.6	246.9±15.8	122.1±14.4	246.9±15.8	2.5±0.74
U (µg/L)					<0.001					
V (µg/L)	13±0.33	0.12±0.01	0.35±0.06	1.15±0.32	8.69±0.77	0.77±0.24	10.3±1.62	5.71±0.1	10.3±1.62	2.9±0.8
Zn (µg/L)	4.12±1.32	8.78±1.85	5.35±0.83	4.89±3.23	3.48±0.98	5.84±3.30	5.28±0.49	3.06±1.14	5.28±0.49	0.5±0.03

The current water quality data are compared to historical data in the Matlabas River (MATL-A41D-WDRAAI) in Table 5.10. Apart from the total dissolved solids, EC and nitrates+nitrites, the water quality variables were within the 50th percentile of the historical data. The nutrient concentrations were three orders of magnitude higher than the average for this site.

TABLE 5.10 COMPARISON BETWEEN HISTORICAL AND CURRENT WATER QUALITY AT SITE MATL-A41D-WDRAAI (MATLABAS RIVER).

	Historical	Current
Sampling period	1971 - 2018	2021
TDS (mg/L)	36.7 (9 - 406)	539*
EC (µS/cm)	540 (150 – 586)	7380*
pH	7.13 (4.43 – 8.48)	7.1
Na (mg/L)	3.5 (0.22 – 94.7)	4.1
Mg (mg/L)	1.6 (0.47 – 13.3)	1.7
Ca (mg/L)	2.9 (0.5 – 10.8)	4.3
K (mg/L)	0.6 (0.15 – 4.66)	1.3
Cl (mg/L)	5 (1.5 – 87.9)	10.4
SO42- (mg/L)	2 (0.6 - 13)	8.7
NO2 + NO3 (mg/L)	0.02 (0.02 – 1.4)	2.5
PO42- (mg/L)	0.01 (0.003 – 0.181)	0.05
NH4+ (mg/L)	0.0253 (0.02 – 0.4)	0.07

* To check the accuracy of these measurements the stored sample will be reanalysed.

The current water quality data are compared to historical data in the Lephalala River (LEPH-A50H-SEEKO) in Table 5.11. Similarly, to the Matlabas River, the total dissolved solids and EC were higher than the historical maximums and the inorganic phosphate levels were higher than the average levels at this site.

TABLE 5.11 COMPARISON BETWEEN HISTORICAL AND CURRENT WATER QUALITY AT SITE LEPH-A50H-SEEKO (LEPHALALA RIVER).

	Historical	Current
Sampling period	1995 - 2018	2021
TDS (mg/L)	72.4 (14 - 343)	591
EC (µS/cm)	112 (27 – 545)	857
pH	7.7 (7.24 – 9.17)	7.6
Na (mg/L)	8.3 (1 – 54.2)	9.6
Mg (mg/L)	3 (0.5 – 15.4)	3.4
Ca (mg/L)	6.4 (1.4 – 37.3)	7
K (mg/L)	1.02 (0.15 – 6.71)	1
Cl (mg/L)	12.1 (3.2 – 230)	10.7
SO42- (mg/L)	6 (0.44 - 450)	4.7
NO2 + NO3 (mg/L)	0.218 (0.02 – 6.01)	0.11
PO42- (mg/L)	0.02 (0.005 – 6.6)	0.46
NH4+ (mg/L)	0.02 (0.015 – 3)	0.01

The current water quality data are compared to historical data in the Luvuvhu River (LUVU-A91K-OUTP) in Table 5.12. The total dissolved solids and EC were higher than the 50th percentiles of the historical data. All nutrients were also above the 50th percentiles.

TABLE 5.12 COMPARISON BETWEEN HISTORICAL AND CURRENT WATER QUALITY AT SITE LUVU-A91K-OUTP (LUVUVHU RIVER).

	Historical	**Current**
Sampling period	1983 - 2017	2021
TDS (mg/L)	102 (47.7 – 657)	262
EC (µS/cm)	148 (76 – 975)	381
pH	7.84 (5.9 – 9.09)	8.3
Na (mg/L)	9.7 (3.5 – 1239)	8.3
Mg (mg/L)	5.86 (2.2 – 40.4)	5.1
Ca (mg/L)	8.22 (4.3 – 31)	8.5
K (mg/L)	1.07 (0.06 – 8.15)	0.9
Cl (mg/L)	13.6 (4.8 – 148)	13.4
SO42- (mg/L)	4.2 (0.375 – 29.9)	4
NO2 + NO3 (mg/L)	0.062 (0.005 – 1.83)	0.42
PO42- (mg/L)	0.017 (0.003 – 7.27)	0.1
NH4+ (mg/L)	0.04 (0.015 – 1.4)	0.1

The current water quality data are compared to historical data in the Shingwedzi River (SHIN-B90H-POACH) in Table 5.13. All the salt and nutrient variables were higher than the historical average but still below the 75th percentile.

TABLE 5.13 COMPARISON BETWEEN HISTORICAL AND CURRENT WATER QUALITY AT SITE SHIN-B90H-POACH (SHINGWEDZI RIVER).

	Historical	Current
Sampling period	1983 - 2018	2021
TDS (mg/L)	268 (54 – 1510)	621
EC (µS/cm)	335 (74 – 2050)	900
pH	8.23 (6.29 – 8.8)	8.2
Na (mg/L)	20.4 (3.6 – 251)	77.8
Mg (mg/L)	13.2 (0.75 – 91.3)	32
Ca (mg/L)	23.6 (4.1 – 92.5)	30
K (mg/L)	5.6 (2.34 – 85.3)	7.5
Cl (mg/L)	16.7 (3.6 – 580)	87.3
SO42- (mg/L)	7.3 (1 – 92.1)	12
NO2 + NO3 (mg/L)	0.097 (0.005 – 8.04)	0.88
PO42- (mg/L)	0.025 (0.003 – 0.489)	0.05
NH4+ (mg/L)	0.06 (0.015 – 19.8)	0.12

The current water quality data are compared to historical data in the Letaba River (LETA-B83E-KNPBR) in Table 5.14. Although the EC level exceeded the RQO numerical value it was still below the 95th percentile for this reach of the Letaba River. All the salt concentrations were within the 50th percentile, whereas the nitrate and nitrite levels were above the mean for the Letaba River in the Kruger National Park.

TABLE 5.14 COMPARISON BETWEEN HISTORICAL AND CURRENT WATER QUALITY AT SITE LETA-B83E-KNPBR (LETABA RIVER).

	Historical	Current	RQOs
Sampling period	1983 - 2018		
TDS (mg/L)	297 (81 – 912)	558	
EC (µS/cm)	412 (136 – 1300)	804	≤ 550 µS/cm mg/l (95th percentile)
pH	8.26 (6.08 – 8.91)	8.4	
Na (mg/L)	32.5 (5.5 – 161)	29.7	
Mg (mg/L)	15.3 (3.7 – 60.1)	15.7	
Ca (mg/L)	22 (6.3 – 63.1)	13.1	
K (mg/L)	4.4 (1.79 – 9.77)	3.2	
Cl (mg/L)	34.1 (9.54 – 188)	28.3	
SO42- (mg/L)	9.25 (1.6 – 41.9)	13	
NO2 + NO3 (mg/L)	0.094 (0.005 – 7.05)	0.29	
PO42- (mg/L)	0.019 (0.003 – 0.445)	0.02	≤ 0.025 mg/l (50th percentile)
NH4+ (mg/L)	0.072 (0.015 – 6.53)	0.02	

5.4 WATER QUALITY REFERENCES

Rossouw, J.N., 2013. Determination of the EWRs: Water Quality Specialist Report In: Limpopo River Basin Monograph, Determination of Present Ecological State and Environmental Water Requirements (No. LRBMS-81137945)

Wepener, V., 2020. Water Quality, In: Dickens, C. (Ed.), E-Flows for the Limpopo Basin: Specialist literature and data review. International Water Management Institute.

6 GROUNDWATER

Contributors: Manuel Magombeyi, Karen Villholth, Girma Ebrahim, Eddie Riddell and Robin Petersen

6.1 INTRODUCTION

The objective of this report is to summarize our understanding of the two groundwater study sites (Letaba and Mapungubwe) and other (basin-wide) sites in the Limpopo River Basin. Comparison of baseflow indices from various methods at two sites was also carried out to understand whether there is an agreement in the way the groundwater flow contribution to E-flows was conceptualized in the surface hydrology component.

6.1.1 SAMPLING SITES BASIN-WIDE AND TWO GROUNDWATER SITES

The freshwater team focused on the basin-wide water sample collection from both surface river flow and boreholes near the river, while the groundwater team collected surface water and borehole water from Letaba and Mapungubwe sites (The in-situ water quality for the two groundwater sites were presented in Table 6.1. The other chemical parameters analysed in the laboratory are presented next.

). The samples collected during this period were representative of the wet season surface water and groundwater quality status.

6.2 GROUNDWATER QUALITY MONITORING

The water samples collected throughout the Limpopo River Basin were used to analyse the proportion of groundwater in the surface water for gaining rivers (perennial) and vice versa for losing sections of the rivers (ephemeral). The separation of proportion of groundwater and surface water was based on the assumption that groundwater and surface water have different signature, and this signature can be used to assess the proportion of groundwater in surface water flow. The signature can be assessed from chemical and isotope analysis of surface water flow and groundwater near the rivers. In some cases, electrical conductivity was used where there is huge difference in levels between surface water and groundwater and there is no additional input of salts to water from other sources in the area.

The average electrical conductivity and total dissolved solids for surface water was 348 µS/cm and 226 mg/L, respectively, for Letaba, while for Mapungubwe it was 458 µS/cm and 298 mg/L, respectively (Figure 104– Figure 107). The groundwater generally showed much higher levels (about 10 times) of electrical conductivity and total dissolved solids (TDS) compared to surface water. The permissible limit of TDS in the drinking water is 1,000 mg/L (WHO, 1993). Letaba groundwater sites had an average of 4,863 µS/cm and 2,798 mg/L for electrical conductivity and total dissolved solids, respectively, while Mapungubwe sites had an average of 3,274 µS/cm and 1,232 mg/L, respectively (Figure 104– Figure 107). The average TDS values in both sites exceeded the permissible WHO limit. Surface water in Letaba was fresher compared to the one in Mapungungwe, while groundwater in

Letaba was more saline compared to the one in Mapungubwe. Detailed results are presented in **Error! Reference source not found.**.

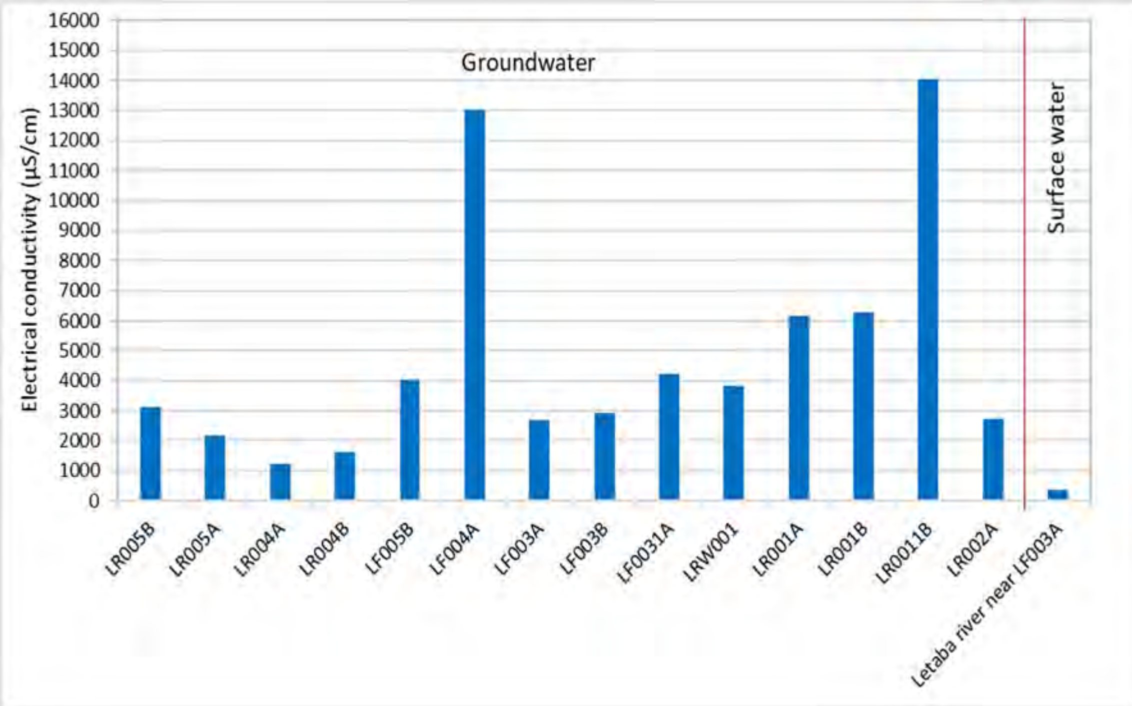


FIGURE 104: ELECTRICAL CONDUCTIVITY OF GROUNDWATER AND SURFACE WATER FROM LETABA SITES. LF – IS UPSTREAM FARMING AREAS, AND LR – IS BOREHOLE WITHIN LETABA RESERVE AREA

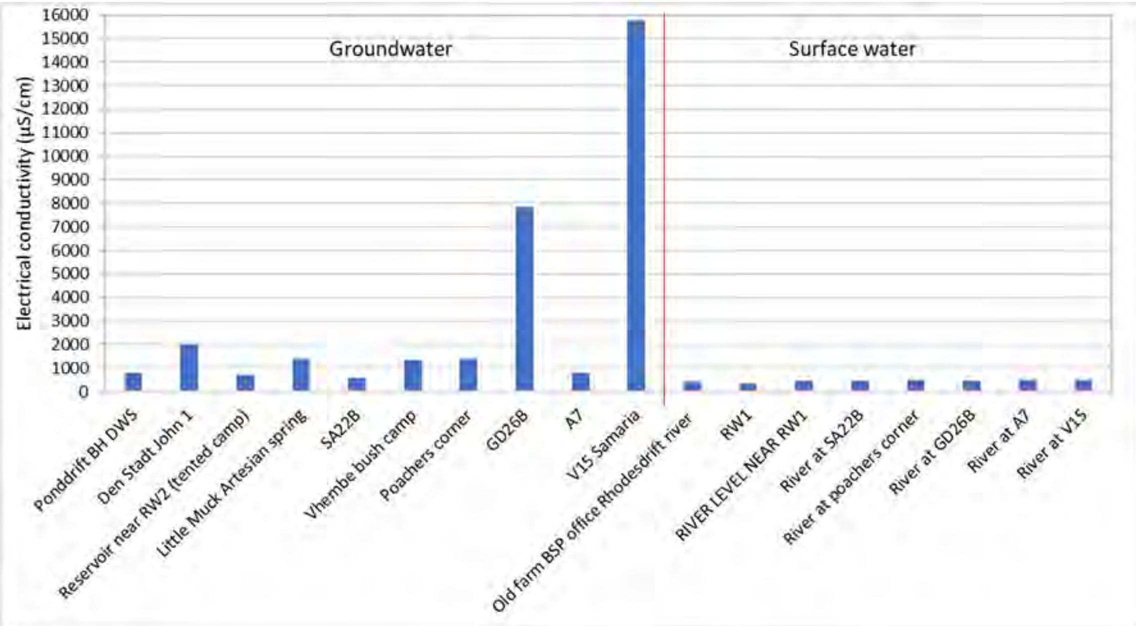


FIGURE 105: ELECTRICAL CONDUCTIVITY OF GROUNDWATER AND SURFACE WATER FROM MAPUNGUBWE SITES

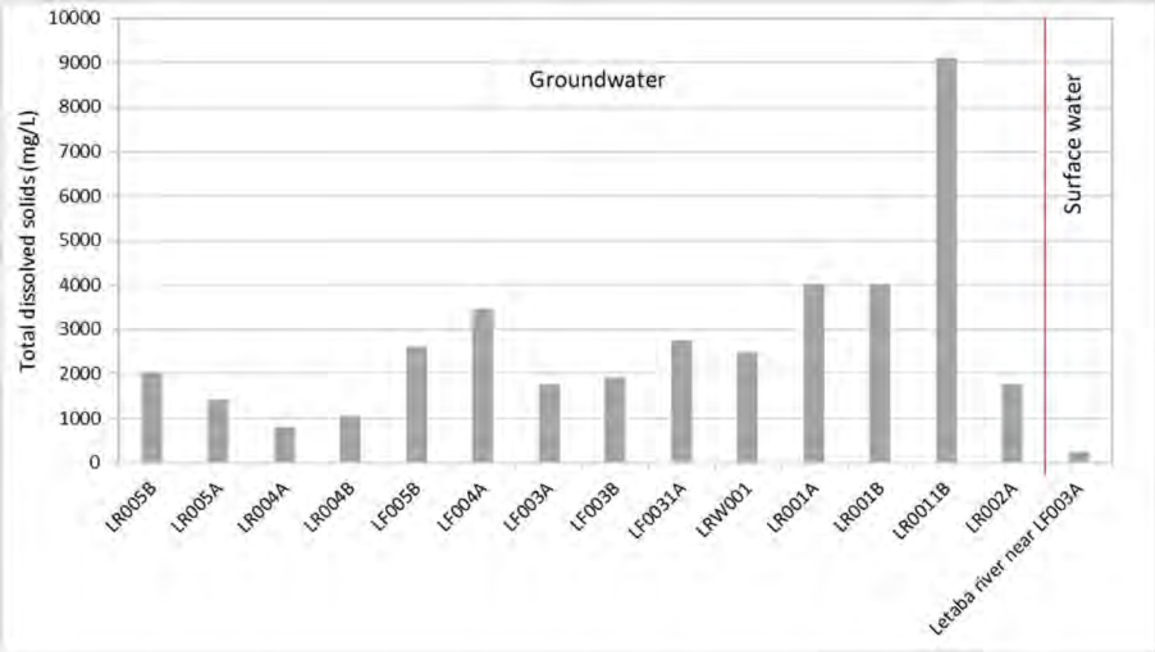


FIGURE 106: TOTAL DISSOLVED SOLIDS OF GROUNDWATER AND SURFACE WATER FROM LETABA SITES. LF – IS UPSTREAM FARMING AREAS, AND LR – IS BOREHOLE WITHIN LETABA RESERVE AREA

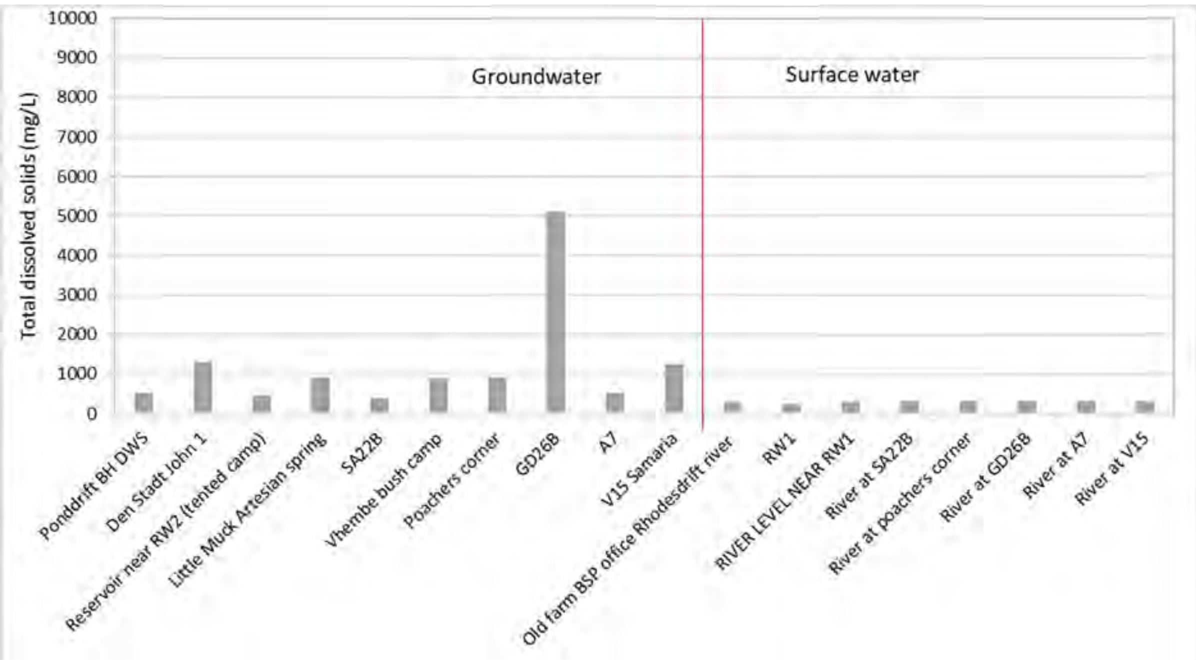


FIGURE 107: TOTAL DISSOLVED SOLIDS OF GROUNDWATER AND SURFACE WATER FROM MAPUNGUBWE SITES

TABLE 6.1 IN-SITU WATER QUALITY FROM SITES IN LETABA AND MAPUNGUBWE

Site Name	DO%	EC microS/cm	TDS mg/L	pH	pH mV	ORP mV	SAMPLE
Letaba							
LR005B	-0.1	3128	2033.96	6.84	-16.2	-193.5	PUMPED
LR005A	-0.9	2168	1409.482	8.65	-124.4	-371.2	PUMPED
LR004A	0	1234	799.8	8.75	-130.3	-270	PUMPED
LR004B	-0.8	1621	1054.685	7.06	-29.8	-241.2	PUMPED
LF005B	0.4	4020	2612.284	9.06	-148.6	-193.6	BAILED
LF004A	7.1	13018	3463.84	7.82	-75	-241.3	PUMPED
LF003A	0.1	2707	1759.628	7.2	-38.1	-214.3	PUMPED
LF003B	11	2931	1905.128	7.2	-38.1	-193.9	PUMPED
LF0031A	0.2	4229	2748.864	6.54	0.9	58.3	PUMPED
LRW001	14	3819	2482.624	7.13	-34	-92	PUMPED
LR001A	-0.3	6167	4008.62	7.81	-74.5	-316.6	PUMPED
LR001B	36.6	6287	4002	6.76	-11.8	-96.5	PUMPED
LR0011B	2.2	14028	9118.479	6.56	-0.3	-176.7	BAILED
LR002A	-0.5	2724	1771.376	8.54	-117.9	-354.3	PUMPED
Letaba river near LF003A	101.3	348	226.217	8.03	-86.5	-72.8	GRAB
Mapungubwe							
PONDRIFT BH DWS	8.2	800	520.193	7.67	-66.1	-165.2	BAILED
DEN STADT JOHN 1	5	2016	1311.79	7.37	-48	-204.6	PUMPED
RESERVOIR NEAR RW2 (Forest tented camp)	65.4	734	482.88	7.53	-57.8	19.9	From TAP
OLD FARM BSP OFFICE RHODESDRIFT RIVER LEVEL	117.1	440.3	286.276	8.46	-112.3	21.1	GRAB
LITTLE MUCK ARTESIAN SPRING	46.1	1399	909.4	7.12	-33.4	62.1	GRAB
SA22B	-0.2	607	391.75	7.49	-55.4	-47.8	Pumped
Vhembe bush camp	71.7	1362	885.36	7.47	-53.1	81.2	jojo storage via borehole
Poachers corner	0.8	1403	927.8	7.51	-56.6	-184.9	PUMPED
GD26B	3.8	7848	5112	7.35	-47.1	-242.4	PUMPED
A7	26.8	789	512.9	6.79	-13.4	-7.5	bailed
V15 Samaria	0.1	15780	1267	6.92	-21.6	-171	PUMPED

Site Name	DO%	EC microS/cm	TDS mg/L	pH	pH mV	ORP mV	SAMPLE
RW1	23.9	348.7	226.604	8.15	-94.4	-118.2	
RIVER LEVEL NEAR RW1	112.2	453.2	294.545	8.21	-97.5	11.8	GRAB
River @ SA22B	89.7	477.6	310.821	8.04	-86.8	35.6	GRAB
River @ poachers corner	106.4	486.3	316.059	8.33	-104.2	-8.4	GRAB
River @ GD26B	196.2	478.7	311.182	9.09	-149.9	-8.1	GRAB
River @ A7	105.9	493.7	320.919	8.25	-99.7	9.2	GRAB
River @ V15	119.8	488.1	317.24	8.53	-116.2	7.2	GRAB

Note: LF – is upstream farming areas, and LR – is borehole within Letaba reserve area

The groundwater and river water sampling was done during recession of high flows in early May 2021. Chemical analyses of the water samples were performed at the University of North West, Potchefstroom, South Africa. The following anions and cations water quality parameters were selected for analysis: Total dissolved solids (TDS), salinity, silica (SiO_2), chloride (Cl^-) (can be used for recharge estimations), sulphate ($SO^{2-}{}_4$), alkalinity ($CO^{2-}{}_3$; $HCO^-{}_3$), calcium (Ca), magnesium (Mg), potassium (K) and sodium (Na).

A piper diagram (Sadashivaiah et al., 2008) was used to identify chemical relationships among water samples from different sources, and to reveals the similarities, dissimilarities and different types of waters and origin of water in the study area (Figure 108). In the Piper diagram major ions are plotted in the two base triangles as major cations (Ca^{2+}, Mg^{2+} and $Na^+ + K^+$) and major anions (Cl^-, SO_4^{2-} and $CO_3^{2-} + HCO_3^-$) in milliequivalent percentages (Figure 108). These plotted points in the triangular fields are projected further into the central diamond field, which provides the overall character of the water. Water type/ hydrochemical facies evaluation are extremely useful in providing a preliminary idea about the complex hydrochemical processes in the subsurface. Determination of hydrochemical facies was extensively used in the chemical assessment of groundwater and surface water for several decades (Piper, 1944).

The legend for the piper diagram shows the different water types, A: Calcium type; B: No dominant type; C: Magnesium type; D: Sodium and potassium type; E: Bicarbonate type; F: Sulphate type; G: Chloride type; 1: Alkaline earths exceed alkalies; 2: Alkalies exceed alkaline earths; 3: Weak acids exceed strong acids; 4: Strong acids exceed weak acids; 5: Magnesium bicarbonate type; 6: Calcium chloride type; 7: Sodium chloride type; 8: Sodium bicarbonate type; 9: Mixed type.

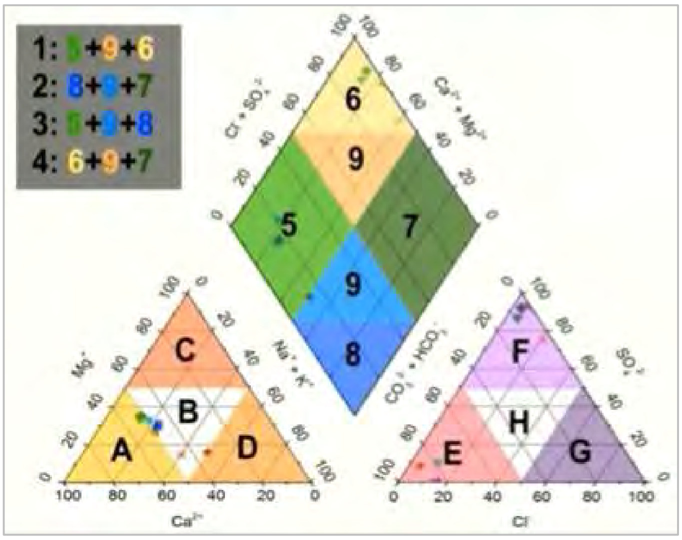


FIGURE 108: PIPER DIAGRAM SHOWING DIFFERENT WATER TYPES (SADASHIVAIAH ET AL., 2008)

The chemical analysis of groundwater and river water in the two-groundwater sites (Letaba and Mapungubwe) is presented in a piper diagram (Figure 109).

6.3 GROUNDWATER QUALITY RESULTS

The in-situ water quality for the two groundwater sites were presented in Table 6.1. The other chemical parameters analysed in the laboratory are presented next.

Water quality characterization of Letaba catchment

The groundwater in Letaba catchment during the recession of high flows was mixed Ca-Na-HCO_3 type (temporary hardness water) and Na-Cl type (saline water), while river water was Ca-HCO_3 type (Figure 109). The saline water is likely from shale geological formation and concentration of NaCl from evaporation. This indicates that there is strong interaction between river and groundwater (Sadashivaiah et al., 2008) and river water evolved from groundwater.

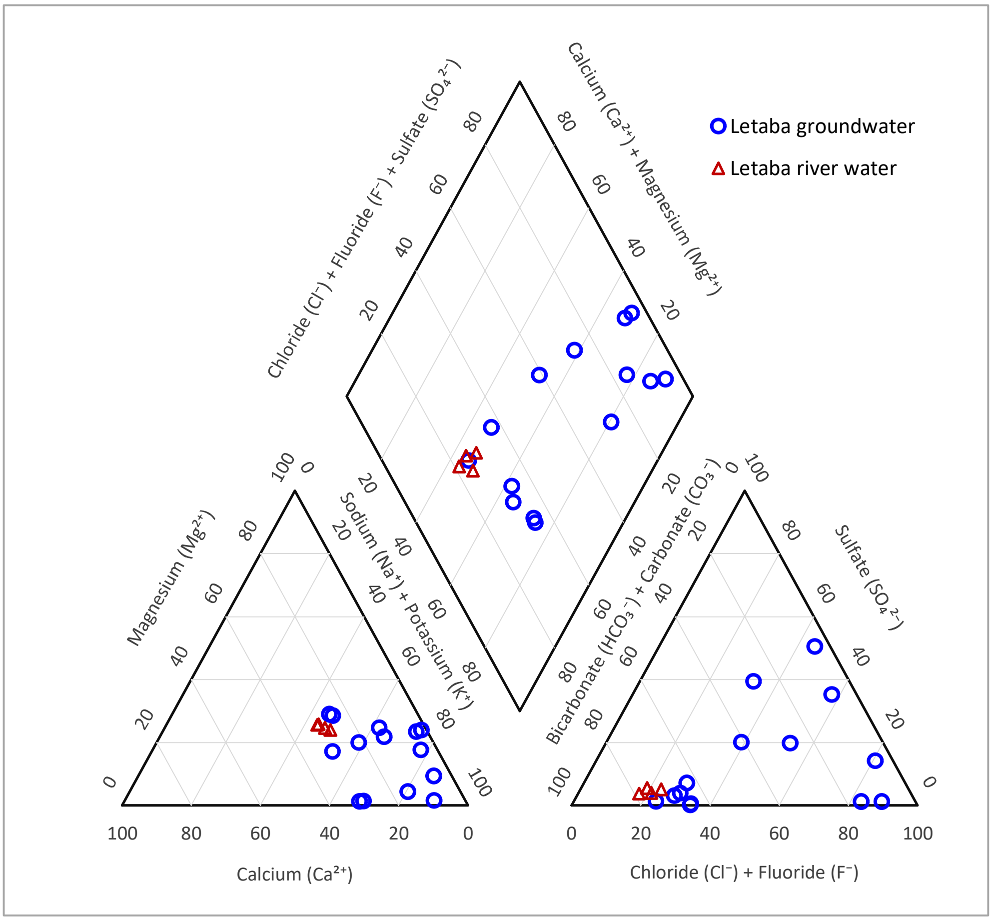


FIGURE 109: THE PIPER DIAGRAM FOR GROUNDWATER AND RIVER WATER FOR LETABA SITES

Water quality characterization of Mapungubwe site

Groundwater in Mapungubwe during the same period was classified as Ca-HCO_3 type (shallow fresh ground water), which is also known for temporary hardness) and mixed Ca-Na-HCO_3 type, while river water was Ca-HCO_3 type (Figure 110). There were a few (2) groundwater samples that demonstrate Na-Cl type (saline) and mixed Ca-Mg-Cl type (Figure 110). In both sites, river water (Ca-HCO_3 type) and groundwater (Ca-HCO_3 type, mixed Ca-Na-HCO_3 type and Na-Cl type) was similar. It is suggested that the chemistry of the groundwater was controlled by a mixing process and cation exchange process.

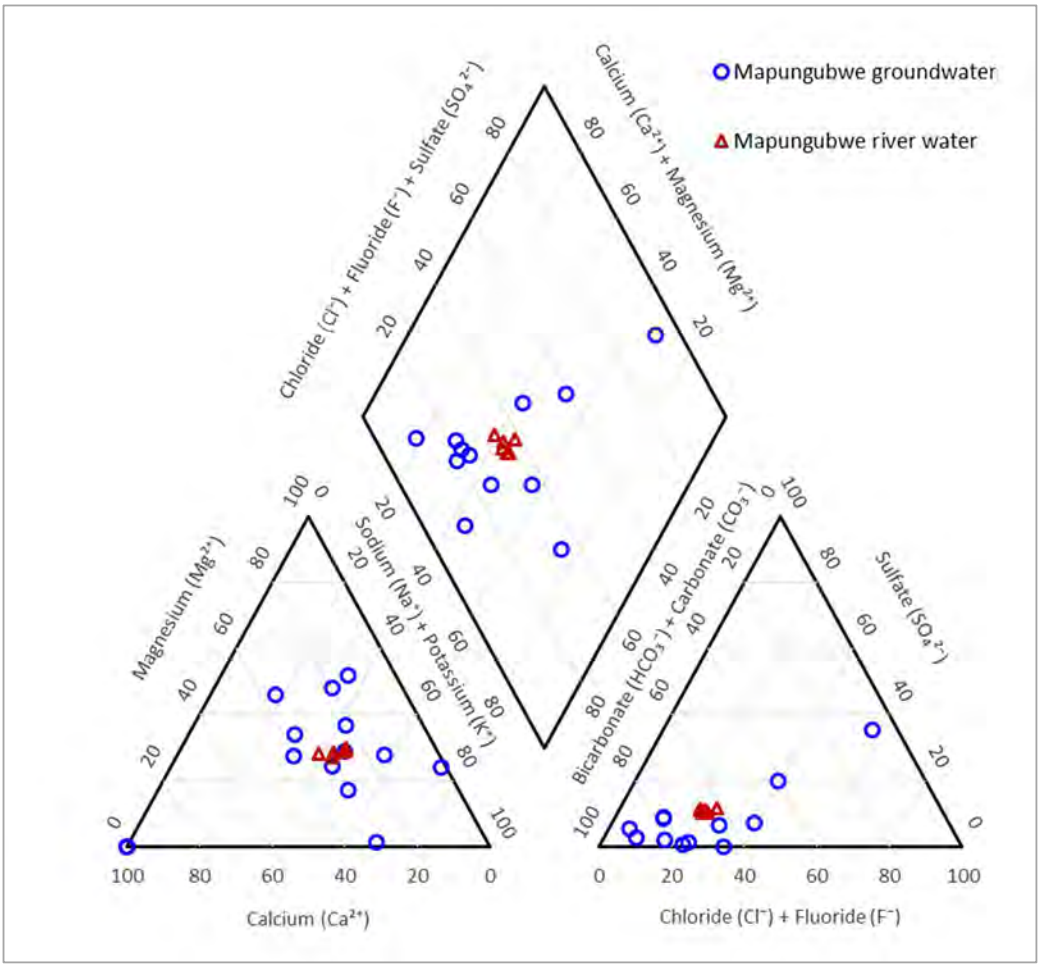


FIGURE 110: THE PIPER DIAGRAM FOR GROUNDWATER AND RIVER WATER FOR MAPUNGUBWE SITES

Water quality characterization of other sites in Limpopo River Basin

Other sites in the basin had groundwater classified as Ca-CI type and Na-CI type, while the river water was classified as Ca-CI type and Na-CI type (Figure 111). The groundwater and river water were associated with permanent hardness. This showed similar groundwater and river water. A few (3) groundwater samples demonstrated mixed Ca-Mg-CI type (Figure 111), indicating permanent hardness.

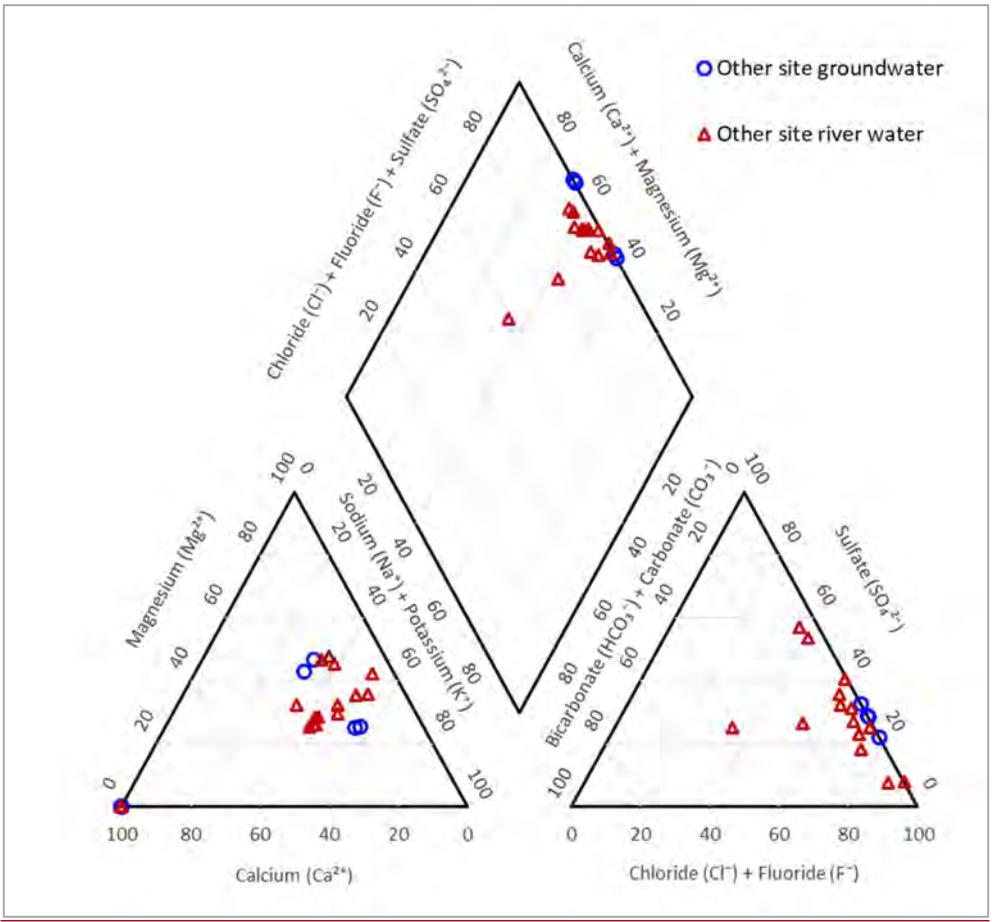


FIGURE 111: THE PIPER DIAGRAM FOR GROUNDWATER AND RIVER WATER FOR OTHER SITES IN THE LIMPOPOPO RIVER BASIN

Considering all sites sampled in the Limpopo River Basin (Figure 112), groundwater was classified as Ca-HCO_3 type, (indicating reverse/ inverse ion exchange (Davis and Dewiest, 1966) responsible for controlling the chemistry of the groundwater), mixed Ca-Na-HCO_3 type, and Na-Cl type. A few (two) samples were classified as Ca-Cl type, giving an indication of groundwater from formations that are composed of limestone and dolomite or from active recharge zones with short residence time (Hounslow, 1995). River water was classified as Ca-HCO_3 type (associated with temporary hardness), Na-HCO_3 type and mixed Ca-Mg-Cl-SO_4 type (associated with permanent hardness), where type of river water cannot be identified as neither anion nor cation dominant (Todd and Mays, 2005).

The spatial configuration of borehoels at Mapungubwe and Letaba were different, with Letaba site having higher density than Mapungubwe site. Results of the hydrochemistry suggest that all the groundwater water samples were slightly acidic to alkaline in nature, pH (6.5-9.2), while river water showed alkaline water with pH (8.0-9.2). This pH range is expected in groundwater sources. The chemistry of groundwater and river water for sites in the Limpopo River Basin, is characterized by similar mixtures of constituents and reflects water with similar history, origin and interactions. In summary, the chemistry of groundwater and river water for sites in the Limpopo River Basin, is characterized by similar mixtures of constituents and reflects water with similar history, origin and interactions. This supports the strong interaction between surface water (river water) and groundwater to provide environmental water flows, even under the recession of high flows in wet season.

Major process controlling the water quality is the silicate weathering, mineral dissolution, cation exchange and inverse cation exchange processes. The geochemical facies in the Piper diagram supports the dominance of alkali-rich waters over alkaline earth metal (viz., Na + K > Ca + Mg) in the groundwater of Limpopo River Basin. Most samples showed that strong acids exceed the weak acids (Figure 112). It is suggested that silicate weathering is dominant in the rock-water interaction that are the primary factors responsible for increase in the major ion concentration in the groundwater (Kumar et al., 2009). The piper diagram supported the strong interaction between surface water (river water) and groundwater to provide environmental water flows in the Limpopo River Basin.

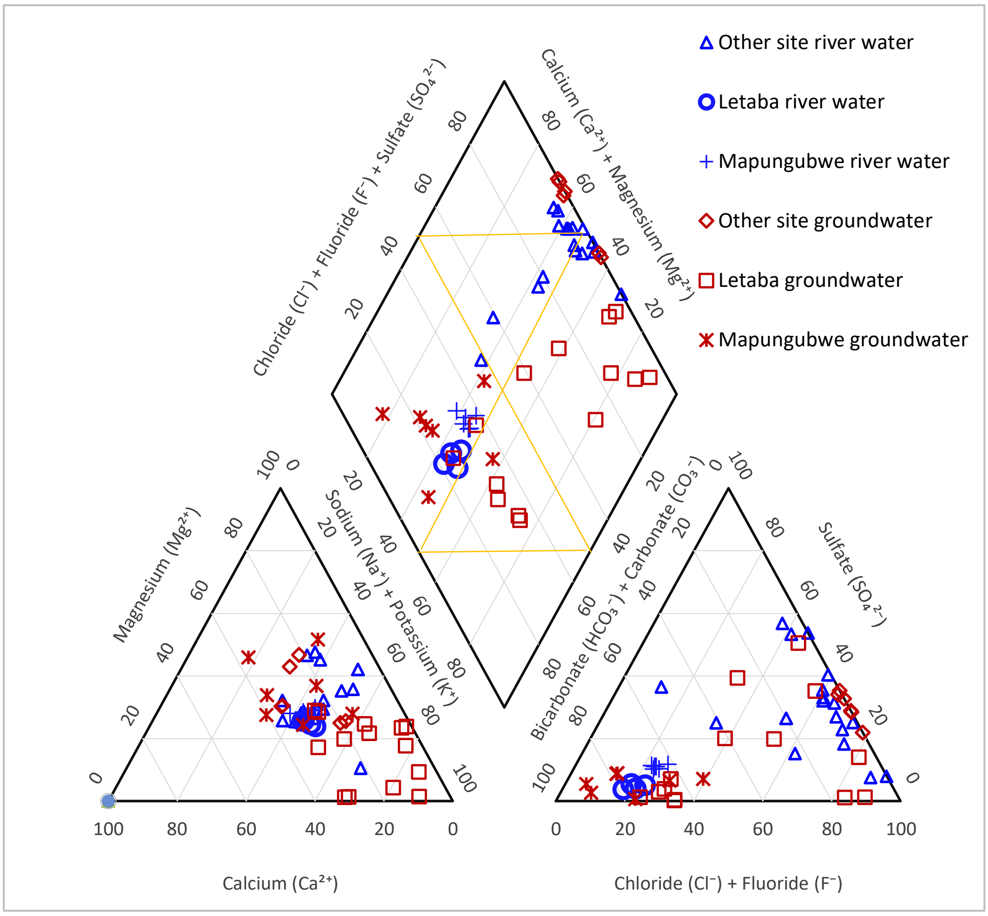


FIGURE 112: THE PIPER DIAGRAM FOR GROUNDWATER AND RIVER WATER FOR LETABA, MAPUNGUBWE AND OTHER SITES IN THE LIMPOPOPO RIVER BASIN

6.4 BASEFLOW SEPARATION USING STABLE ISOTOPE AND CHEMICAL PARAMETERS

For base-flow separations, two components are commonly determined that include (1) pre-event water (old water), consisting of unsaturated-zone water and groundwater and (2) event water (new water), consisting of surface runoff and lateral stormflow (Kish et al., 2010). In this study, old water was taken as groundwater, while event water was taken as rainfall. Water moving along different pathways picks up different minerals, organic matter and nutrients, depending on the characteristics of the geological pathway and the water residence time. Therefore, different parts of a catchment and selected components (Figure 113) can contribute to different quality signatures (fingerprint).

An isotopic signature is a ratio of non-radiogenic 'stable isotopes', stable radiogenic isotopes, or unstable radioactive isotopes of particular elements in sampled water (Kumar et al., 2018).

A favourable condition for isotope or chemical hydrograph separation method exists if the old water was condensed at a different temperature than the new water (Zhang et al., 2009). Isotopic and chemical hydrograph separation methods are mostly applicable for short-term river flow applications due to high laboratory analyses costs.

In a perennial river catchment, the total river flow may be approximated by a simple model as the sum of two components of surface runoff or rainfall (higher organic carbon, than groundwater) and baseflow or groundwater (with higher mineral content). The two-component isotope and chemical hydrograph separation method (Wang et al., 2015) using ^{2}H, ^{18}O and chloride (Cl) as tracers was applied to separate the total river flow hydrograph into surface runoff and baseflow components. The model shown in Figure 113 was applied with the assumption that rainfall/precipitation can be used to represent the surface runoff (new water), and total river flow to be a summation of rainfall (assumed to represent surface runoff) and groundwater (old water).

To separate pre-event water (Q_b, baseflow) from event water (Q_r, surface runoff) using stable isotopes (^{18}O and ^{2}H) measurement, a one tracer and two-component (rainfall or precipitation water and groundwater) mass balance equation was used to identify the origin and amounts of mixing components in the surface water system. The mass balance equations were taken over each sampling period. This technique was selected for this study due to the fact that it is physically-based, effective and has been widely used across the world in combination with other methods (Wang et al., 2015).

The two-component isotope hydrograph separation method equations were expressed after Hooper and Shoemaker (1986). The mass balance equation was used for a time-based (e.g., sampling period, one month or day) two-component method, representing surface runoff and baseflow from groundwater. Separation using a tracer (*C*) as an example can be described by Equations 1-3 (Wang et al., 2015; Kish et al., 2010; Hooper and Shoemaker, 1986):

$$Q_n = Q_t - Q_o \qquad \text{Equation 1}$$

$$Q_o = [(C_n - C_t)/(C_n - C_o)]Q_t \qquad \text{Equation 2}$$

Where Q_t [$m^3 s^{-1}$], is the total river runoff, and Q_n [$m^3 s^{-1}$] and Q_o [$m^3 s^{-1}$] are the event and pre-event flow components, respectively. C_t is the total concentration of a specific observed tracer such as deuterium (^{2}H) or oxygen 18 (^{18}O) in total river flow, and C_n and C_o are the tracer concentrations for event (new water) and pre-event (old) water, respectively. ^{2}H and ^{18}O isotopes concentrations are generally expressed as sigma values which are per mil (‰) variations with respect to Standard Mean Ocean Water (Pellerin et al., 2008). The tracer concentrations were obtained from the laboratory analyses of rainfall, river flow and groundwater from monitoring and production boreholes.

Dividing Equation (2) by Q_t, the volume contribution of event water and pre-event water to the total river flow is estimated by Equation 3:

$$Q_o/\ Q_t = [(C_n\text{-}C_t)/(C_n - C_o)] \qquad \text{Equation 3}$$

Where the terms of the equation are as described in Equations 1 and 2.

The concentration values for baseflow (C_o) and surface runoff or rainfall (C_n) are assigned and assumed to be constant throughout the monitoring period (Stewart et al., 2006).

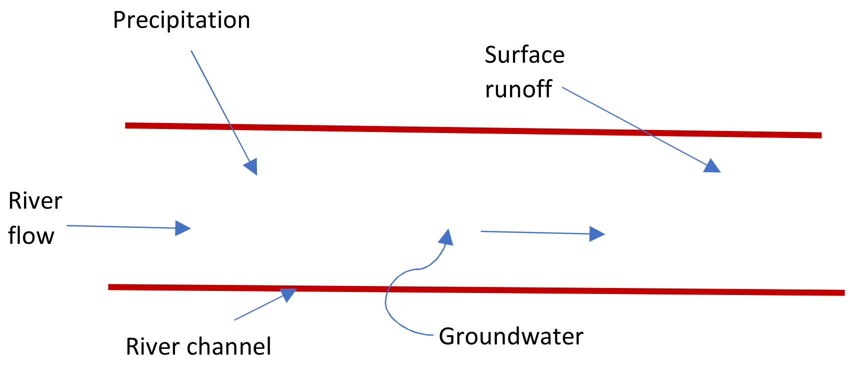


FIGURE 113: RIVER WATER FLOW CONSISTING OF WATER FROM DIFFERENT FLOW PATHWAYS

Using, the constant concentration values of baseflow or groundwater (C_o) and rainfall/surface runoff (C_n) and total river flow (C_t) in the mass balance Equation 3, the baseflow component of the hydrograph was calculated (TABLE 6.2). The ^{2}H isotope consistently overestimated BFI for Letaba, Mapungubwe and other sites compared to ^{18}O. The rainfall isotope analysis results (2017-2019) from a catchment (B81D –in Letsitele) (Magombeyi et al., 2019) and B81J (Gokool, 2017) all the Letaba Water Management Area was used as new water (C_n) for the Letaba, Mapungubwe and other sites in the Limpopo River Basin. There was a limitation on lack of chemical and isotopic data for rainfall in other parts of the basin besides Letaba and Mapungubwe sites.

TABLE 6.2. SUMMARY OF THE SEPARATION OF GROUNDWATER AND SURFACE WATER USING ISOTOPES IN THE LIMPOPO RIVER BASIN

PARAMETER	LETABA		MAPUNGUBWE		OTHER LIMPOPOPO SITES	
Tracer	^{2}H (‰)	^{18}O (‰)	^{2}H (‰)	^{18}O (‰)	^{2}H (‰)	^{18}O (‰)
C_n (Rainfall)	-2.53	-1.93	-19.40	-2.30	-20.00	-3.00
C_t (River)	-14.70	-2.98	-21.13	-2.70	-34.55	-5.37
C_o (Groundwater)	-26.69	-4.53	-28.07	-4.47	-22.98	-3.39
Q_o (GW)/Q_t (River)	0.50	0.40	0.20	0.18	0.23	0.22

C_n is tracer concentrations for event (new water); C_t is tracer concentration in the river; C_o is tracer concentration of old water; Q_o [m^3 s^{-1}] is groundwater flow or old or prevent flow, Q_t [m^3 s^{-1}], is the total river runoff and GW is groundwater.

Chloride, being one of the conservative tracers in the hydrochemistry domain can be used to demonstrate the proportion of groundwater in river flow. However, in this study it did not yield good results of proportion of groundwater to river water (0.21 for Letaba and 0.33 for Mapungubwe) as there is an input of chloride from other sources (e.g., domestic effluent discharged to rivers) as was reported by Magombeyi et al. (2019) for a subcatchment of the Letaba catchment.

6.4.1 Isotope water quality

The oxygen-18 and deuterium (^2H) analysis was used to assess groundwater and surface water interaction. This was done by calculating the proportion of groundwater in total river flow. Stable isotope analyses of the water samples were performed using Thermo Delta V mass spectrometer connected to a Gasbench at Environmental Isotope Group (EIG) at iThemba Laboratories in Johannesburg, South Africa.

The relative content of stable isotopes of ^{18}O and ^2H in water samples was expressed in $\delta^{18}O$ and δ^2H values, respectively, from the liquid hydrogen and oxygen stable isotope analyser, and reported using the δ notation, defined according to the Vienna Standard Mean Ocean Water (VSMOW) as $\delta^{18}O$ and δ^2H (Craig, 1961). The $\delta^{18}O$ vs. δ^2H from rainfall, river water and groundwater from boreholes were compared to the Local Meteoric Water Line (LMWL), which takes into account local climate variations by bivariate plot. However, in the absence of local precipitation data in this study area, a Global Meteoric Water Line (Wang et al., 2015), Pretoria Meteoric Water Line and Taaiboschgroet (Limpopo) Meteoric Water Line (Wyk, 2010) were used for comparison (IAEA/WMO, 2018). The Taaiboschgroet LMWL used observed rainfall from 2003-2009 in the semi-arid summer rainfall in Limpopo Province, South Africa.

These non-radioactive (stable) isotopes of hydrogen (^2H) and oxygen (^{18}O) were applied in this study for the following reasons:

- Stable isotopes in rainwater contain a unique signature that is marked by atmospheric processes (i.e., geographic positions (altitude and latitude) and time of the year.
- Depletion of the heavier stable isotopes due to heavy rainfall events, marks the rainwater stable isotope composition (^2H and ^{18}O) with respect to the most abundant rainwater molecule $^1H_2\,^{16}O$. This effect specifically mark the recharge-producing rainfall surplus in the arid/semi-arid regions of South Africa.
- Once rainwater falls on to the ground surface, evaporation either at surface, depression storage, or from field capacity will alter the isotope composition and an evaporative composition may be established, which is a very useful tracer for estimating the groundwater recharge flow path from ground surface to the saturated zone.

Comparison of isotopes with Global and Local Meteoric Water Line (LMWL)

Some of the groundwater and river water samples for different sites in the Limpopo River Basin are distributed along the LMWL in a δ^2H- $\delta^{18}O$ diagram (Figure 114- Figure 117). This suggests rapid rainfall infiltration to groundwater and is not affected by evaporation processes during infiltration owing to the presence of geological faults and vegetation cover. Other groundwater and river water samples for ^2H and ^{18}O were offset to the right of the Meteoric Water Line (MWL), Global Meteoric Water Line, Pretoria Meteoric Water Line and Taaiboschgroet (Limpopo) Meteoric Water Line), and plotted along the local evaporation trend line, indicating that groundwater and surface water were influenced by evaporation. River water and groundwater samples were depleted (plotted on the left bottom quadrant) in heavy isotopes due to precipitation from higher altitudes in the basin. The closeness of river water and groundwater samples to the local evaporation trend line suggests that these waters are composed of rainwater that underwent some evaporation. The similar isotopic signatures of the groundwater and surface (river) water or isolated pools along the river further indicates the occurrence of groundwater in the river during dry and wet periods. Hence, the isolated pools are sustained by groundwater during the dry season. The proportion of groundwater to total river flow was assessed by isotope baseflow separation presented next.

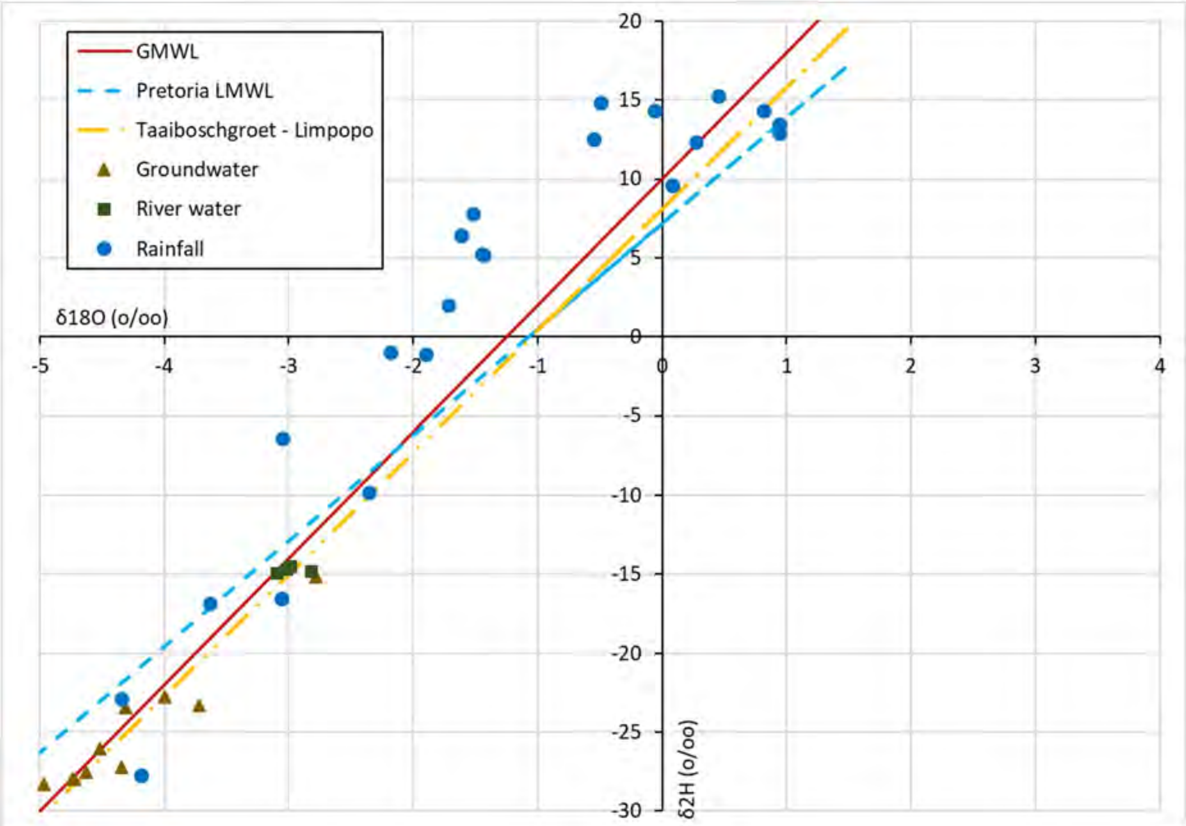


FIGURE 114: THE VARIATION OF $\delta^{18}O$ AND $\delta^{2}H$ FOR RAINFALL (2016-2018), RIVER (2021), AND GROUNDWATER (2021) FOR LETABA SITE.

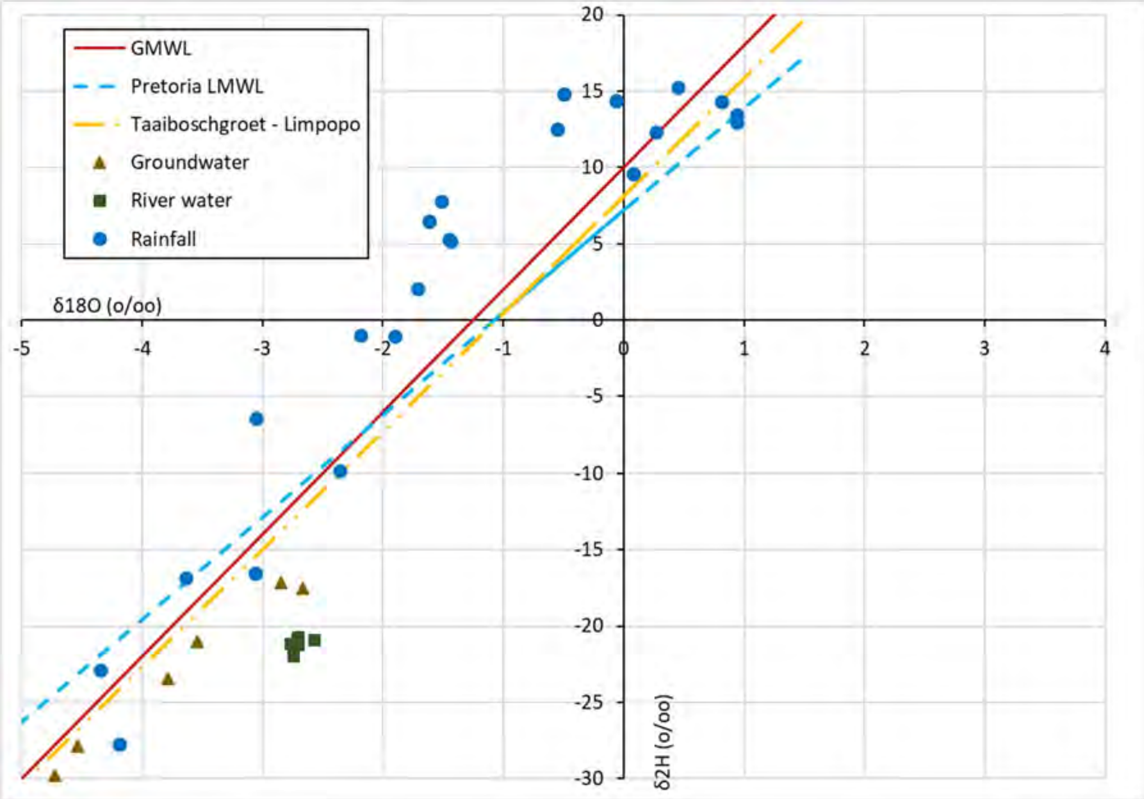


FIGURE 115: THE VARIATION OF $\delta^{18}O$ AND $\delta^{2}H$ FOR RAINFALL (2016-2018), RIVER (2021), AND GROUNDWATER (2021) FOR MAPUNGUBWE.

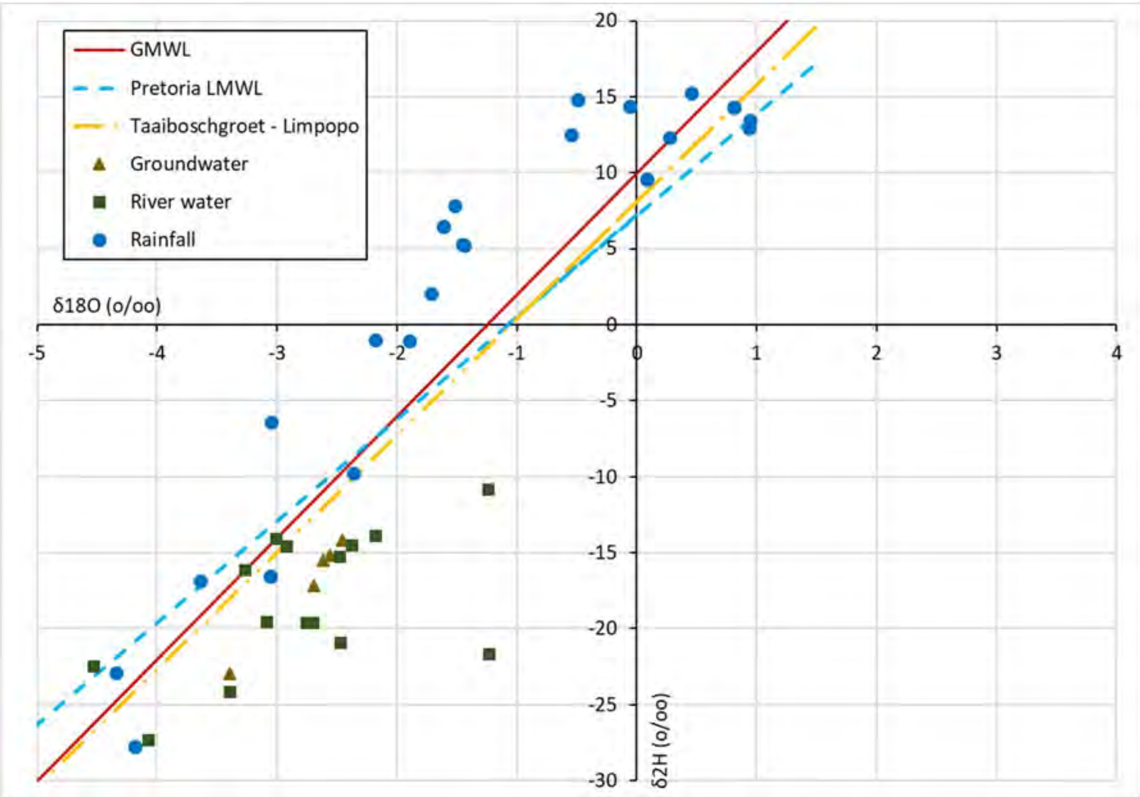


FIGURE 116: THE VARIATION OF $\delta^{18}O$ AND $\delta^{2}H$ FOR RAINFALL (2016-2018), RIVER (2021), AND GROUNDWATER (2021) FOR OTHER SITES IN LIMPOPO RIVER BASIN.

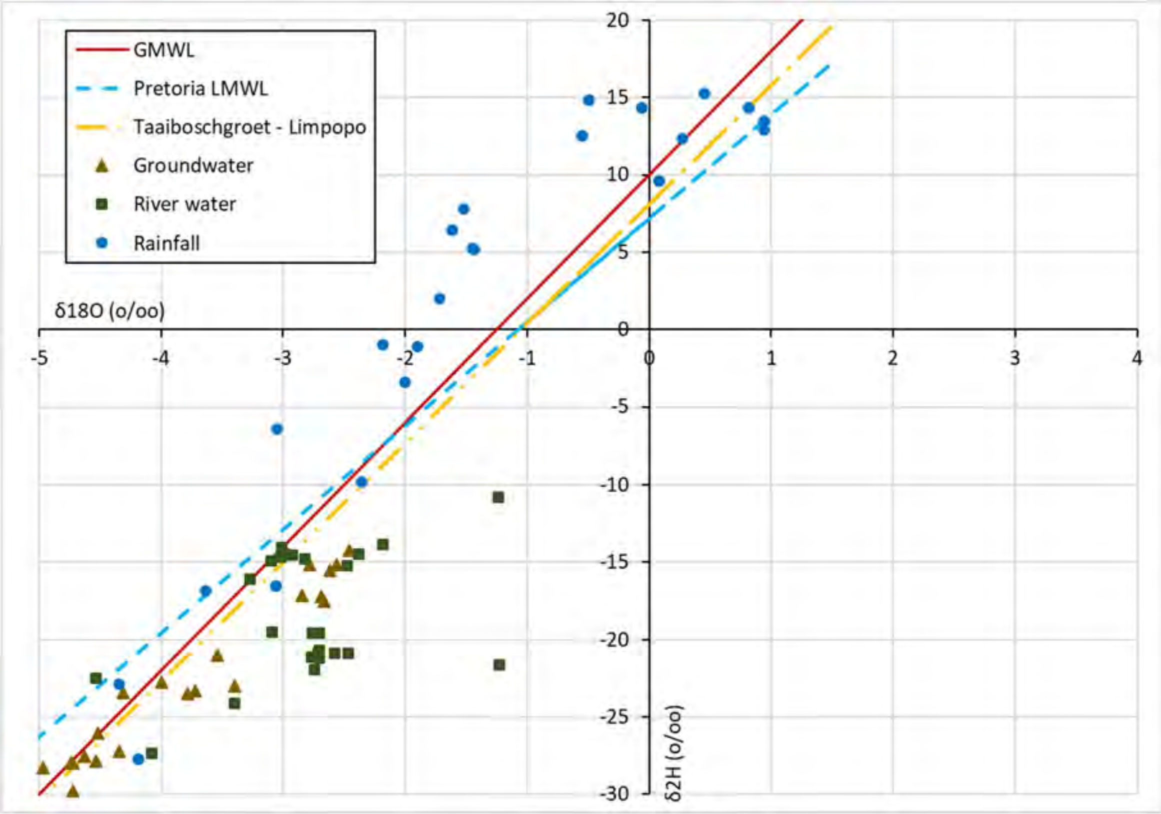


FIGURE 117: THE VARIATION OF $\delta^{18}O$ AND $\delta^{2}H$ FOR RAINFALL (2016-2018), RIVER (2021), AND GROUNDWATER (2021) FOR ALL SITES SAMPLED IN THE LIMPOPO RIVER BASIN.

6.4.2 Baseflow separation using the recursive digital filter techniques

Baseflow is the rate of groundwater flow that a given catchment provides from all upstream phreatic aquifers along the river banks in the absence of precipitation, melting snow or any upstream water inputs (Brutsaert and Nieber, 1977). Baseflow, in this study was then assumed to represent the groundwater discharge and is important in water allocation to both human and environmental purposes. In this study the baseflow was used to understand the groundwater surface water interactions, and to estimate the contribution of groundwater to the environmental water flow requirement in the Limpopo River Basin.

There are several methods that can be used to estimate the baseflow (Brutsaert and Nieber, 1977). These include graphical (Tallaksen, 1995), and digital filtering (Hughes et al., 2003; Nathan and McMahon, 1990) techniques. The recursive digital filter technique by Nathan and McMahon (1990) was used to separate baseflow from daily streamflow records (For detailed method description see the Groundwater specialist report). The daily flows were aggregated to monthly flows and BFI based on monthly flows determined and compared to BFI based on monthly flows by Hughes et al. (2003). The hydrological procedure for the determination of environmental water flow requirements for South African rivers is based on monthly naturalized flows/modelled flows (Hughes et al., 2003; Hughes, 2001).

6.4.3 Baseflow Index (BFI) comparisons

The representation of groundwater contribution to E-flows contribution is important. This representation was done through estimation of baseflow index (BFI). There are several methods that can be used to estimate BFI. In this study, BFI was estimated for naturalized flows (Surface hydrology component of the E-Flows project) and observed flows (Groundwater component). The baseflow separation methods used were digital recursive filter method, the Hughes & Smaktin Model (Stassen, 2021), which use digital recursive method, but based on monthly baseflow separation, and physical methods based on tracers such as silica and isotopes. The BFI (Stassen, 2021) for two sites in Letaba Catchment (B8H010 and B8H018), shown in Figure 118 were compared with previous studies.

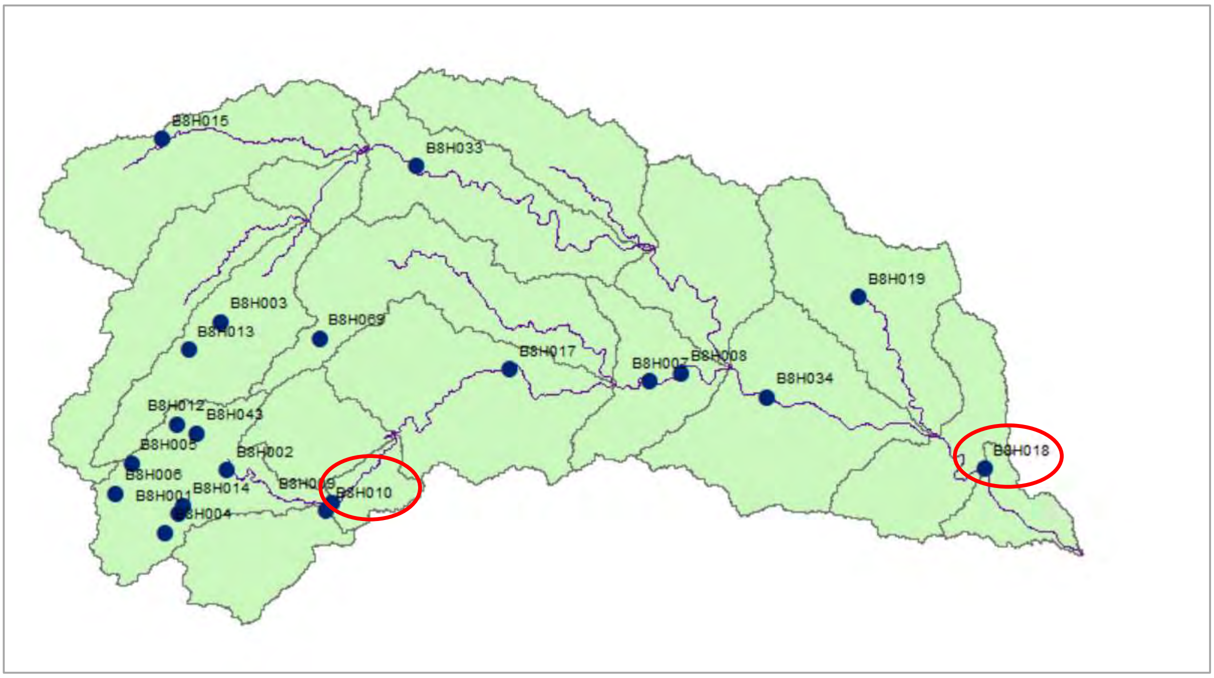


FIGURE 118: LOCATION OF ALL RIVER GAUGING STATIONS INCLUDING THE TWO SITES (B8H010 AND B8H018) UNDER COMPARISON IN THE LETABA CATCHMENT

6.4.4 Calculation of monthly BFI from aggregated daily flows

The previous studies calibrated the baseflow index using field investigations of oxygen-18 and deuterium isotopes and silica (Magombeyi et al., 2019) and digital recursive method (Ebrahim and Villholth, 2016). First, the daily baseflow separation was done and then the daily flows were aggregated to monthly flows, and the recursive digital filter method was re-run, and the two filter parameters (alpha and beta) were calibrated for the monthly filter to get the monthly BFI. The daily and monthly BFI recalculated based on the method used by Ebrahim and Villholth (2016) for the two sites are shown in Figure 119 and Figure 120. A comparison of the results of BFI from the two sites in Letaba catchment is shown in TABLE 6.3.

The baseflow index based on Nathan and McMahon (1990) for Letsitele at B8H010 gauging station for the period 1960-1983 was 0.343. The beta and alpha values were 0.95 and 0.44, respectively. The baseflow index of 0.343 was smaller (by 19%) than 0.422, calculated based Hughes & Smaktin model (Stassen, 2021). The baseflow index for Letsitele at BH8010 based on isotope separation method was 0.38, with beta and alpha values were 0.919 and 0.443, respectively (Figure 121).

The BFI for the station at B8H008 in Letaba site was not calculated due to missing data and the discharge pattern showed that the flow was controlled or the flow gauge capacity was exceeded over the recorded period (Figure 122). The station (B8H008) had a maximum flow measurement capacity of 30 m³/s, capable of capturing low flows from groundwater contributions to E-flows during dry season.

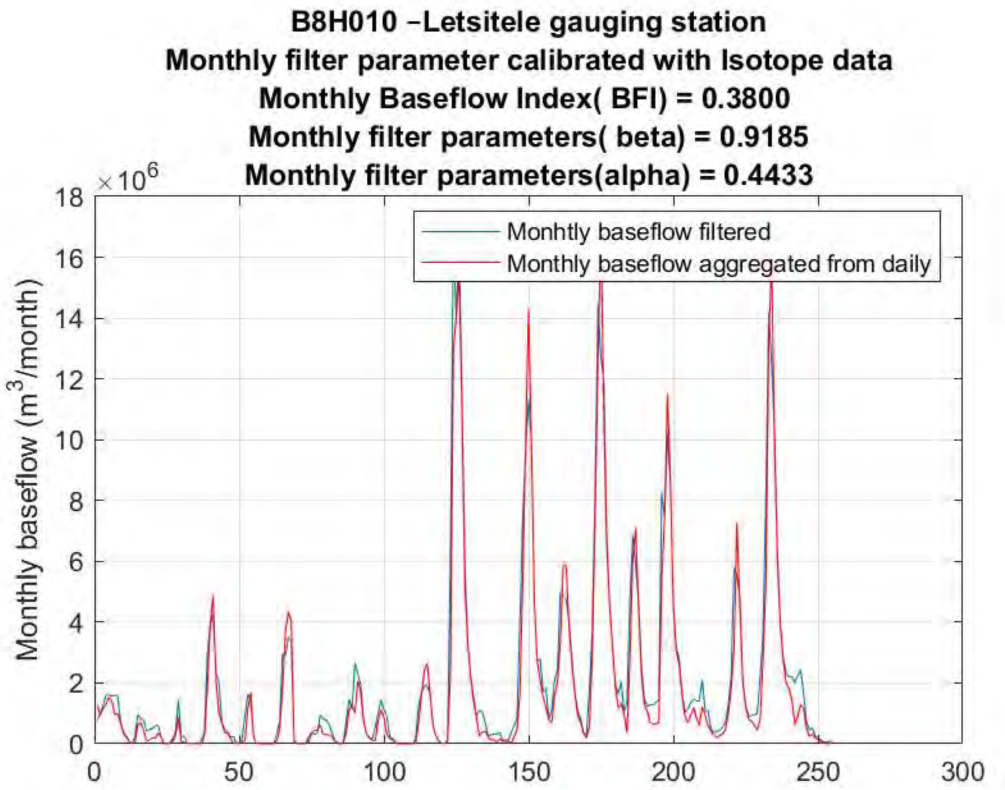


FIGURE 119: DAILY AND MONTHLY BASEFLOW INDEX FOR B8H010 IN LETABA CATCHMENT

The baseflow index based on method by Nathan and McMahon (1990) for Letaba at BH8018 gauging station for the period 1960-1973 was 0.297, with beta and alpha values of 0.97 and 0.44, respectively. The baseflow index of 0.297 was smaller (by 9.2%) than 0.327, calculated based Hughes & Smaktin Model, beta value of 0.97 and alpha value of 0.44 (Stassen, 2021). The period 1960-1973, was selected to ensure the flows used were not influenced by development (e.g., dams), and were as close as possible to naturalized flows used by Stassen (2021).

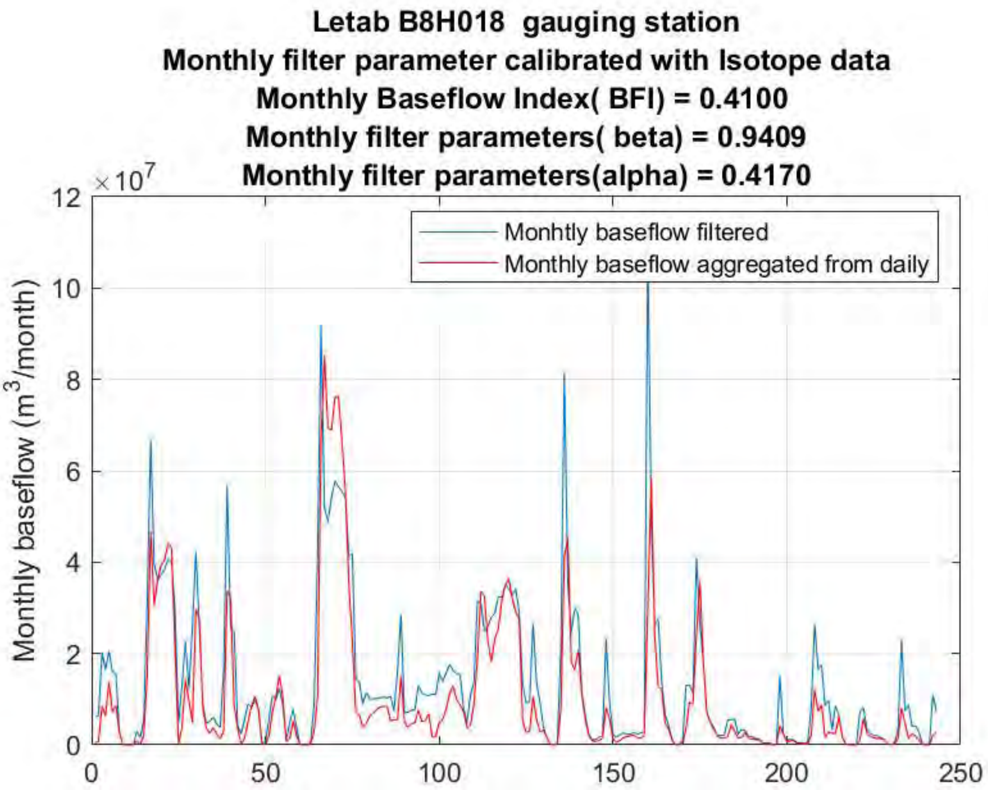


FIGURE 120: DAILY AND MONTHLY BASEFLOW INDEX FOR B8H018 IN LETABA CATCHMENT

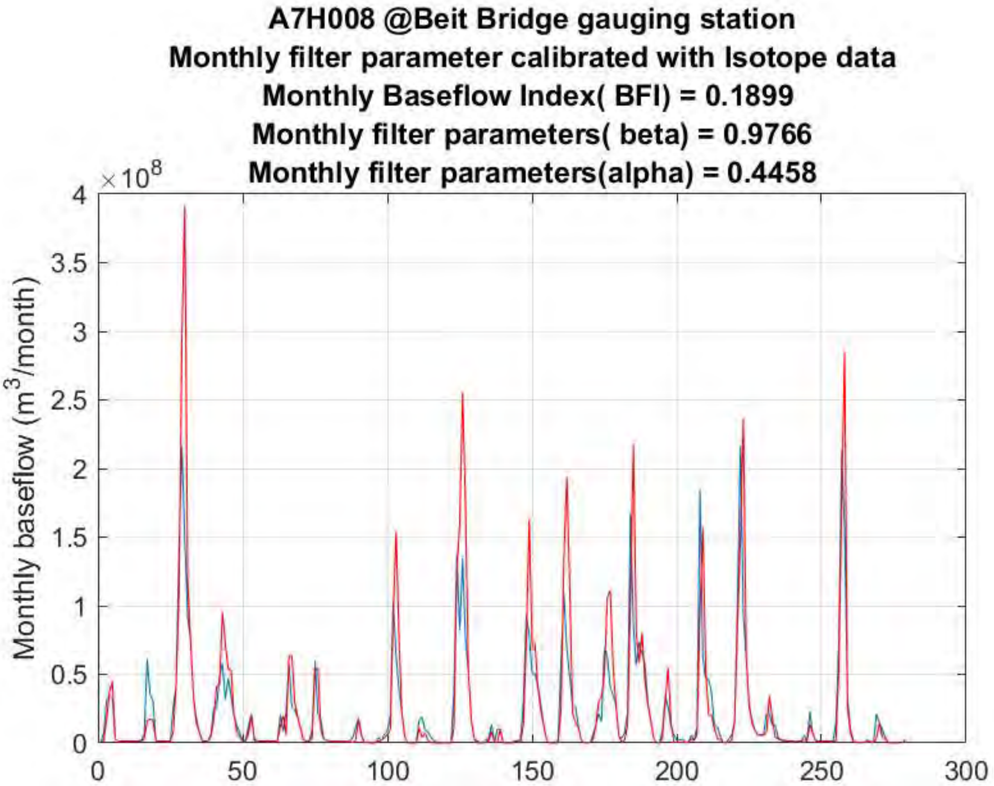


FIGURE 121: DAILY AND MONTHLY BASEFLOW INDEX FOR A7H008 AT BEIT BRIDGE, REPRESENTATIVE OF MAPUNGUBWE SITE

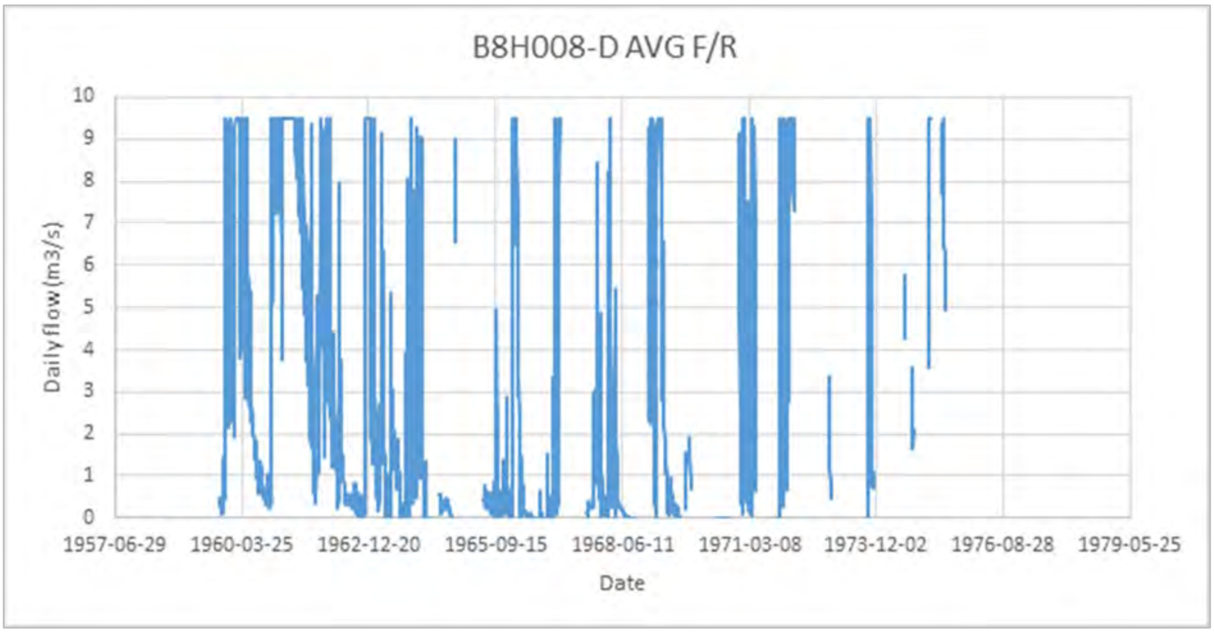


FIGURE 122: DISCHARGE AT B8H008 IN LETABA CATCHMENT.

A summary of baseflow comparison from methods based on Nathan and McMahon (1990), Hughes & Smaktin Model (Hughes et al., 2003), and isotope baseflow separation by Magombeyi et al. (2019) and current study are presented in TABLE 6.3.

The comparison between BFI used by Stassen (2021) and the monthly BFI from the digital recursive filter method (Ebrahim and Villholth, 2016) showed comparable results for the two stations, with the approach used by Stassen (2021) consistently overestimating the BFI by 9.2% (BH8018) and 19% (BH8010). The comparison of the BFI (0.38) calibrated by chemical tracer with BFI by Stassen (2021) for B8H010 showed that the approach used by Stassen (2021) overestimated the BFI by 11%. Stassen (2021) considered long-term period (1920-2010), while Magombeyi et al. (2019), considered 2016-2018. However, further constraining of the BFI based on alpha and beta parameters in this study was done with the isotope tracers (^{2}H and ^{18}O) and the results are presented in TABLE 6.4.

TABLE 6.3. COMPARISON OF BASEFLOW INDEX (BFI) UNDER PREVIOUS AND CURRENT STUDIES

Catchment ID	Catchment name	River gauge ID	A (km^2)	Previous & current studies BFI based on Recursive digital filter method by Nathan and McMahon (1990)		Current study - BFI based on monthly Recursive digital filter method by Hughes & Smaktin Model (Stassen, 2021)		BFI based on ^2H and ^{18}O stable isotopes (2021)
				BFI – daily flows	Period of record (daily)	BFI – monthly flows	Period of record (monthly)	Wet season 2021
B81D	Letsitele	B8H010	473	0.37 (Ebrahim & Villholth, 2016)	1960 - 2016	0.422	1920 - 2010	-
B81D	Letsitele	B8H010	473	0.38 (Magombeyi et al., 2019)	1960-2018	0.422	1920 - 2010	0.38 – based on silica (Magombeyi et al., 2019)
B81D	Letsitele	B8H010	473	0.343 (current study)	*1960 - 1983	0.422	1920 - 2010	-
B81J	Letaba	B8H008	4,710	*** (current study)	**1920 -1975	0.327	1920 - 2010	0.41
Outlet of Letaba (downstream B81J)	Letaba	B8H018	12,938	0.297 (current study)	**1920 -1975	0.327	1920 - 2010	0.41
Mapungubwe	Limpopo River at Beit Bridge	A7H008	202,985	0.2197	1992-2019	0.221	1920 - 2010	0.19

*Period considered before Thabina Dam was commissioned in 1984. ** Period considered before Tzaneen Dam was commissioned in 1976. *** the BFI could not be calculated because of missing data. BFI (Ebrahim & Villholth, 2016) was based on daily flows; BFI by Stassen (2021) was based on monthly flow using Hughes & Smaktin Model (Hughes et al., 2003), which applied digital recursive method on monthly flow and used constant values of beta of 0.97 and alpha of 0.44.

The calibrated monthly BFI, beta and alpha values for monthly baseflow separation aggregated from daily flows were compared with an average isotope baseflow separation. The difference in BFI between the Hughes & Smaktin Model (Hughes et al., 2003) method used by Stassen (2021) and isotope separation method ranged from -16% to 20% (TABLE 6.4). However, we expected BFI by Stassen (2021) which is based on naturalized flows to be higher than the one from isotope separation, which is based on current flows. This difference indicates the need for slight additional calibration of the alpha and beta parameters based on the physical data from isotope results. The suggested alpha and beta parameters for perennial rivers (e.g., Letaba) were 0.419 and 0.943, respectively; while for ephemeral rivers (e.g., Limpopo River at Mapungubwe site, downstream

Limpopo/Shashe confluence) they were 0.446 and 0.977, respectively (see Figure 123 for riverflow regime classification).

TABLE 6.4. COMPARISON OF ALPHA AND BETA PARAMETERS FOR BFI FROM RECURSIVE DIGITAL FILTER AND BASEFLOW ISOTOPE SEPARATION

Catchment ID	River gauge ID	BFI by Stassen (2021)			BFI from isotope separation			BFI difference (%) between isotope and Stassen (2021)
		Alpha	Beta	BFI	Alpha	Beta	BFI	
B81D	B8H010	0.44	0.97	0.422	0.420	0.919	0.38	-11
Outlet of Letaba	B8H018	0.44	0.97	0.327	0.417	0.941	0.41	20
Mapungubwe	A7H008	0.44	0.97	0.221	0.446	0.977	0.19	-16

BFI is baseflow index

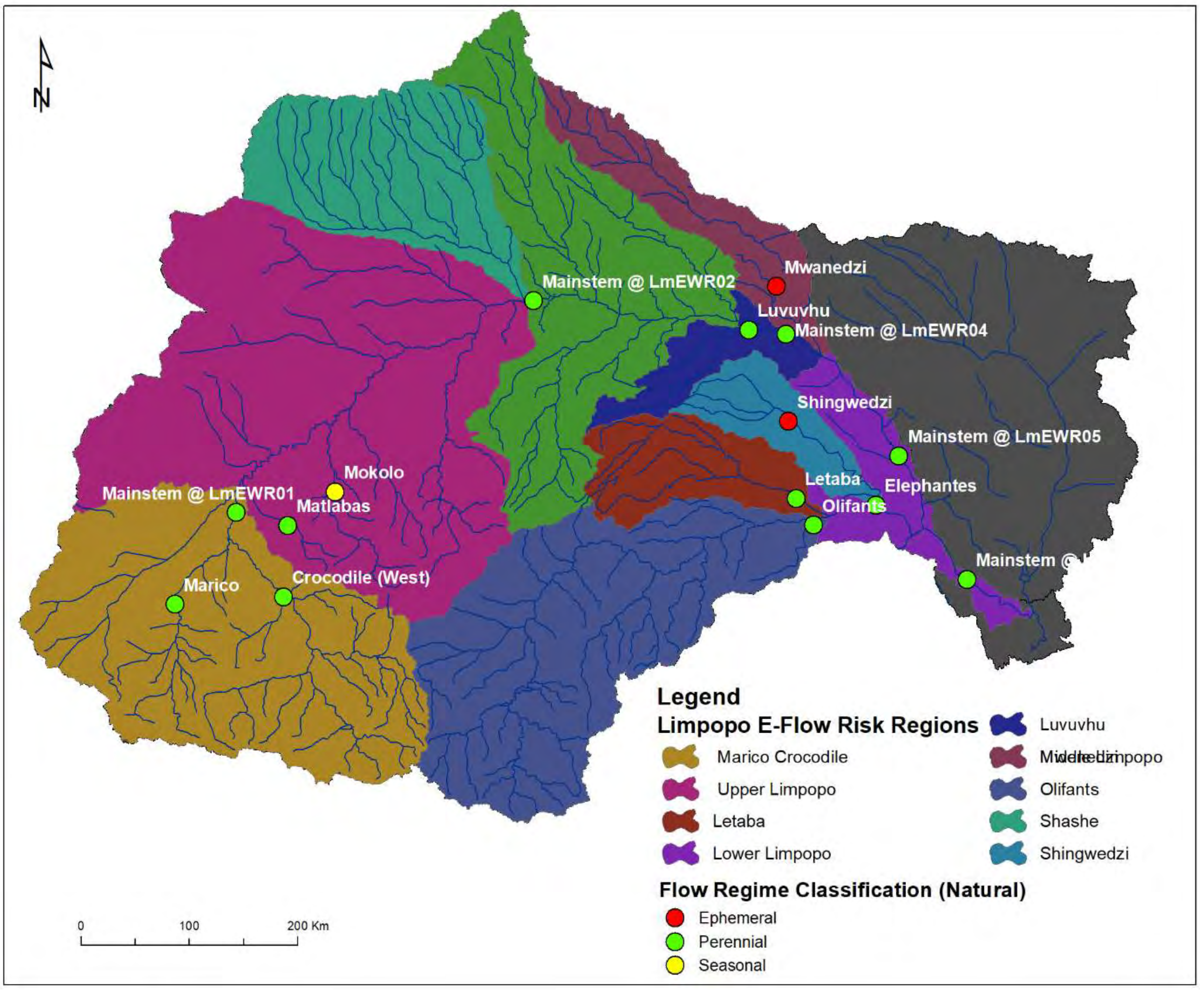


FIGURE 123: RIVERLOW REGIME CLASSIFICATION

6.3.6 Hydraulic gradients from the Differential-GPS data

The differential Global Positioning System (GPS) data from groundwater and river water levels collected during fieldwork was used complement the isotope approach of assessing groundwater-surface water interaction. If the hydraulic gradient is sloping way from the river, it means the river is losing water to the groundwater and if hydraulic gradient is sloping away from the groundwater or borehole, it means the groundwater is losing. Considering that some of the boreholes are near the river (Figure 124) the loss of water from the groundwater feeds that river and vice versa.

The Letaba sites – all sites showed groundwater gradient was towards the river (this was also observed at the same sites by SANParks prior to the drought. This indicates that the river gain from the groundwater. For Mapungubwe, all sites showed a gentle groundwater gradient away from the river (hence this section is losing to groundwater and explains the almost cessation of flows by the time the river gets to Beitbridge weir). This water loss and gain from either river or groundwater supports the similar chemical and isotope signature noted from river and groundwater for the two groundwater sites.

FIGURE 124: BOREHOLE IN MAPUNGUBWE CLOSE TO LIMPOPO RIVER, PUMPING WATER TO A NEARBY MINE

6.3.7 Summary

One of the limitations of the current approach of constraining BFI based on isotope baseflow separation was that the sampling was done during recession of high flows and should have been done in the dry season as well to understand the changes of BFI index with seasons. The proportion of baseflow to total flow increase during dry season compared to wet season or high flow period. Upstream water users would be pushed into utilising baseflow during dry season – which would otherwise be for E-flow provision. The other limitation was that the streamflow gauge used for

Mapungubwe is further downstream at Beit Bridge and may not be representative of the site where water for isotopes analysis was sampled. There was no isotope data on rainfall for Mapungubwe and rainfall data from Letaba catchment was used. Hence, the results for Mapungubwe site can be improved if isotope data for rainfall is collected. Sampling during dry season would assists in quantifying groundwater in isolated pools, and whether it is from groundwater or perched water table due to an impermeable layer. Current results showed a mixture of groundwater and surface water in the riverflow, and as surface water flow decrease the groundwater dominance becomes key to supply water in the river and pools.

6.5 ISOLATED POOLS

Isolated pools are water features that form because of drop in flow that creates a pool of still water isolated from water flowing in the river (Pucherelli and Goettlicher, 1992). In non-perennial rivers one of the most critical factors impacting ecological functioning is the dynamics of pool storage (Bonada et al., 2020; Seaman et al., 2010). According to Bonada et al.(2020) isolated pools in temporary rivers are transitional habitats of major ecological relevance as they support aquatic ecosystems during no-flow periods, and can act as refugees for maintaining local and regional freshwater biodiversity. 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. They 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 nature and means of persistence of pools are poorly understood in terms of their location, nature, and geomorphic persistence (Hattingh, 2020). 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). The presence and temporal extent of isolated pools depends on several factors including: rainfall, riparian vegetation, geology of the riverbed, river geomorphology and direct or indirect water withdrawals (Bonada et al., 2020). Detail about the occurrence of pools and factors controlling their size for coarse-grained forest river can be found in Buffington et al. (2002). Isolated pools are formed in a side channel when the flow decreases to the point where the side channel flow becomes cut off. Portions of the side channel that are deeper than the rest of the side channel and cannot drain become isolated pools (Pucherelli and Goettlicher, 1992).

6.5.1 Isolated pool mapping using sentinel 2 remote sensing data

Based on data availability, five Sentinel 2 images for the Mapungubwe area (where the Shashe River is joining the main Limpopo River) is downloaded and Normalized Water Index (Gao, 1996; McFeeters, 1996) is calculated using SNAP1 software and isolated pools were identified. The five

1 https://step.esa.int/main/download/snap-download/

dates of images were: 2020-08-04, 2020-10-28, 2020-11-07, 2020-12-22 and 2021-01-06. Sample results are shown in Figure 125and Figure 126.

The initial plan was to map isolated pools at the Limpopo-Shashe confluence using Sentinel 2 data. However, in the process we found an alternative data source from South Africa National Space Agency (SANSA) that support isolated pool mapping. Monthly surface water feature were obtained from SANSA for the South African portion of the Limpopo River basin for the period of January 2016-June 2021 free of charge. Isolated pools area for the main Limpopo River Basin is calculated for every month. We made a comparison analysis of Isolated pool mapping using Sentinel -2 (Figure 125) and SANSA datasets (Figure 127) for the dry season (August 2020). Result show that there is good correlation between the two datasets. Hence, as the SANSA dataset cover the whole Limpopo River basin, we requested the project leader to purchase the raster image for the whole Limpopo River basin. This is because even if the southern African potion of the Limpopo River basin is available free of charge, data for the other riparian countries need to be purchased. Since the monthly water surface feature map is not available with the available budget, SANSA agreed to provide spatial map of frequency of water occurrence with the allocated limited budget. The water frequency map shows the number of time a given grid cell having water. The total number of months for the data period January 2016- June 2021 is 66. The Frequency is calculated by simply summing the number of monthly occurrences within the full temporal dataset. So, if a cell is coded as 37, it means that water was detected and mapped as such in that cell, in 37 / 66 months.

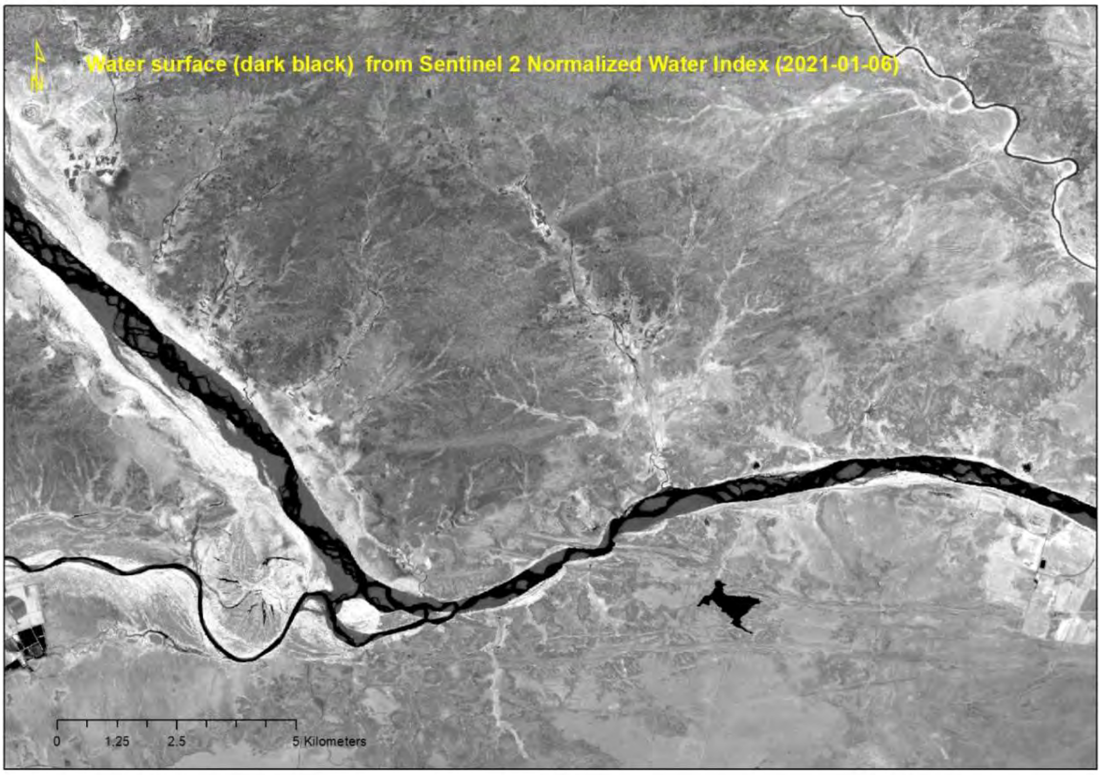


FIGURE 125: WATER SURFACE FEATURE MAPPING USING SENTINEL 2 (JANUARY –WET SEASON)

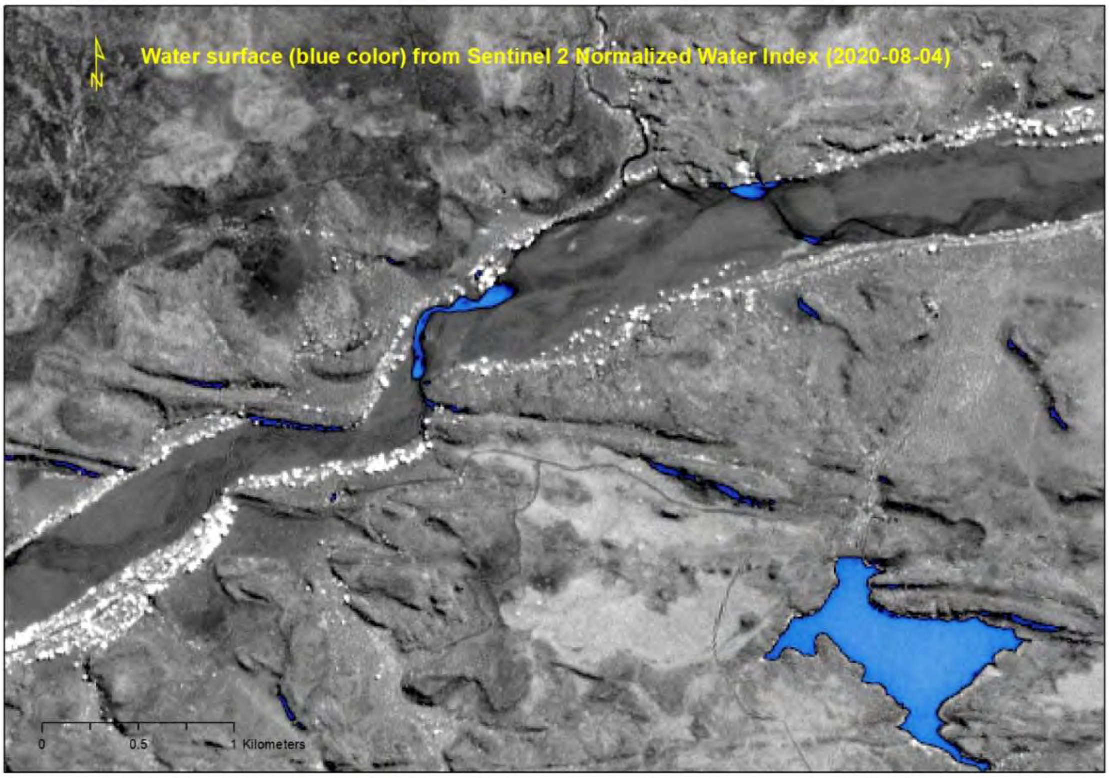


FIGURE 126: WATER SURFACE FEATURE MAPPING USING SENTINEL 2 (AUGUST 2020 – DRY SEASON), THE RIGHT BOTTOM BLUE WATER FEATURE IS DAM RESERVOIR

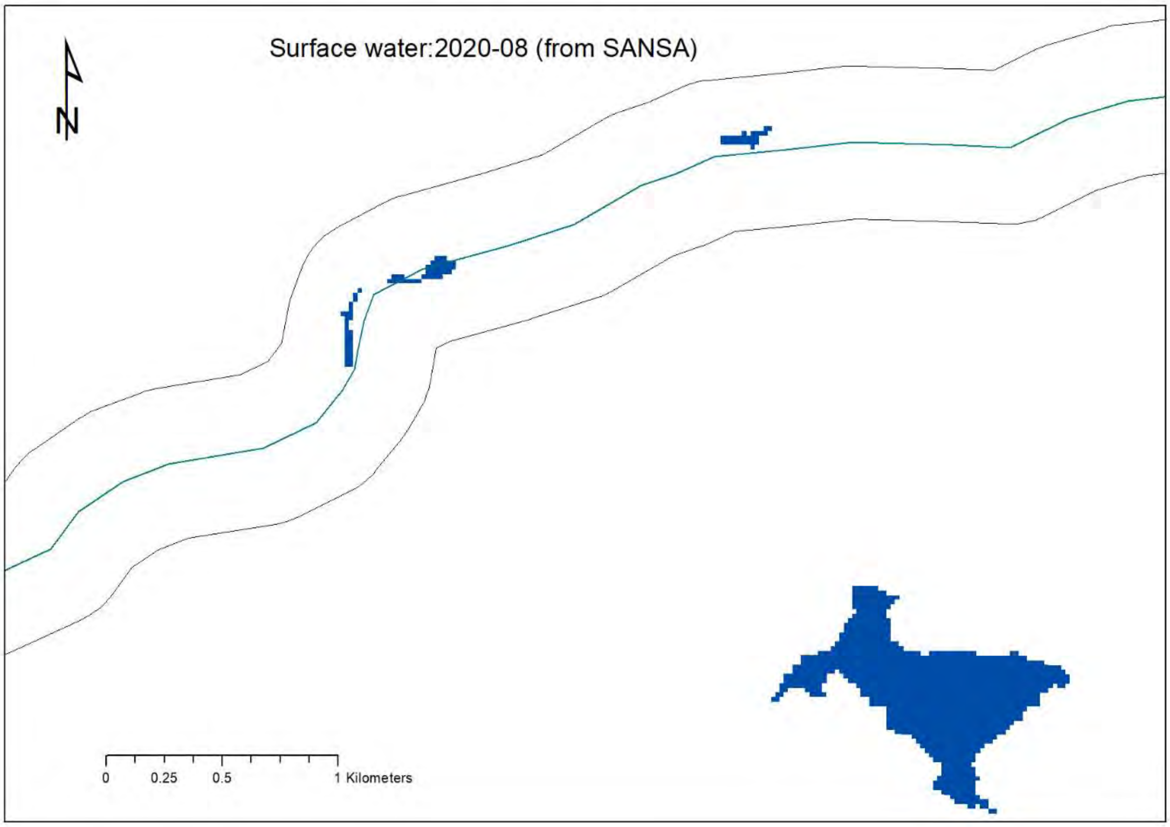


FIGURE 127: ISOLATED POOL MAPPING USING DATA FROM SOUTH AFRICA NATIONAL SPACE AGENCY (AUGUST 2020-DRY SEASON)

6.5.2 Isolated pool mapping using sentinel data from South Africa Space Agency

Two kind of data from the South African Space agency were received

1. Monthly water feature spatial data for the south African portion of the Limpopo River basin
2. Water frequency map (spatial map showing how many times in a given period there is water in a given pixel). The spatial coverage of this data is the Limpopo River basin

Note: Since we are interested in the spatial coverage of the whole Limpopo River basin we decided to use the second dataset that show the frequency of occurrence

Data source and resolution the image source is Sentinel-2, which has 20 x 20 m pixels.

As a guideline rule, for a particular landscape feature to be successfully identified within that 20 x 20 m pixel (i.e. 400 sq m), the target feature in question has to be:

1. significantly spectrally different from surrounding non-target features (which is water, so that's OK); and
2. approximately should be equal to at least 40% of the spatial coverage of that 20 x 20m pixel cell,

So that would mean conceptually that if the water feature was at least 160 - 200 sq m in extent, there is a good chance that the overlying image pixel would be tagged as "water", all other influencing factors being favourable to identification.

6.5.3 Data processing

The aim of the data processing is to identify the isolated pools per risk region. To do so, we followed the following steps:

- The Limpopo River shape file is too course and do not match with the water feature data which have a resolution of 20 m with a lot of meandering. Hence, we opt to use the SRTM 30 m resolution. The SRTM 30 m have better capture the meandering observed in the water feature data though not well representing all the meandering. To overcome this issue we digitized the main Limpopo River channel using google earth and the tributaries were digitized using following the water feature frequency data.
- Since the water feature data contain all kind of water features inside and outside of the river channel we decided to use buffer zone with the digitized river channel. During digitization dams were excluded. Therefore, by trial and error we decided to use buffer zone distance of 330 m
- Using a buffer zone of 330 m we used extraction by mask and extracted all water features within 330 m of the river bank.
- Using water feature data extracted in step 3 we extracted water feature data for each risk region using risk region GIS shape file
- Once the extraction per risk region was done we opened the attribute table for each risk region and copied the attribute table. This attribute table contains essential information (the value and the number of counts that particular value occurrence or COUNT
- The number of counts for each value can be multiplied by the grid area (20 x 20 m) to get the total area covered by a given value in each risk region
- Output from step 5 and 6 can be summarized to see the variation across risk regions

6.5.4 Results

The number of grid cells with water for each frequency of occurrence per risk regions is tabulated in TABLE 6.5. The number of gird cells with water all the time (frequency of 66) for each risk region is presented in Figure 128. What is clear from this Figure is that Olifants risk region has the highest number of grid cells with permanent water features while Shashe and Shingwedzi do not have a single grid with permanent water feature. Figure 129 shows the mean monthly rainfall for the period of period of January 2016 to June 2021 for the Limpopo River basin overlaid with risk regions. The Figure 129 also presents the mean monthly rainfall per risk region and number of grid cells with frequency of 66 (perennial water features). The correlation coefficient between mean monthly rainfall and number of grid cells with water all the time (frequency of 66) is about 0.5. Figure 130 shows aquifers of Limpopo River basin overlaid with risk regions. TABLE 6.7 presents the percentage area of each risk region covered by a given aquifer type and number of grid cells with frequency of 66 (perennial water features). Correlation results of percentage area of each aquifer types and number of grid cells with frequency of 66 (perennial water features) is presented in TABLE 6.8. The number of grid cells with frequency of 66 (perennial water features) and unconsolidated intergranular aquifer type is negative which indicate that high permeable unconsolidated sand may prevent the formation of isolated pool whereas bedrock and low permeable geology can facilitate the formation of isolated pools (positive correlation), which is consistence with Bonada et al.(2020).

TABLE 6.5. NUMBER OF PIXELS/GRID FOR A GIVEN FREQUENCY OCCURRENCE PER RISK REGION. THE NUMBER OF PIXEL/COUNT CAN BE CONVERTED TO AREA OF PIXEL BY MULTIPLYING THE NUMBER OF COUNT BY GRID AREA (20 M X 20 M)

Frequency	Limpopo Chokwe	Letaba	Lower Limpopo	Luvuvhu	Marico & Crocodile	Middle Limpopo	Mwenedzi	Olifants	Shashe	Shingwedzi	Upper Limpopo
1	38540	14848	24283	14657	11748	40469	15085	14768	17753	7758	46930
2	14712	9569	13922	10030	4362	30674	10475	8168	17058	4222	20520
3	10701	6691	10544	7927	2675	24918	8488	5160	16194	2824	11965
4	11643	5113	7395	8607	2058	19222	7738	3838	16016	1793	8516
5	7039	4037	4927	6333	1769	15761	7014	3001	13908	1116	6911
6	6143	3025	3906	5057	1656	12530	6875	2487	11399	764	5482
7	5852	2397	3185	3643	1476	10593	6003	2204	8784	571	4925
8	5418	1834	2780	3154	1363	9293	5433	1914	6408	502	4205
9	5307	1483	2508	3030	1277	8440	4751	1896	5270	484	4081
10	5304	1143	2484	3079	1208	7676	3782	1728	4228	344	3640
11	5281	992	2415	2888	1188	7206	3204	1636	3803	306	3323
12	5063	876	2353	2805	1107	6596	2800	1475	3295	264	3100
13	4692	755	2264	2791	990	6132	2513	1431	2868	234	2760
14	4658	641	2051	2739	931	5534	2255	1352	2374	179	2799
15	4609	550	1920	2641	814	5219	1922	1360	2081	154	2665
16	4438	482	1843	2731	766	4849	1635	1296	1758	131	2478
17	4076	389	1649	2592	679	4573	1390	1189	1455	136	2361
18	3890	365	1443	2582	638	4396	1149	1260	1158	109	2230
19	3507	326	1431	2534	565	4143	961	1065	932	83	1969
20	3418	295	1323	2031	457	3789	793	1077	778	84	1734
21	3160	267	1153	1770	405	3284	724	1015	678	80	1579
22	2877	272	1120	1529	428	2884	627	990	529	83	1426
23	2561	249	1040	1490	364	2618	535	988	480	77	1199
24	2308	199	992	1290	368	2231	503	958	383	73	1111
25	2025	192	977	1176	325	1810	399	898	337	60	944
26	1732	198	895	996	276	1457	380	907	286	63	903
27	1526	170	845	945	267	1199	328	928	223	64	849
28	1343	167	885	848	242	995	305	828	187	54	806
29	1131	165	845	730	210	901	286	859	156	47	767

Frequency	Limpopo Chokwe	Letaba	Lower Limpopo	Luvuvhu	Marico & Crocodile	Middle Limpopo	Mwenedzi	Olifants	Shashe	Shingwedzi	Upper Limpopo
30	1036	163	847	603	211	718	249	760	112	30	725
31	918	150	865	601	206	662	220	760	77	52	635
32	799	152	843	500	196	543	202	727	74	39	636
33	782	156	781	446	191	476	197	731	61	34	631
34	729	172	748	412	196	379	176	703	59	35	577
35	649	150	760	367	162	288	172	683	41	34	546
36	596	141	722	336	168	274	164	698	51	28	575
37	520	141	725	283	141	241	129	686	22	15	575
38	487	145	697	243	129	214	147	660	13	17	682
39	561	141	695	242	112	207	128	637	20	17	705
40	484	157	678	187	141	175	105	663	20	9	629
41	470	132	703	180	138	157	121	653	20	13	630
42	473	131	693	182	117	137	121	649	11	13	605
43	432	140	744	160	113	127	111	686	10	20	557
44	503	132	760	159	136	119	86	680	5	14	598
45	489	118	769	142	127	104	98	585	5	13	567
46	434	115	870	149	120	79	100	577	9	11	582
47	511	135	943	129	115	73	94	570	8	10	568
48	508	126	965	132	164	74	128	581	4	8	564
49	453	131	1014	95	133	68	121	681	7	13	566
50	416	138	1112	116	110	48	123	637	6	13	602
51	345	131	1217	108	91	61	98	647	2	12	605
52	273	137	1055	94	85	56	116	605	2	6	616
53	235	145	999	101	97	51	103	601	1	3	586
54	228	161	994	92	99	42	86	561	1	5	558
55	233	179	867	97	100	40	97	529		6	583
56	171	165	799	100	96	38	91	480		10	591
57	190	179	671	124	99	44	112	458		5	563
58	184	140	695	122	98	47	115	400		4	660
59	175	141	578	177	115	45	140	330		5	578
60	166	173	540	182	240	44	168	225		3	655

Frequency	Limpopo Chokwe	Letaba	Lower Limpopo	Luvuvhu	Marico & Crocodile	Middle Limpopo	Mwenedzi	Olifants	Shashe	Shingwedzi	Upper Limpopo
61	207	188	511	166	309	76	180	222		8	542
62	171	207	553	179	154	154	198	244		13	578
63	191	213	487	217	114	163	209	236		7	488
64	192	262	348	261	126	196	229	259		2	416
65	196	492	239	461	195	187	195	367		1	459
66	257	446	129	560	620	132	391	945			254

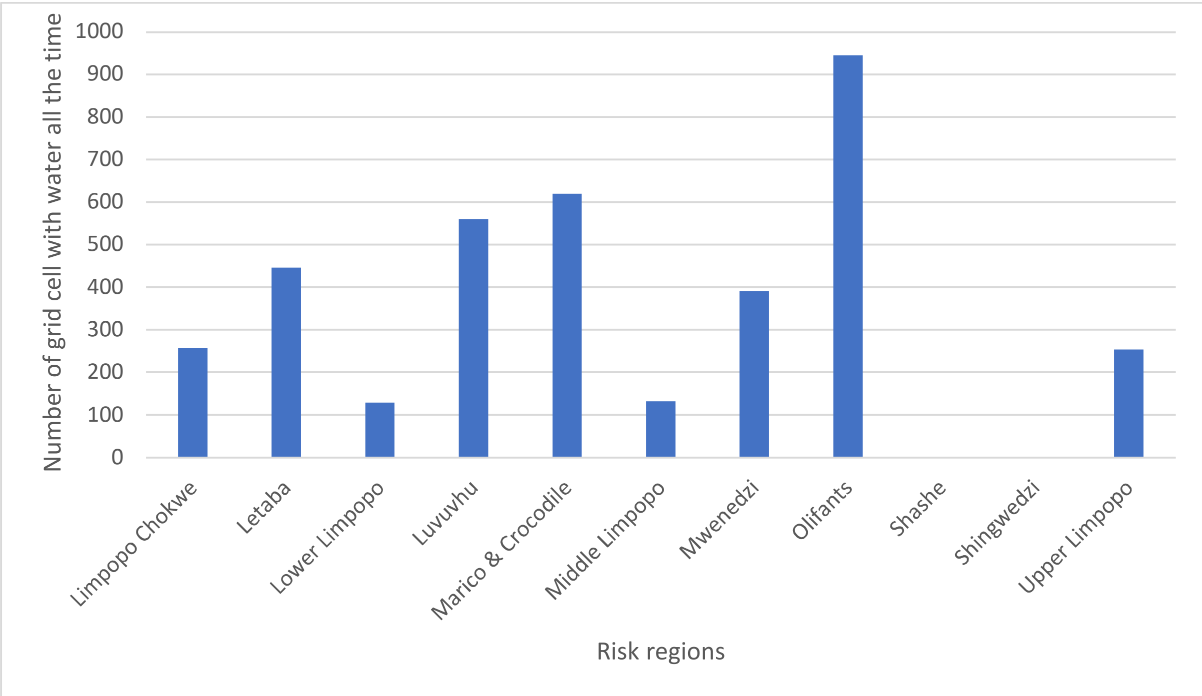


FIGURE 128: NUMBER OF GRID CELLS WITH FREQUENCY OF 66 (WITH WATER ALL THE TIME) PER RISK REGIONS

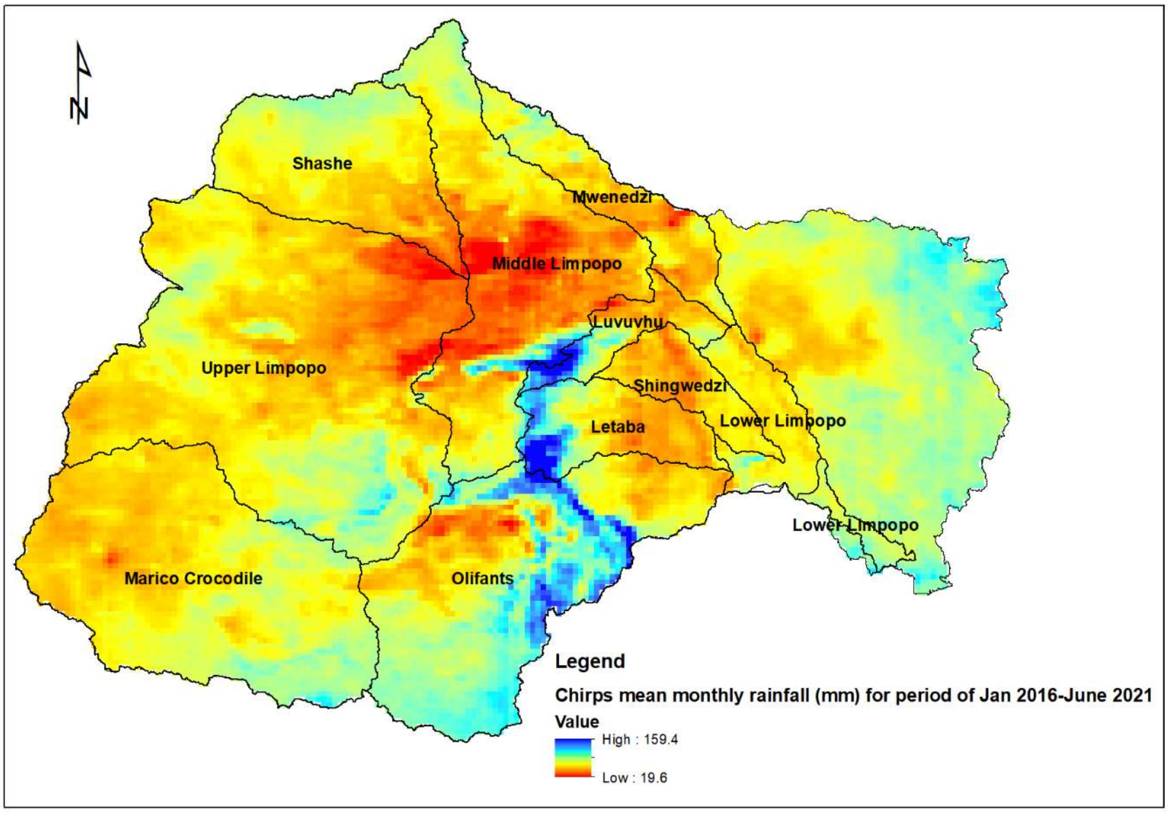


FIGURE 129: CHIRPS MEAN MONTHLY RAINFALL (MM) FOR PERIOD OF JANUARY 2016 TO JUNE 2021 OVERLAID WITH RISK REGIONS

TABLE 6.6. CHRIPS MEAN MONTHLY RAINFALL (MM) STATISTICS FOR THE PERIOD OF JANUARY 2016 TO JUNE 2021 PER RISK REGIONS AND NUMBER OF PERENNIAL RIVER GRID PER RISK REGIONS (CORRELATION =0.5)

Risk Region	Number of pixels with frequency of 66 (Perennial Isolated pools)	Chirps mean monthly rainfall
Limpopo Chokwe	257	48.41
Letaba	446	55.38
Lower Limpopo	129	57.27
Luvuvhu	560	55.77
Marico & Crocodile	620	49.11
Middle Limpopo	132	42.94
Mwenedzi	391	45.96
Olifants	945	58.08
Shashe		48.40
Shingwedzi		42.58
Upper Limpopo	254	46.02

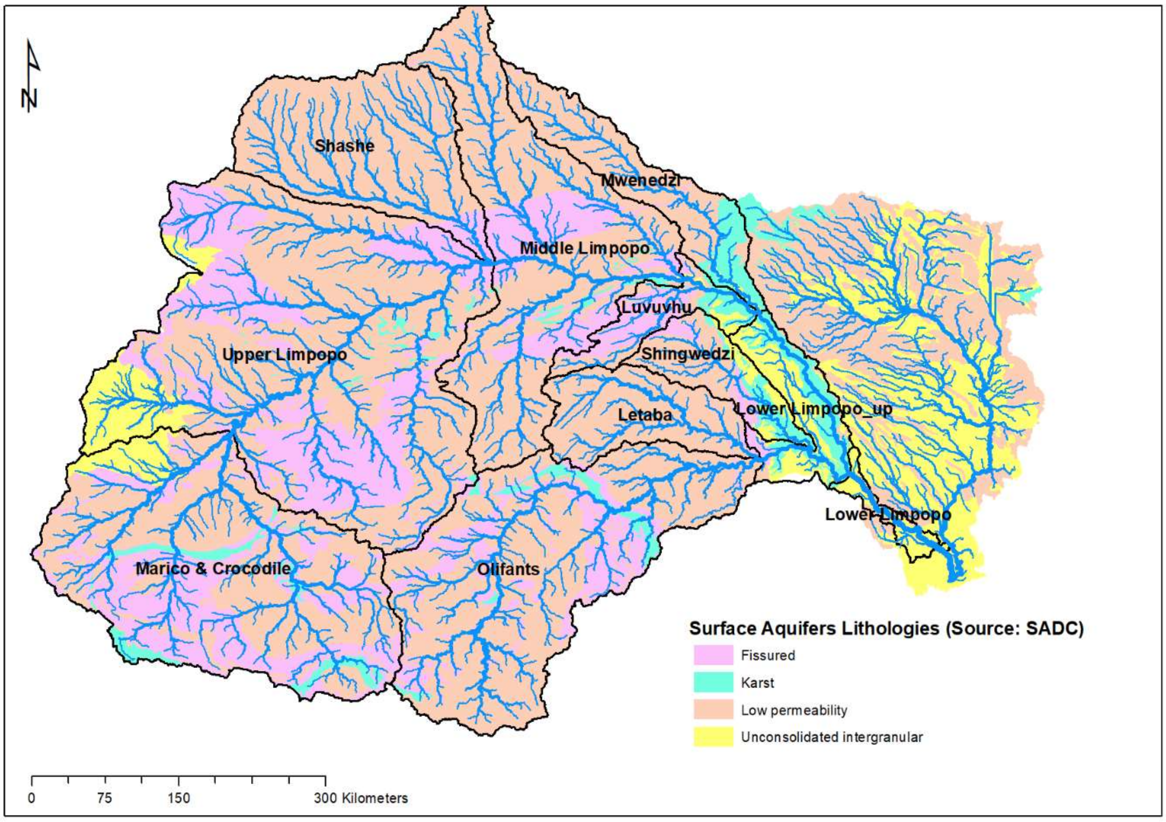


FIGURE 130: LIMPOPO SURFACE GEOLOGY OVERLAID WITH RISK REGIONS

TABLE 6.7. PERCENTAGE AREA OF EACH RISK REGION COVERED BY A GIVEN AQUIFER TYPE AND NUMBER OF PERENNIAL GRID PER RISK REGION

	Number of pixels with frequency of 66 (Perennial Isolated pools)	Unconsolidated intergranular	Low permeability	Fissured
Limpopo Chokwe	257	52.07	5.42	4.54
Letaba	446		97.63	2.37
Lower Limpopo	129	88.73	10.90	
Luvuvhu	560	9.57	30.42	44.91
Marico & Crocodile	620	5.23	56.09	33.33
Middle Limpopo	132	0.08	76.53	21.92
Mwenedzi	391	2.10	80.42	0.73
Olifants	945		75.72	20.58
Shashe			94.95	5.05
Shingwedzi		15.67	52.54	14.33
Upper Limpopo	254	7.61	57.99	33.39

TABLE 6.8. CORRELATION TABLE BETWEEN NUMBERS OF PERENNIAL RIVER GRID CELLS PER RISK REGION AND PERCENTAGE AREA OF AQUIFER TYPE PER RISK REGIONS

	Number of pixels with frequency of 66 (Perennial Isolated pools)	Unconsolidated intergranular	Low permeability	Fissured	Karst
Number of pixels with frequency of 66 (Perennial Isolated pools)	1				
Unconsolidated intergranular	-0.48117	1			
Low permeability	0.32506	-0.82635	1		
Fissured	0.209776	-0.39813	-0.35675	1	
Karst	-0.05947	0.120174	-0.44625	-0.54171	1

6.6 GROUNDWATER REFERENCES

Bonada, N., Cañedo-Argüelles, M., Gallart, F., von Schiller, D., Fortuño, P., Latron, J., Llorens, P., Múrria, C., Soria, M., and Vinyoles, D., 2020, Conservation and management of isolated pools in temporary rivers: Water, v. 12, no. 10, p. 2870.

Brutsaert, W, Nieber, J.L., 1977. Regionalized drought flow hydrographs from a mature glaciated plateau. Water Resources Research 13, 637-643.

Buffington, J. M., Lisle, T. E., Woodsmith, R. D., and Hilton, S., 2002, Controls on the size and occurrence of pools in coarse-grained forest rivers: River Research and Applications, v. 18, no. 6, p. 507-531.

Craig, H., 1961. Standards for reporting concentrations of deuterium and oxygen-18 in natural waters. Science 133 1833–1834.

Davis, S.N., Dewiest, R.J.M., 1966. Hydrogeology. John Wiley and Sons Inc., New York, USA, p 463

Ebrahim, G.Y., Villholth, K.G., 2016. Estimating shallow groundwater availability in small catchments using streamflow recession and instream flow requirements of rivers in South Africa. Journal of Hydrology 541 (Part B), 754-765. https://doi.org/10.1016/j.jhydrol.2016.07.032.

Gao, B.-C., 1996, NDWI—A normalized difference water index for remote sensing of vegetation liquid water from space: Remote sensing of environment, v. 58, no. 3, p. 257-266.

Gokool, S., 2017. Evaluating the potential of using satellite earth observation data to quantify the contribution of riparian total evaporation to streamflow transmission losses. PhD thesis. Centre for Water Resources Research, School of Agriculture, Earth and Environmental Sciences, University of KwaZulu-Natal. Pietermaritzburg, South Africa.

Hattingh, K. J., 2020, Geomorphological controls on pool formation and pool persistence in non-perennial river systems.

Hounslow, A.W., 1995. Water quality data: analysis and interpretation. CRC Lewis Publisher, New York, USA, p 396.

Hughes, D., 2001. Providing hydrological information and data analysis tools for the determination of ecological instream flow requirements for South African rivers. Journal of hydrology 241, 140-151.

Hughes, D.A., Hannart, P., Watkins, D., 2003. Continuous baseflow separation from time series of daily and monthly streamflow data. Water SA 29 (1), 43-48. DOI: 10.4314/wsa.v29i1.4945.

International Atomic Energy Agency (IAEA) and the World Meteorological Organization (WMO) (IAEA/WMO)., 2018. Global Network of Isotopes in Precipitation (GNIP). The GNIP Database, available at: https://nucleus.iaea.org/wiser.

Kumar, S.P.J., 2013. Interpretation of groundwater chemistry using piper and Chadha´s diagrams: a comparative study from perambalur taluk. Elixir Geoscience 54, 12208-12211.

Magombeyi, M., Villholth, K.G., Healy, R., 2019. Understanding Surface Water-Groundwater Interactions in Perennial Sub-Humid Systems: A Study of the Letsitele River Catchment, Limpopo Basin, South Africa. Deliverable 3.1 for the project: Understanding Groundwater Recharge in the Limpopo River Basin (GRECHLIM). Pretoria, South Africa.

McFeeters, S. K., 1996, The use of the Normalized Difference Water Index (NDWI) in the delineation of open water features: International journal of remote sensing, v. 17, no. 7, p. 1425-1432.

Piper, A.M., 1944. A graphic procedure in geochemical interpretation of water analyses. Trans Am Geophys Union 25, 914– 923.

Pucherelli, M. J., and Goettlicher, W. P., 1992, Mapping Instream Habitat on the San Juan River Using Airborne Videography, US Bureau of Reclamation.

Sadashivaiah, C., Ramakrishnaiah, C.R., Ranganna, G., 2008. "Hydrochemical Analysis and Evaluation of Groundwater Quality in Tumkur Taluk, Karnataka State, India". International Journal of Environmental Research and Public Health 5 (3), 158–164. doi:10.3390/ijerph5030158. PMC 3699986. PMID 19139534.

Seaman, M., Avenant, M., Watson, M., King, J., Armour, J., Barker, C., Dollar, E., Du Preez, P., Hughes, D., and Rossouw, L., 2010, Developing a method for determining the environmental water requirements for non-perennial systems: Water Research Commission Report No. TT459/10.

Stassen, R., 2021. Hydrology component of the E-Flows project. E-FLOWS FOR THE LIMPOPO RIVER BASIN. Pretoria, South Africa.

Tallaksen, L.M., 1995. A review of baseflow recession analysis. Journal of hydrology 165, 349-370.

Todd, D.K., Mays, L.W., 2005. Groundwater hydrology. Wiley, New York, p 636

Van Wyk, E., 2010. Estimation of episodic groundwater recharge in semi-arid fractured hard rock aquifers. PhD Thesis. Faculty of Natural and Agricultural Sciences, Department of Geohydrology. University of the Free State. Bloemfontein, South Africa.

Wang, X., Li, Z., Ross, E., Tayier, R., Zhou, P., 2015. Characteristics of water isotopes and hydrograph separation during the spring flood period in Yushugou River basin, Eastern Tianshans, China. J. Earth Syst. Sci. 124 (1), 115–124.

Winter, T.C., 2006. The role of ground water in generating streamflow in headwater areas and in maintaining base flow. USGS Staff -- Published Research. 616. https://digitalcommons.unl.edu/usgsstaffpub/616

World Health Organization (WHO)., 1993. Guidelines for drinking-water quality (2nd Edition), Vol 2 – Health criteria and other supporting information, and Vol 3 – Drinking-water quality control in small community.

World Health Organization (WHO)., 2004. Guidelines for drinking-water quality volume 1: recommendations, 3rd Edn. WHO, Geneva.

7 CONCLUSIONS

This report is a precursor for the next report on the Ecological Response to Change in the drivers documented here. This report documents the status quo and also provides the raw data of those aspects of the ecosystem that are subject to anthropogenic change (hydrology, hydraulics, geomorphology, water quality and groundwater) and consider how much they have changed from natural. Note that this data is NOT interpreted in this report in terms of e-flows, that being the subject of subsequent reports.

This data is used in the population of the Conceptual Models, and the Conditional Probability Tables, and ultimately in the Bayesian Networks, that describe in detail the relationships between these drivers and the response indicators (the fish, benthic macroinvertebrates and riparian vegetation). These relationships are then used to estimate the e-flows required to support the ecosystem services.

In summary:

The components of the ecosystem that are shown here are those that are directly affected by land-use changes and developments, as well as by climate change, and have a direct impact on the instream and riparian ecosystem. Each of these is pivotal in understanding what drives the system, so that the required amounts of water at the right time can be estimated.

Hydrology

The report includes the analysis of the long-term natural hydrological flow time series at the selected e-flow sites for the main stem Limpopo River and the major tributaries. These include basic hydrographs, flow duration curves and statistics based on monthly modelled natural flow data at the e-flows sites. Additional information is also provided in terms of drought flows, sizes and duration of freshets and floods. The information used in this report is mainly based on the results from the hydrological study (Volume C – hydrological assessment, 2013) that was part of the Limpopo Monograph study as well as data from the Limpopo Reconciliation study (DWS, 2015). 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 the current e-flow study, accept the scaling of flows to a specific e-flow sites using catchment area.

Hydraulics and geomorphology

The hydraulic habitat, i.e. a combination of the water depth, velocity and the underlying sediments and river shape, are important drivers of ecosystem condition. This specialist component of the e-flow study describes this habitat at all of the available sites.

The hydraulics for 21 sites across the Limpopo Basin have been determined. The methods used, cross sections, site description and data output are presented below. A single cross section was surveyed at each site in order to capture critical hydraulic habitats that are sensitive to flow. Survey benchmarks were established, and all surveys tied into these.

Data gathering consisted of transect selection and demarcation, survey of the topography along the transect (perpendicular to flow); survey of water levels, energy gradient and historical flood marks;

and measurement of depth and velocity along each transect. Roughness was calculated using the Mannings n formula based on the measured data. In order to extrapolate the observed hydraulic data to other stage levels so that a continuous rating function can be determined for a wide range of discharges, 1 dimensional hydraulic modelling of higher flows was undertaken using the Mannings formula. HABFLO, a 1 dimensional free-ware empirical hydraulic habitat-flow simulation model, was used to derive frequency distribution data for the various hydraulic habitats. HABFLO is designed to simulate flow dependent, ecologically relevant hydraulic data.

The hydraulic character represents the habitat characteristic that determines the suitability of the river for fish and invertebrates and to a less extent riparian vegetation. These descriptions are foundational for the consideration of ecological response.

Water quality

The quality of that water is the second key driver of the condition of the ecosystem. The objective of this report is to present the water quality data that were collected at selected sites during the survey of April-June 2021.

The general water quality data and metal concentrations are presented and show that the quality of the water varied across the basin, some in a poor state and other acceptable. Where possible, the data has been compared with historical data in order to show the change.

Groundwater

The first objective of this report was to summarize our understanding of the two groundwater study sites (Letaba and Mapungubwe) that were analysed at a level of detail that was not possible for the entire basin. Water samples collected throughout the Limpopo River Basin were used to analyse the proportion of groundwater to total streamflow (perennial) based on their chemical signatures.

The chemistry of groundwater and river water for sites in the Limpopo River Basin, was characterized by similar mixtures of constituents and reflects water with similar history, origin and interactions. This supports the hypothesis that there is a strong interaction between surface water (river water) and groundwater to provide environmental water flows, even under the high flows. There is rapid rainfall infiltration to groundwater that is not affected by evaporation processes during infiltration although groundwater and surface water were influenced by evaporation under relatively arid and semi-arid conditions. The similar isotopic signatures of the groundwater and surface (river) water further indicate the occurrence of groundwater in the river during dry and wet periods.

Baseflow is the rate of groundwater flow that a given catchment provides from all upstream aquifers along the riverbanks. In this study, the baseflow was used to understand the groundwater surface water interactions, and to estimate the contribution of groundwater to the environmental water flow requirement in the Limpopo River Basin.

Isolated pools

Isolated pools are water features that form because of drop in flow that creates a pool of still water isolated from water flowing in the river. These pools have a major impact on the ecological functioning of the river ecosystem, as they provide transitional habitats during no-flow periods, and can act as refugees for maintaining local and regional freshwater biodiversity. 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. They may be a source of water for a wide variety of wildlife and local rural people and their livestock.

The similar isotopic signatures of the groundwater and isolated pools indicate the presence of groundwater suggesting that they are fed from groundwater in the dry season.

Data from the South Africa National Space Agency (SANSA) was used to map isolated pools. Isolated pools area for the main Limpopo River Basin was calculated for every month of the year.

This groundwater information, the quality, the movement of groundwater and its contribution to baseflow, and the existence of surface pools maintained by groundwater, are all pivotal to the estimation of e-flows. This information is built into the Conceptual Models that are used to derive the e-flows and are the subject of the next report

8 DATA APPENDICES

8.1 APPENDIX A: HYDRAULIC AND SITE CROSS-SECTIONAL DATA

8.1.1 Crocodile

Location	Coordinates	Description
BM (STATION POSITION):	-24.314167, 27.046139	Peg in ground
BENCHMARK 01	-24.314194, 27.046194	Drilled into base of Vachellia robusta on RB
BENCHMARK 02	-24.314139, 27.045944	Drilled into base of Vachellia robusta on RB
BENCHMARK 03	-24.313861, 27.046083	Fence post (post that does not support the gate hinges).

Cross section		
Chainage (m)	Elevation relative to thalweg (m)	Comment
0.000	5.043	
6.303	3.859	
9.640	3.031	
11.033	1.990	
12.116	0.920	
12.712	0.570	
14.807	0.493	
15.998	0.443	
16.876	0.261	
19.491	0.074	
22.323	0.069	
26.113	0.169	
29.303	0.069	

Cross section		
Chainage (m)	Elevation relative to thalweg (m)	Comment
32.077	0.000	
34.365	0.025	
35.084	0.222	
35.969	0.923	
38.377	1.026	
42.652	1.228	
45.260	1.009	
46.635	0.968	
49.810	1.260	
51.847	1.583	
52.507	1.859	
54.260	3.029	
56.304	3.587	
60.850	4.629	
62.765	4.842	
68.506	6.034	
71.009	6.138	
78.619	6.228	

8.1.2 Limpopo at Spanwerk

Cross section		
Chainage (m)	Elevation relative to thalweg (m)	Comment
0.00	1.88	23˚ 56’ 41.6”S; 26˚ 55’ 57.6”E; LB - LH cross-section. No peg
1.47	0.78	
5.03	0.13	
7.99	0.81	

Cross section		
Chainage (m)	Elevation relative to thalweg (m)	Comment
11.21	1.29	
12.73	0.79	
16.39	0.15	
20.02	0.23	
24.65	0.81	
30.59	1.45	23˚ 56' 40.7"S; 26˚ 55' 52.3"E; Top bank island. No peg
31.19	0.88	
33.59	0.58	
38.59	0.59	
43.59	0.41	
48.59	0.29	
53.59	0.25	
58.59	0.00	
63.59	0.01	
68.59	0.18	
73.59	0.41	
78.59	0.58	
82.59	0.62	
84.59	0.55	
86.49	0.75	
92.59	0.82	
102.65	2.34	
113.35	1.37	
120.14	1.42	23˚ 56' 41.2"E; 26˚ 55' 55.4"S; RB island – LH cross-section. No peg
XS was concatenated here – but in reality, the LH		XS was concatenated here – but in reality, the LH and RH cross-sections are separated by the rest of an island

Cross section		
Chainage (m)	Elevation relative to thalweg (m)	Comment
and RH cross-sections are separated by the rest of an island		
121.14	1.74	23˚ 56’ 41.7”E; 26˚ 55’ 55.6”S; LB island – RH cross-section. No peg
123.81	0.87	
125.11	0.69	
132.32	0.71	
137.43	0.62	
140.50	0.80	
141.22	1.46	
142.74	0.76	
144.48	0.65	
144.98	0.80	
146.66	2.55	
148.67	2.81	23˚ 56’ 41.9”E; 26˚ 55’ 56.3”S; RB – RH cross-section. No peg
Weir crest level, 14.4 m downstream of XS	0.80	23˚ 56’ 40.4”E; 26˚ 55’ 53.1”S; Weir crest level which causes pool – use this as datum in any further work here. This point lies 14.4 m downstream of the XS line

8.1.3 Matlabas

Location	Coordinates	Description
BM (STATION POSITION):	-24.051861, 27.359639	Peg in ground
BENCHMARK 01	-24.051583, 27.358889	Drilled on bridge
BENCHMARK 02	-24.052250, 27.359639	LB: Fence Post

BENCHMARK 03	-24.051528, 27.359639	RB: Peg in ground

Cross section		
Chainage (m)	Elevation relative to thalweg (m)	Comment
0.000	3.046	
28.522	1.454	
38.179	1.784	
43.982	1.807	
49.658	1.390	
53.771	1.716	
58.551	1.506	
61.246	1.059	
63.399	1.203	
64.675	0.595	
66.856	1.326	
73.321	0.911	
75.063	1.091	
77.294	1.245	
80.146	1.252	
82.169	1.014	
83.054	0.777	
83.581	0.463	
84.203	0.226	
84.203	0.216	
84.344	0.136	
84.779	0.052	
85.411	0.078	
85.942	0.101	
86.458	0.000	

Cross section		
Chainage (m)	Elevation relative to thalweg (m)	Comment
87.169	0.043	
87.863	0.066	
88.382	0.029	
88.723	0.095	
89.047	0.162	
89.501	0.228	
89.594	0.303	
90.775	0.558	
92.196	0.531	
94.322	0.675	
96.607	0.800	
98.335	1.064	
101.297	1.293	
105.086	1.462	
107.669	1.765	
111.045	1.765	
116.649	2.201	
125.432	1.812	
130.027	2.336	

8.1.4 Lephalala

Location	Coordinates	Description
BM (STATION POSITION):	-23.141278, 27.885028	No peg
BENCHMARK 01	-23.141435, 27.885189	Peg at base of large Vachellia faidherbia (Anna Tree)

Cross section		
Chainage (m)	Elevation relative to thalweg (m)	Comment
0.000	4.183	
13.655	2.996	
14.448	2.332	
15.944	2.247	
16.922	1.709	
17.167	1.180	
18.489	0.964	
18.878	0.828	
19.553	0.618	
21.045	0.397	
22.231	0.183	
24.314	0.234	
26.078	0.388	
27.307	0.604	
28.867	0.391	
29.077	0.321	
30.488	0.000	
31.553	0.139	
32.419	0.787	
32.637	0.955	
33.079	1.176	
37.582	3.006	
39.249	3.825	
42.878	3.291	
45.229	3.421	
45.611	3.970	

8.1.5 Limpopo at Limpokwena

Location	Coordinates	Description
BENCHMARK 01	-22.453490, 28.902211	Peg in cut stump of Combretum imberbe (RB)
BENCHMARK 02	-22.455748, 28.901249	Peg at base of Schota brachypatela (LB)
BENCHMARK 03	-22.455194, 28.901750	Drilled into flat rock

Cross section		
Chainage (m)	Elevation relative to thalweg (m)	Comment
0.000	5.663	
1.095	5.125	
8.282	2.430	
11.495	1.519	
23.346	1.205	
29.596	1.123	
36.503	0.888	
46.773	1.075	
51.257	0.960	
57.395	0.905	
62.136	1.102	
63.482	1.271	
67.458	0.878	
70.422	0.699	
76.210	0.932	
84.103	0.781	
87.518	0.377	
88.677	1.005	
90.308	1.127	
90.607	0.915	

Cross section		
Chainage (m)	Elevation relative to thalweg (m)	Comment
92.685	0.073	
95.012	0.000	
101.763	0.020	
107.482	0.310	
109.453	0.266	
116.899	0.439	
123.791	0.806	
126.865	0.248	
133.276	0.436	
141.280	0.345	
147.378	0.242	
151.740	0.498	
156.954	0.246	
162.165	0.441	
164.996	0.900	
173.853	0.914	
182.874	0.796	
189.695	1.220	
202.449	2.256	
206.135	1.484	
207.207	1.015	
207.441	0.889	
209.601	0.643	
212.757	1.052	
217.902	0.497	
222.943	1.227	
224.734	2.363	

Cross section		
Chainage (m)	Elevation relative to thalweg (m)	Comment
229.584	4.090	
237.150	3.856	
254.251	3.624	
270.812	4.131	
278.853	4.374	

8.1.6 Mogalakwena

Location	Coordinates	Description
BM (STATION POSITION):	-22.473444, 28.919500	No peg
BENCHMARK 01	-22.473444, 28.919139	LB, Peg: Base of Schotia brachypatela
BENCHMARK 02	-22.474361, 28.919389	LB, Drilled on weir wall
BENCHMARK 03	-22.473472, 28.920083	RB, Peg at base of Combretum imberbe

Cross section		
Chainage (m)	Elevation relative to thalweg (m)	Comment
0.000	5.778	BENCHMARK 02
0.723	5.224	Schotia brachypatela
7.261	4.563	Philenoptera violacea
10.153	4.470	Croton megalocarpus
16.889	4.829	Grewia flavescens
21.832	4.020	Croton megalocarpus
24.432	3.729	Croton megalocarpus
29.544	3.323	Croton megalocarpus
30.580	3.101	Cyperus textilis

Cross section		
Chainage (m)	Elevation relative to thalweg (m)	Comment
32.712	2.595	None
40.313	2.374	Nuxia oppositifolia
42.572	0.204	None
47.562	0.221	None
53.197	0.223	None
56.193	0.204	Water Level, LB (Pool) (Z: -2.531)
56.193	0.204	Filamentous algae
58.023	0.000	Filamentous algae
59.222	0.192	Water Level, RB (Pool) (Z: -2.543)
62.594	1.287	Cyperus longus
71.170	1.088	None
79.205	1.212	None
82.542	1.292	Phragmites mauritianus
86.062	1.967	Phragmites mauritianus
89.555	1.758	Phragmites mauritianus
93.869	2.407	Cyperus textilis
99.559	3.512	Colophospermum mopane
99.693	3.968	BENCHMARK 03 (RB Peg)

8.1.7 Limpopo @ Poachers Corner

Location	Coordinates	Description
BM (STATION POSITION):	-22.183833, 29.405194	No peg, alluvial bank
BENCHMARK 01	22˚ 10’ 56.9”S; 29˚ 24’ 17.8”E	LB - Existing BM - Ontop of large boulder at the base of a Ficus.
BENCHMARK 02	-22.184167, 29.405250	RB - on transect line, in tree-line

BENCHMARK 03	-22.184111, 29.404694	RB - Base of Ficus sycamorus, off-line

Cross section		
Chainage (m)	Elevation relative to thalweg (m)	Comment
0.000	7.467	Benchmark 1
4.442	6.799	
6.069	3.044	Lower limit of F.sycamorus
11.981	1.920	
12.091	0.823	
12.113	0.544	Edge of boulder
13.088	0.280	
15.024	0.018	
18.454	0.000	
21.022	0.008	
24.055	0.240	
27.897	0.210	
31.996	0.192	
34.063	0.558	
35.990	0.157	
38.137	0.167	
41.287	0.653	
44.611	0.773	
47.374	0.649	Filamentous algae
53.428	0.774	Filamentous algae
60.989	0.761	Filamentous algae
67.121	0.766	Filamentous algae
75.194	0.654	Filamentous algae
78.493	0.733	
85.105	0.634	

Cross section		
Chainage (m)	Elevation relative to thalweg (m)	Comment
93.604	0.605	
96.088	0.649	Filamentous algae
102.025	0.821	Filamentous algae
105.599	0.908	
107.503	0.816	Benthic algae
110.396	0.709	Benthic algae
116.659	0.711	Benthic algae
122.551	0.698	Benthic algae
129.579	0.596	Benthic algae
135.206	0.661	Benthic algae
140.673	0.749	Benthic algae
142.014	0.599	Benthic algae
144.364	0.811	Benthic algae
145.884	1.761	
157.020	2.384	Alluvial lateral bar - Dead vegetation
166.935	2.448	Alluvial lateral bar - Dead vegetation
168.314	2.252	Alluvial lateral bar - No vegetation
175.340	2.019	Fine sand over course sand
177.767	2.718	Lower limit of C. Megalocarpus
179.755	3.639	Lower limit of P.reticulatus
181.322	4.794	Top of Macro-channel Bank
183.667	5.444	
186.952	5.296	
193.622	5.392	Benchmark 2
193.628	5.298	Bramble, off-line near a V.tortilis
202.629	5.387	
218.244	7.279	Next to road

Cross section		
Chainage (m)	Elevation relative to thalweg (m)	Comment
229.486	7.793	RB Macro-channel Bank. Lower limit of P.violaceae

8.1.8 Sand River

Location	Coordinates	Description
BM (STATION POSITION):	-22.399278, 30.099417	LB: No peg
BENCHMARK 01	-22.399167, 30.098722	LB: Peg at tree stump / log
BENCHMARK 02	-22.399222, 30.099222	LB: Drilled Rock with Spray Paint
BENCHMARK 03	-22.399315, 30.100247	RB: Peg

Cross section		
Chainage (m)	Elevation relative to thalweg (m)	Comment
0.000	4.452	BENCHMARK 01
0.016	4.320	Setaria sphacelata
5.588	3.419	Lipia sp.
10.696	2.063	Lipia sp.
21.846	2.115	Lipia sp.
27.321	1.908	Vachellia tortilis
31.776	0.963	Lipia sp.
38.065	1.436	Ricinus communis
46.026	1.098	Lipia sp.
49.694	1.121	None
52.296	1.294	None
53.667	1.371	None
58.897	1.057	None

Cross section		
Chainage (m)	Elevation relative to thalweg (m)	Comment
62.128	1.005	None
64.792	0.874	None
69.338	0.916	None
77.369	1.166	Lipia sp.
77.918	1.598	None
78.970	0.705	None
80.612	0.797	None
82.680	1.060	None
85.391	0.776	None
89.276	1.278	Combretum imberbe
92.249	0.774	Panicum maximum
95.657	0.228	Panicum maximum
97.929	0.082	None
99.754	0.306	Cyperus sexangularis
101.211	0.720	Cyperus sexangularis
104.481	0.826	Cyperus sexangularis
107.718	0.700	Cyperus sexangularis
110.061	1.049	Cyperus sexangularis
112.749	0.738	Lipia sp.
114.390	0.501	Lipia sp.
117.204	0.290	Cyperus sexangularis
120.502	0.119	Water Level, LB (Z: -1,022)
121.779	0.000	None
123.536	0.116	Water Level, RB (Z: -1,025)
124.830	0.469	Cyperus sexangularis
127.442	0.587	Lipia sp.
130.868	0.501	Lipia sp.

Cross section		
Chainage (m)	Elevation relative to thalweg (m)	Comment
133.578	0.319	Phragmites mauritianus
135.771	1.084	Cyperus sexangularis
139.172	2.373	Panicum maximum
140.501	2.779	Combretum imberbe
141.652	3.076	Philenoptera violaceae
146.833	3.842	Panicum maximum
149.523	4.214	Panicum maximum
155.098	4.996	Combretum imberbe
155.098	4.996	Faidherbia albida
158.690	5.465	Schotia brachypatela
160.926	6.118	BENCHMARK 03 (RB)
161.393	5.991	Panicum maximum

8.1.9 Levuvhu

Location	Coordinates	Description
BM (STATION POSITION):	-22.444444, 31.083444	LB: Peg
BENCHMARK 01	-22.444583, 31.083278	LB: Peg in base of Syzigium gerardii (Forest waterberry)
BENCHMARK 02	-22.444333, 31.083306	LB: Peg with rocks surrounding - up-slope from BM
BENCHMARK 03	-22.445039, 31.083969	RB: Ontop of bank, between two large Vachellia faidherbia's and a large Ziziphus macrunata

Cross section		
Chainage (m)	Elevation relative to thalweg (m)	Comment
0.000	10.688	
3.638	10.835	Benchmark 2

Cross section		
Chainage (m)	Elevation relative to thalweg (m)	Comment
4.280	10.698	
6.678	10.091	
9.665	8.967	
12.351	7.763	
15.120	6.329	
18.695	4.419	
21.064	1.530	
21.807	0.652	
25.119	0.021	
27.292	0.034	
30.030	0.042	
32.719	0.091	
33.897	0.239	
35.516	0.000	
37.393	0.214	
39.925	0.127	
41.444	0.073	
43.732	0.202	
46.204	0.233	
48.670	0.387	
49.878	0.250	
51.989	0.327	
54.083	0.391	
56.002	0.461	
57.208	0.407	
59.646	0.383	
62.615	0.502	

Cross section		
Chainage (m)	Elevation relative to thalweg (m)	Comment
65.583	0.265	
67.607	0.333	
70.164	0.331	
73.108	0.649	
77.803	0.223	
79.835	0.118	
81.424	0.058	
83.990	0.294	
87.642	0.545	
89.919	0.792	
91.649	1.256	
93.683	2.726	
96.355	4.597	
97.471	5.406	
101.377	6.871	
103.198	7.136	
118.320	7.519	
107.024	7.556	
109.115	7.735	
111.584	7.937	
110.922	8.050	Benchmark 3

8.1.10 Shingwedzi

Location	Coordinates	Description
BM (STATION POSITION):	-23.221944, 31.554917	Drilled into rock with spraypaint
BENCHMARK 01	-23.222250, 31.554556	RB Peg

BENCHMARK 02	-23.221750, 31.555000	RB Drilled into rock with spraypaint
BENCHMARK 03	-23.221333, 31.555667	LB Drilled into base of Spirostachys africana trunk

Cross section		
Chainage (m)	Elevation relative to thalweg (m)	Comment
	6.808	Benchmark 03 LB
0.000	6.368	Spirostachys africana
2.282	5.688	Euclea divinorum
8.425	3.250	Spirostachys africana
9.527	2.832	Philenoptera violacea
11.470	1.761	Hyphaene coriacea
12.676	1.250	Phragmites mauritianus
13.073	1.050	Cyperus textilis
13.677	0.265	Phragmites mauritianus
21.888	0.345	None
29.917	0.421	None
41.451	0.683	None
51.513	0.459	Xanthium strumarium
59.137	0.304	None
61.619	0.222	Water Level, LB (Z: -2,380)
66.932	0.139	None
72.856	0.184	None
76.291	0.122	None
78.667	0.066	None
80.114	0.000	None
80.538	0.235	Water Level, RB (Z: -2,367)
80.612	0.436	None
81.356	0.344	None

Cross section		
Chainage (m)	Elevation relative to thalweg (m)	Comment
85.031	0.856	None
86.830	1.635	Gymnosporia senegalensis
88.322	1.776	Gymnosporia senegalensis
96.286	1.873	None
98.511	2.264	Heteropogon contortus
102.559	2.406	None
107.648	2.432	Heteropogon contortus
118.966	2.592	Sporobolus fimbriatus
120.121	2.618	Xanthium strumarium
129.381	3.352	Xanthium strumarium
137.317	4.534	Gymnosporia senegalensis
142.735	4.601	Euclea divinorum
146.860	4.898	BENCHMARK 01, RB (Peg)

8.1.11 Letaba at lone bull

Location	Coordinates	Description
BM (STATION POSITION):	-23.758333, 31.369972	No Peg
BENCHMARK 01	-23.758333, 31.371861	LB: Drilled into bridge
BENCHMARK 02	-23.757500, 31.370500	LB: Drilled into Rock
BENCHMARK 03	-23.758935, 31.369382	RB Peg (Ontop of Bank)
BENCHMARK 04	-23.756740, 31.371410	LB Peg (Ontop of bank, base of Mopani)

Cross section		
Chainage (m)	Elevation relative to thalweg (m)	Comment
0.000	10.454	BENCHMARK 03 (Peg)
2.398	10.302	Top of bank
8.911	6.110	Lower limit of C.megalocarpus
13.071	3.980	Lower limit of C.megalocarpus
19.749	2.851	On bank
20.477	1.672	Upper limit of C.dactylon
21.925	0.961	
24.263	0.609	Back channel pool
26.286	1.079	
30.736	1.192	
36.475	0.546	Vegetated lateral bar
41.196	0.564	
44.747	0.520	Lower limit of P.mauritianus
49.372	0.544	Water Level, RB (Z: -1,548)
50.656	0.252	Benthic green algae
51.111	0.137	Benthic green algae
51.561	0.075	Benthic green algae
52.565	0.026	Benthic green algae
53.667	0.051	Benthic green algae
54.960	0.017	Benthic green algae
56.239	0.000	Benthic green algae
57.526	0.007	Benthic green algae
58.928	0.112	Benthic green algae
60.160	0.332	Water Level, LB (Z: -1,468)
60.969	0.539	Large woody debris
64.108	0.903	Lateral gravel bar
72.016	1.411	Lateral gravel bar

Cross section		
Chainage (m)	Elevation relative to thalweg (m)	Comment
80.961	1.734	
96.376	1.992	Large gravel bar.
108.452	1.676	Large gravel bar. Argemone seedlings
113.858	1.823	Large gravel bar. X.strumarium seedlings and C.dactylon remnants.
117.931	1.850	Large gravel bar. Datura stramonium seedlings and C.dactylon remnants
125.769	1.400	Large gravel bar
137.461	1.366	Large gravel bar
153.091	1.414	Large gravel bar
160.226	1.091	Water Level of back pool (Z: -0,709)
162.307	1.004	In back pool
164.299	0.941	In back pool
165.108	1.080	Water Level of gravel bar (Z: -0,720)
165.158	1.078	Water Level of pool (Z: -0,722)
165.944	1.241	Flood Channel
169.380	1.277	
171.103	1.668	Xanthium & Argemone seedlings
175.915	1.603	
181.931	1.406	
192.270	1.780	
199.368	1.786	Flood Channel
201.329	2.111	
201.329	2.111	
205.919	2.384	
210.224	2.090	Flood Channel
219.261	2.633	Lower limit of C.mopane recruitment
223.790	2.821	

Cross section		
Chainage (m)	Elevation relative to thalweg (m)	Comment
232.980	3.196	
237.725	3.374	
248.483	3.735	
258.733	4.093	Upper limit of N.oppositifolia
265.580	4.853	
265.580	4.853	
271.404	5.779	Lower limit of large P.violacea
271.404	5.779	
277.158	5.969	
283.905	5.632	Lower limit of sub-adult C.mopane
293.307	5.686	Also dead C.imberbe
312.136	7.207	G.senegalensis adults
317.710	7.895	Lower limit of adult C.imberbe
324.600	8.349	Upper limit of Indigofera sp.
335.208	9.116	Lower limit of adult C.imberbe

8.1.12 Groot Letaba

Location	Coordinates	Description
BM (STATION POSITION):	-23.677073, 31.098329	
BENCHMARK 01	-23.677350, 31.098115	RB Peg, BM01
BENCHMARK 02	-23.677755, 31.098976	RB: Drilled Rock, BM02
BENCHMARK 03	-23.676237, 31.098852	LB: Peg, BM03

Cross section		
Chainage (m)	Elevation relative to thalweg (m)	Comment
0.000	5.972	Lower limit of terrestrial treeline
5.511	4.759	Lower limit of G.senegalensis
15.683	3.410	Lower limit of young P.violacea
15.683	3.410	
15.683	3.410	
24.081	3.031	
29.298	3.252	
31.496	3.528	
35.096	2.929	
42.512	3.406	C.erythrophyllum line along flood bench
47.098	3.171	
53.253	1.987	Lower limit of S.fimbriatus
56.201	2.076	Lower limit of C.sexangularis
59.864	1.197	Lower limit of C.dactylon
61.180	1.237	
66.537	1.280	
72.942	1.177	
75.517	1.774	
76.942	1.570	
79.900	0.953	
81.331	0.947	
82.750	1.133	
83.501	1.483	
83.913	0.918	Water Level for Back Channel (Z: -3.488)
84.509	0.867	Lower limit of I.fasciculatum
86.122	0.985	
87.457	1.032	

Cross section		
Chainage (m)	Elevation relative to thalweg (m)	Comment
89.228	1.012	
90.534	1.122	
92.000	0.840	Fine sand over gravel. Lower limit of I.fasciculatum
93.307	1.329	
94.717	1.025	Upper limit of I.fasciculatum
97.063	0.867	Water Level, LB (Z: -3.539)
97.523	0.729	Lower limit of I.fasciculatum in active channel
97.993	0.584	Lower limit of G.fruticosus in active channel
98.896	0.380	Benthic green algae
99.768	0.540	Benthic green algae
100.766	0.224	Benthic green algae
102.012	0.000	Benthic green algae
103.220	0.188	
104.317	0.181	Benthic green algae
105.301	0.240	Benthic green algae
105.853	0.679	Benthic green algae
106.350	0.755	Lower limit of G.fruticosus in channel
106.350	0.755	Lower limit of I.fasciculatum in channel
106.501	0.839	Water Level, RB (Z: -3.567)
108.021	1.119	
110.171	1.056	
111.846	1.101	
114.006	1.077	
114.877	0.906	Water Level of back channel, LB (Z: -3.500)
115.512	0.742	Lower limit of I.faciculatum
116.194	0.615	Back Channel
116.792	0.748	Fine sand over gravel. Lower limit of I.fasciculatum

Cross section		
Chainage (m)	Elevation relative to thalweg (m)	Comment
117.571	0.919	Water Level of back channel, RB (Z: -3.487)
119.628	1.072	
121.403	1.325	
122.646	1.381	
124.623	1.562	
126.657	1.495	
130.091	1.492	
133.585	1.337	
137.879	1.317	End of Macro-channel floor
139.178	2.797	
142.412	3.451	Flood bench
170.322	4.873	
183.111	7.146	
193.151	7.692	Lower limit of large adult P.violacea

8.1.13 Olifants at Mamba T2

Location	Coordinates	Description
BENCHMARK 02	-24.086428, 31.250930	LB: Drilled on Bedrock, Downstream of BM
BENCHMARK 03	-24.086128, 31.250688	In-line, on mid-channel bar (Drilled on bedrock)
BENCHMARK 04	-24.085922, 31.250774	Off-line, slightly upstream, on mid-channel bar (Drilled on bedrock)
BENCHMARK 05	-24.086248, 31.251344	Wooden stake inserted at base of Philenoptera violaceae

Cross section		
Chainage (m)	Elevation relative to thalweg (m)	Comment
0.000	7.534	
21.239	1.376	
22.386	1.018	
23.505	1.433	
25.146	1.745	
27.426	1.664	
29.791	1.393	
31.891	0.901	
33.691	0.711	
34.689	0.836	
36.225	0.446	Water Level (Elevation: -7,129)
37.011	0.254	
41.072	0.112	
44.168	0.246	
45.641	0.116	
47.990	0.000	
48.032	0.446	Water Level (Elevation: -7,129)
48.631	0.814	
49.284	0.684	
50.480	0.940	
54.661	0.920	
56.347	0.604	
57.670	0.834	
58.531	0.458	Water Level (Elevation: -7,117)
58.998	0.393	
59.877	0.493	
61.072	0.389	

Cross section		
Chainage (m)	Elevation relative to thalweg (m)	Comment
62.249	0.240	
63.925	0.162	
65.633	0.107	
67.173	0.071	
69.744	0.206	
70.862	0.481	Water Level (Elevation: -7,094)
71.729	0.941	
72.974	1.188	
74.768	1.438	
77.023	1.606	
79.055	1.349	
80.953	1.253	
83.132	1.037	
84.946	0.778	Water Level (Elevation: -6,799)
86.156	0.535	
86.707	0.532	
88.143	0.607	
89.652	0.655	
91.158	0.576	
92.165	0.545	
93.730	0.624	
94.808	0.593	
95.956	0.541	
97.143	0.541	Defined cobble bar - submerged
98.584	0.750	Defined cobble bar - submerged
100.618	0.711	
101.773	0.573	

Cross section		
Chainage (m)	Elevation relative to thalweg (m)	Comment
102.692	0.637	
103.570	0.681	
104.441	0.792	Water Level (Elevation: -6,783)
105.683	0.930	
107.561	1.212	
107.561	1.212	
110.915	1.383	
110.915	1.383	
113.580	1.554	
113.580	1.554	
113.580	1.554	
116.299	1.627	
116.299	1.627	
121.326	1.997	
123.286	2.305	
125.432	1.894	
126.761	1.451	
128.215	0.904	Water Level (Elevation: -6,671)
128.215	0.904	Water Level (Elevation: -6,671)
129.453	0.697	
130.714	0.572	
132.490	0.448	
133.866	0.581	
135.249	0.602	
137.166	0.486	
138.636	0.373	
139.818	0.378	

Cross section		
Chainage (m)	Elevation relative to thalweg (m)	Comment
141.315	0.359	
142.548	0.512	
143.439	0.595	
145.182	0.688	
145.978	0.653	
147.109	0.902	Water Level (Elevation: -6.673)
147.109	0.902	
147.109	0.902	
148.157	1.101	
149.175	1.515	
151.005	1.732	
153.833	2.036	
157.011	2.021	
158.668	1.747	
160.685	1.503	
160.685	1.503	
160.685	1.503	
161.917	1.261	
161.917	1.261	
163.971	1.464	
163.971	1.464	
163.971	1.464	
164.903	1.532	
164.903	1.532	
164.903	1.532	
168.189	1.763	
168.189	1.763	

Cross section		
Chainage (m)	Elevation relative to thalweg (m)	Comment
170.203	1.504	
170.751	1.503	Upper limit of Gomphostigma
170.751	1.503	
172.523	1.706	
172.523	1.706	
174.127	2.000	Upper limit of Schoenoplectus
174.127	2.000	
176.161	2.117	
178.783	2.406	
178.783	2.406	
183.698	2.684	Upper limit of Phragmites
186.881	2.760	
193.904	3.056	
199.153	3.445	
201.879	3.429	
205.135	3.341	
210.362	3.016	
214.062	3.002	
217.460	3.237	
220.083	4.603	
222.478	5.639	
224.342	7.112	

8.1.14 Olifants at Balule T2

Location	Coordinates	Description
BM (STATION POSITION):	-24.05214, 31.72879	LB: Drilled into bedrock with spraypaint
BENCHMARK 01	N/A	N/A

BENCHMARK 02	-24.05184, 31.72937	LB: Drilled into bedrock
BENCHMARK 03	-24.05223, 31.72844	LB: Drilled into bedrock upstream of BM
	-24.051317, 31.729137	Upstream pillar on top of Bridge

Cross section		
Chainage (m)	Elevation relative to thalweg (m)	Comment
0.000	6.667	
8.616	5.793	
16.130	5.657	
25.611	5.205	
30.498	4.072	
38.172	3.209	
46.518	2.902	
53.440	2.520	
59.099	2.101	
60.944	1.820	
63.905	2.289	
66.917	2.515	
72.810	2.051	
76.304	2.618	
80.847	1.704	
84.686	1.453	
89.041	1.504	
92.193	1.271	Upper limit of Ishaemum fasciculatum
93.164	1.197	
93.164	1.197	
93.164	1.197	

Cross section		
Chainage (m)	Elevation relative to thalweg (m)	Comment
95.586	0.841	
98.148	0.646	Water Level
100.234	0.389	
101.473	0.379	
102.863	0.669	Water Level (No Flow, backpool)
102.863	0.669	
104.066	1.156	
105.726	1.536	
107.645	1.350	
109.042	1.783	
109.042	1.783	
110.068	1.432	
111.762	1.458	
111.762	1.458	
113.289	1.639	Upper limit of Flueggea virosa
114.498	0.926	
114.498	0.926	
115.923	0.635	Water Level (Elevation: -3,230)
115.923	0.635	
115.923	0.635	
116.705	0.324	
117.506	0.277	
118.355	0.170	
119.632	0.424	
119.874	0.153	
120.986	0.466	
121.412	0.000	

Cross section		
Chainage (m)	Elevation relative to thalweg (m)	Comment
122.411	0.114	
123.761	0.317	
124.290	0.356	
125.128	0.499	
125.919	0.556	
126.980	0.502	
127.582	0.600	
128.930	0.662	
129.345	0.733	Water Level (Elevation: -3,209)
130.150	0.777	
130.701	0.901	Silt on bedrock
131.428	0.763	
131.428	0.763	
134.260	1.050	
134.260	1.050	
134.260	1.050	
135.919	0.812	
137.015	1.187	
139.363	0.971	
139.363	0.971	
139.363	0.971	
139.363	0.971	
139.363	0.971	
139.363	0.971	
142.264	0.545	
143.522	0.586	
144.948	0.752	

Cross section		
Chainage (m)	Elevation relative to thalweg (m)	Comment
146.858	0.593	Water Level (Elevation: -3,278)
147.935	0.445	
149.378	0.374	
150.937	0.253	
152.193	0.179	
153.451	0.320	
153.489	0.314	
155.208	0.341	
156.854	0.241	
158.129	0.215	
159.941	0.222	
161.754	0.412	
163.567	0.477	
165.577	0.282	
166.036	0.358	
167.664	0.368	
169.301	0.295	
170.915	0.209	
172.583	0.186	
174.036	0.260	
175.582	0.318	
177.429	0.406	
179.383	0.482	
181.205	0.486	
183.137	0.473	
184.470	0.457	
185.689	0.378	

Cross section		
Chainage (m)	Elevation relative to thalweg (m)	Comment
187.484	0.205	
188.184	0.613	Water Level (Elevation: -3,258)
188.454	0.950	
188.454	0.950	
188.454	0.950	
189.710	1.189	
189.710	1.189	
191.344	0.592	Water Level (Elevation: -3,279)
191.344	0.592	
191.344	0.592	
192.085	0.400	
193.259	0.599	
194.119	0.542	
195.835	0.493	
197.154	0.460	
198.235	0.443	
199.078	0.450	
200.187	0.424	
201.319	0.405	
202.512	0.594	Water Level (Elevation: -3,277)
202.512	0.594	
202.512	0.594	
202.684	0.901	
204.220	0.963	
206.353	0.888	
206.353	0.888	
209.767	1.406	

Cross section		
Chainage (m)	Elevation relative to thalweg (m)	Comment
209.767	1.406	
209.767	1.406	
213.924	1.439	
213.924	1.439	
217.138	1.276	
220.181	1.081	
220.181	1.081	
222.149	1.252	
222.149	1.252	
224.480	1.307	
227.645	1.423	
227.645	1.423	
229.998	1.187	
229.998	1.187	
233.149	1.466	
233.149	1.466	
234.877	1.471	
234.877	1.471	
238.093	1.408	
240.593	1.035	
240.593	1.035	
241.791	0.642	
241.791	0.642	
242.483	0.529	Water Level (Elevation: -3.342)
242.483	0.529	
242.483	0.529	
243.658	0.407	

Cross section		
Chainage (m)	Elevation relative to thalweg (m)	Comment
244.746	0.408	
246.903	0.452	
248.570	0.521	Water Level (Elevation: -3.350)
251.134	0.737	
255.937	0.841	
259.423	0.858	
262.917	0.821	
267.400	0.749	
272.678	0.532	Water Level (Elevation: -3,339)
273.942	0.419	
275.030	0.522	
275.616	0.516	Water level (Elevation: -3,355)
279.953	0.907	
282.168	1.154	
282.168	1.154	
282.336	1.237	Upper limit of Ishaemum fasciculatum
288.224	1.461	
288.224	1.461	
288.224	1.461	
289.860	2.011	
293.293	3.030	Upper limit of Phragmites; soil in transect is moist due to recent heavy rains that saturated soils
293.293	3.030	
294.936	3.442	
301.621	3.020	
309.399	3.455	Vachellia spp. Encroaching into upper riparian zone on lateral bar.

Cross section		
Chainage (m)	Elevation relative to thalweg (m)	Comment
316.733	4.718	Croton sp. line growing parallel to river flow (defined cohort)
318.539	5.080	
325.287	5.545	Cairne position on Right Bank - define line of transect
328.665	5.889	Flood debris line & Philenoptera violaceae cohort line (parallel to river flow)
337.691	6.495	
361.381	8.280	
372.559	8.919	
388.888	9.121	Begin of Transect 2: Lannea defines line of transect 2

8.1.15 Elephantes

Location	Coordinates	Description
BM (STATION POSITION):	-23.879722, 32.2261667	RB on dirt road. No peg
BENCHMARK 01	-23.8759722, 32.226500	Previously utilized Benchmark on corner fence post of adjacent fields
BENCHMARK 02	-23.8759444, 32.2260833	Newly inserted BM on base of Vachellia xanthophloea
BENCHMARK 03		RB on dirt road. No peg

Cross section		
Chainage (m)	Elevation relative to thalweg (m)	Comment
0	6.436	LB
8.25292	6.6	
11.20184	6.004	Edge of macro-channel bank, indicator of F. sycamorus recruitment
15.56842	4.78	

Cross section		
Chainage (m)	Elevation relative to thalweg (m)	Comment
28.93036	4.883	
46.39931	4.888	
72.84007	5.302	
89.79682	5.926	
108.1585	5.679	
122.1896	4.89	
125.5409	5.099	
133.0925	4.785	
154.6015	4.095	
179.0074	4.025	
201.0978	3.874	Gravel bar, Left edge
210.705	3.677	Gravel bar, Right edge
219.1953	3.918	
231.3819	3.54	Point at transition between lower and upper zone - distinctive bench / terrace
235.513	2.254	Gravel bar, Left edge
237.986	2.066	Gravel bar, Right edge
243.84	2.127	
255.2672	2.164	
260.0454	2.254	
264.0762	2.864	Transition between marginal and lower zone - distinct flood bench
266.0325	1.899	
267.6113	1.257	
269.5757	0.491	WATERS EDGE, LEFT BANK
270.5248	0.003	
272.4696	0.119	
275.4427	0.268	Filamentous algae here

Cross section		
Chainage (m)	Elevation relative to thalweg (m)	Comment
277.0487	0.294	
279.0398	0.327	
282.1797	0.277	
285.6189	0.22	
288.3316	0.147	
291.6363	0	
294.8552	0.016	
300.1698	0.225	
302.575	0.178	
304.3735	0.22	Course gravel bar
306.7446	0.392	
308.6019	0.499	WATERS EDGE, RIGHT BANK
314.5976	0.914	
323.1734	0.854	Shells of corbiculids & Tarebia
335.4099	1.054	
342.7922	1.154	
348.4586	1.052	
349.0599	1.061	
354.0277	1.242	
358.1039	2.023	
363.0991	3.14	
367.2799	4.043	
370.7041	4.785	
374.9534	5.275	
377.3109	5.499	RB

8.1.16 Limpopo at Chokwe

Location	Coordinates	Description
BM (STATION POSITION):	-24.500444, 33.010111	
BENCHMARK 01	-24.500389, 33.010222	Corner of wall

Cross section		
Chainage (m)	Elevation relative to thalweg (m)	Comment
0.000	8.315	
6.820	6.445	
21.208	4.932	Flood Bench
30.155	4.735	
43.207	4.275	Sapling
49.666	4.460	
58.587	3.411	End of flood bench
64.749	2.205	Edge of bank to flood bench
80.523	1.748	MCF. Wide open alluvium - silt over sand.
89.276	1.293	Silt over sand, WL
95.598	1.057	Silt over sand
102.735	0.637	Silt over sand
109.790	0.740	Silt over sand
111.626	1.315	Small side channel adjacent to small in-channel sand bar
112.751	1.886	In-channel sand bar
116.831	1.862	
118.309	1.241	Main channel, WL
124.461	0.988	Silt over sand
135.677	0.737	Silt over sand
142.832	0.441	Silt over sand
155.052	0.232	Silt over sand
170.855	0.180	Silt over sand

Cross section		
Chainage (m)	Elevation relative to thalweg (m)	Comment
194.333	0.000	Silt over sand
209.345	0.179	Silt over sand
223.787	0.575	Silt over sand
231.999	0.546	Silt over sand
240.004	0.488	Silt over sand
243.283	0.723	Silt over sand
244.982	0.992	Silt over sand
245.506	1.268	Silt over sand, WL
249.209	1.406	Lateral bar, Silt over sand
251.575	1.909	Silt over sand
259.224	1.550	Silt over sand
269.319	2.176	Silt over sand
272.130	1.819	Silt over sand
276.071	1.476	Silt over sand
278.308	1.276	Back Channel WL
282.034	1.051	Silt over sand
286.275	1.280	Back Channel
289.330	1.341	Silt over sand
291.807	1.270	Back Channel
294.706	1.004	Silt over sand
298.961	1.277	WL
303.501	1.789	
313.789	1.451	
320.274	1.432	
325.222	1.677	Start of agricultural fields (Sweet Potatoes) on a slope.
331.376	3.534	End of Sweet potatoes plantations, start of Maize plantations’

Cross section		
Chainage (m)	Elevation relative to thalweg (m)	Comment
347.349	4.082	Maixed fields mixed with beans (Castor oil beans). Plantation approximately 30m broad
358.416	3.449	
367.405	2.599	Point added manually for pool due to restricted access
377.735	2.599	Point added manually for pool due to restricted access
388.489	2.099	Point added manually for pool due to restricted access
392.540	2.099	Point added manually for pool due to restricted access
403.106	4.782	

8.2 APPENDIX B: HYDRAULICS - VELOCITY DEPTH FREQUENCY TABLES

8.2.1 Crocodile

Hydraulic parameter							Percentage of width occupied by fish hydraulic habitat						
Maximum Depth (m)	Average Depth (m)	Discharge (m3/s)	Width (m)	Wetted perimeter (m)	Average velocity (m/s)	Velocity 98% (m/s)	SVS	SS	SD	FVS	FS	FI	FD
0.02	0.01	0	2.6	2.6	0.02	0.06	100	0	0	0	0	0	0
0.04	0.02	0.003	4	4	0.03	0.11	100	0	0	0	0	0	0
0.06	0.04	0.007	4.8	4.8	0.04	0.14	100	0	0	0	0	0	0
0.08	0.04	0.012	8.9	9	0.04	0.14	100	0	0	0	0	0	0
0.1	0.05	0.024	10.7	10.7	0.05	0.17	99	1	0	0	0	0	0
0.12	0.06	0.042	12.4	12.5	0.06	0.19	79	21	0	0	0	0	0
0.14	0.07	0.064	14.2	14.2	0.06	0.22	72	28	0	0	0	0	0
0.16	0.08	0.092	15.9	16	0.07	0.24	69	30	0	0	0	0	0
0.18	0.1	0.13	16.9	17	0.08	0.27	50	48	0	1	1	0	0
0.2	0.11	0.177	17.3	17.3	0.09	0.3	37	60	0	1	2	0	0
0.22	0.13	0.231	17.6	17.7	0.1	0.33	29	67	0	1	2	1	0
0.24	0.15	0.291	17.9	18	0.11	0.35	19	76	0	1	3	1	0
0.26	0.17	0.358	18.2	18.3	0.12	0.38	12	82	0	1	4	2	0
0.28	0.19	0.434	18.4	18.4	0.13	0.41	7	86	0	1	3	3	0
0.3	0.2	0.516	18.5	18.6	0.14	0.44	5	88	0	0	3	4	0
0.32	0.22	0.605	18.6	18.7	0.15	0.47	5	86	0	0	2	5	1
0.34	0.24	0.701	18.7	18.8	0.15	0.5	3	86	0	0	2	6	2
0.36	0.26	0.804	18.9	19	0.16	0.52	3	85	0	0	2	7	3
0.38	0.28	0.913	19	19.1	0.17	0.54	2	85	0	0	1	6	6
0.4	0.3	1.029	19.1	19.2	0.18	0.56	2	83	0	0	1	5	9
0.42	0.31	1.153	19.2	19.4	0.19	0.59	2	80	0	0	1	5	12
0.44	0.33	1.283	19.4	19.5	0.2	0.62	2	77	0	1	1	4	15
0.46	0.34	1.406	19.8	19.9	0.21	0.64	3	74	0	1	1	3	18

Hydraulic parameter							Percentage of width occupied by fish hydraulic habitat						
Maximum Depth (m)	Average Depth (m)	Discharge (m3/s)	Width (m)	Wetted perimeter (m)	Average velocity (m/s)	Velocity 98% (m/s)	SVS	SS	SD	FVS	FS	FI	FD
0.48	0.36	1.533	20.3	20.5	0.21	0.66	5	72	0	1	1	2	19
0.5	0.37	1.668	20.8	21	0.22	0.67	5	68	2	2	1	1	21
0.52	0.38	1.808	21.4	21.6	0.22	0.69	7	57	8	3	1	1	22
0.54	0.39	1.956	22	22.1	0.23	0.7	8	50	13	3	1	1	24
0.56	0.4	2.113	22.5	22.7	0.24	0.71	7	46	16	3	1	1	25
0.58	0.41	2.294	22.9	23	0.24	0.73	7	36	25	3	2	1	26
0.6	0.43	2.502	22.9	23.1	0.25	0.75	5	29	31	3	3	1	28
0.62	0.45	2.718	23	23.2	0.26	0.78	4	25	35	2	4	1	30
0.64	0.47	2.945	23	23.3	0.27	0.81	3	21	37	2	4	1	32
0.66	0.49	3.181	23.1	23.3	0.28	0.83	1	17	40	1	5	2	34
0.68	0.51	3.428	23.1	23.4	0.29	0.86	1	14	41	1	5	2	36
0.7	0.52	3.686	23.2	23.5	0.3	0.88	1	13	40	1	4	3	38
0.72	0.54	3.954	23.3	23.5	0.31	0.91	1	12	39	1	4	4	40
0.74	0.56	4.233	23.3	23.6	0.32	0.94	1	11	39	1	3	5	41
0.76	0.58	4.524	23.4	23.7	0.33	0.95	0	10	39	0	2	5	44
0.78	0.6	4.826	23.4	23.8	0.34	0.97	0	10	37	0	1	6	46
0.8	0.62	5.139	23.5	23.8	0.35	1	0	9	36	0	1	5	49
0.82	0.64	5.466	23.6	23.9	0.37	1.02	0	9	35	0	1	4	52
0.84	0.65	5.804	23.6	24	0.38	1.04	0	8	34	0	1	2	54
0.86	0.67	6.156	23.7	24	0.39	1.07	0	8	33	0	1	2	57
0.88	0.69	6.52	23.7	24.1	0.4	1.09	0	8	32	0	1	1	59
0.9	0.71	6.898	23.8	24.2	0.41	1.13	0	7	30	1	1	1	60
0.92	0.73	7.291	23.9	24.3	0.42	1.15	0	6	28	1	1	1	63
0.94	0.73	7.692	24.3	24.7	0.43	1.16	1	6	28	1	1	1	62
0.96	0.74	8.055	24.8	25.2	0.44	1.17	1	5	28	2	1	0	62
0.98	0.73	8.427	25.8	26.2	0.45	1.19	3	4	26	5	1	1	60

Hydraulic parameter							Percentage of width occupied by fish hydraulic habitat						
Maximum Depth (m)	Average Depth (m)	Discharge (m3/s)	Width (m)	Wetted perimeter (m)	Average velocity (m/s)	Velocity 98% (m/s)	SVS	SS	SD	FVS	FS	FI	FD
1	0.71	8.808	27.2	27.6	0.46	1.2	4	4	25	8	2	0	58
1.02	0.7	9.198	28.3	28.7	0.46	1.21	5	3	24	10	2	1	56
1.04	0.7	9.597	29.2	29.7	0.47	1.22	5	3	23	11	2	1	55
1.06	0.7	10.005	30.1	30.6	0.47	1.21	5	3	23	10	4	0	54
1.08	0.7	10.423	31	31.5	0.48	1.23	4	3	22	10	6	0	53
1.1	0.7	10.85	31.9	32.4	0.49	1.23	4	4	21	10	7	1	52
1.12	0.7	11.286	32.8	33.3	0.49	1.23	4	4	21	10	8	2	51
1.14	0.7	11.732	33.7	34.2	0.5	1.25	4	5	20	9	9	3	50
1.16	0.7	12.187	34.6	35.1	0.5	1.26	4	6	19	9	10	4	49
1.18	0.7	12.652	35.5	36	0.51	1.26	4	6	18	9	10	5	48
1.2	0.71	13.126	36.4	36.9	0.51	1.26	3	7	18	8	9	7	48
1.22	0.71	13.609	37.3	37.9	0.51	1.27	3	7	18	8	9	8	47
1.24	0.72	14.102	37.8	38.4	0.52	1.27	3	7	17	7	9	8	48
1.26	0.74	14.604	38	38.6	0.52	1.28	2	8	17	6	9	9	49
1.28	0.75	15.116	38.2	38.8	0.53	1.29	2	9	17	5	9	9	51
1.3	0.77	15.638	38.3	38.9	0.53	1.31	2	9	16	5	8	9	52
1.32	0.79	16.169	38.5	39.1	0.53	1.32	1	9	16	2	9	9	54
1.34	0.8	16.71	38.6	39.2	0.54	1.33	1	9	16	2	8	9	55
1.36	0.82	17.261	38.8	39.4	0.54	1.34	1	10	16	2	6	9	57
1.38	0.84	17.821	38.9	39.5	0.55	1.36	1	9	16	2	5	9	59
1.4	0.85	18.391	39.1	39.7	0.55	1.37	1	9	16	2	3	9	61
1.42	0.87	18.971	39.2	39.9	0.56	1.38	1	9	16	2	2	8	62
1.44	0.89	19.56	39.4	40	0.56	1.38	1	9	16	2	2	7	64
1.46	0.9	20.16	39.5	40.2	0.56	1.4	1	9	16	2	2	5	66
1.48	0.92	20.769	39.7	40.3	0.57	1.41	0	8	16	2	2	5	68
1.5	0.94	21.388	39.8	40.5	0.57	1.43	0	7	17	1	1	4	69

Hydraulic parameter							Percentage of width occupied by fish hydraulic habitat						
Maximum Depth (m)	Average Depth (m)	Discharge (m3/s)	Width (m)	Wetted perimeter (m)	Average velocity (m/s)	Velocity 98% (m/s)	SVS	SS	SD	FVS	FS	FI	FD
1.52	0.95	22.017	39.9	40.6	0.58	1.43	0	7	17	1	1	2	70
1.54	0.97	22.656	40.1	40.8	0.58	1.44	0	6	18	1	1	1	71
1.56	0.99	23.305	40.2	41	0.59	1.46	0	6	18	1	1	1	72
1.58	1	23.964	40.4	41.1	0.59	1.47	0	5	18	1	1	1	73
1.6	1.02	24.632	40.5	41.2	0.6	1.47	0	5	19	1	1	1	73
1.62	1.04	25.311	40.5	41.3	0.6	1.48	0	4	19	1	1	1	73
1.64	1.06	26	40.6	41.4	0.61	1.5	0	4	19	1	1	1	73
1.66	1.08	26.699	40.7	41.4	0.61	1.5	0	3	20	0	1	1	74
1.68	1.09	27.408	40.7	41.5	0.61	1.51	0	3	20	0	1	1	74
1.7	1.11	28.127	40.8	41.6	0.62	1.53	0	3	20	0	1	1	75
1.72	1.13	28.856	40.9	41.7	0.62	1.54	0	2	21	0	1	1	75
1.74	1.15	29.595	40.9	41.8	0.63	1.55	0	2	20	0	1	1	76
1.76	1.17	30.345	41	41.8	0.63	1.56	0	2	20	0	1	1	76
1.78	1.18	31.104	41.1	41.9	0.64	1.58	0	2	20	1	1	1	76
1.8	1.2	31.874	41.1	42	0.64	1.59	0	1	20	1	1	1	76
1.82	1.22	32.654	41.2	42.1	0.65	1.61	0	1	20	1	1	1	76
1.84	1.24	33.444	41.3	42.2	0.65	1.62	0	1	20	1	1	1	77
1.86	1.26	34.245	41.3	42.2	0.66	1.63	0	1	20	1	1	1	77
1.88	1.28	35.056	41.4	42.3	0.66	1.64	0	1	20	1	1	1	77
1.9	1.29	35.877	41.4	42.4	0.67	1.65	0	1	20	1	1	1	77
1.92	1.31	36.709	41.5	42.4	0.67	1.67	0	1	19	1	1	1	78
1.94	1.33	37.551	41.5	42.5	0.68	1.67	0	1	19	1	1	1	78
1.96	1.35	38.403	41.6	42.6	0.68	1.68	0	1	19	1	1	1	78
1.98	1.37	39.266	41.6	42.6	0.69	1.68	0	1	19	0	0	1	79
2	1.39	40.139	41.7	42.7	0.69	1.69	0	1	19	0	0	1	79
2.02	1.4	41.022	41.8	42.8	0.7	1.71	0	1	19	0	0	1	79

Hydraulic parameter							Percentage of width occupied by fish hydraulic habitat						
Maximum Depth (m)	Average Depth (m)	Discharge (m3/s)	Width (m)	Wetted perimeter (m)	Average velocity (m/s)	Velocity 98% (m/s)	SVS	SS	SD	FVS	FS	FI	FD
2.04	1.42	41.916	41.8	42.8	0.71	1.73	0	1	19	1	1	1	79
2.06	1.44	42.821	41.9	42.9	0.71	1.75	0	1	19	1	1	1	79
2.08	1.46	43.736	41.9	43	0.72	1.74	0	1	19	0	0	1	80
2.1	1.48	44.661	42	43	0.72	1.76	0	1	19	0	0	1	80
2.12	1.49	45.597	42	43.1	0.73	1.77	0	1	18	1	1	1	80
2.14	1.51	46.544	42.1	43.2	0.73	1.78	0	1	18	1	1	1	80
2.16	1.53	47.501	42.2	43.3	0.74	1.79	0	1	18	1	1	1	80
2.18	1.55	48.468	42.2	43.3	0.74	1.78	0	0	18	0	0	1	81
2.2	1.57	49.447	42.3	43.4	0.75	1.8	0	0	18	0	0	1	81
2.22	1.58	50.436	42.3	43.5	0.75	1.83	0	0	17	1	1	1	80
2.24	1.6	51.435	42.4	43.5	0.76	1.84	0	0	17	1	1	1	80
2.26	1.62	52.445	42.4	43.6	0.76	1.84	0	0	17	0	0	1	81
2.28	1.64	53.466	42.5	43.7	0.77	1.85	0	0	17	0	0	1	82
2.3	1.65	54.498	42.6	43.7	0.77	1.87	0	0	17	1	1	1	81
2.32	1.67	55.54	42.6	43.8	0.78	1.88	0	0	17	1	1	1	81
2.34	1.69	56.593	42.7	43.9	0.78	1.89	0	0	16	1	1	1	81
2.36	1.71	57.657	42.7	43.9	0.79	1.88	0	0	17	0	0	1	82
2.38	1.73	58.732	42.8	44	0.8	1.9	0	0	16	0	0	1	82
2.4	1.74	59.817	42.8	44.1	0.8	1.91	0	0	16	0	0	1	82
2.42	1.76	60.913	42.9	44.2	0.81	1.94	0	0	16	1	1	1	81
2.44	1.78	62.02	43	44.2	0.81	1.96	0	0	16	1	1	1	81
2.46	1.8	63.138	43	44.3	0.82	1.95	0	0	16	0	0	1	82
2.48	1.81	64.267	43.1	44.4	0.82	1.96	0	0	16	0	0	1	82
2.5	1.83	65.406	43.1	44.4	0.83	1.97	0	0	16	0	0	1	83
2.52	1.85	66.557	43.2	44.5	0.83	2	0	0	15	0	1	1	82
2.54	1.87	67.718	43.2	44.6	0.84	1.99	0	0	15	0	0	1	83

Hydraulic parameter							Percentage of width occupied by fish hydraulic habitat						
Maximum Depth (m)	Average Depth (m)	Discharge (m3/s)	Width (m)	Wetted perimeter (m)	Average velocity (m/s)	Velocity 98% (m/s)	SVS	SS	SD	FVS	FS	FI	FD
2.56	1.88	68.89	43.3	44.6	0.84	1.99	0	0	15	0	0	1	83
2.58	1.9	70.073	43.3	44.7	0.85	2	0	0	15	0	0	1	83
2.6	1.92	71.267	43.4	44.8	0.86	2.03	0	0	15	0	1	1	83
2.62	1.94	72.473	43.5	44.9	0.86	2.04	0	0	15	0	1	1	83
2.64	1.95	73.689	43.5	44.9	0.87	2.03	0	0	15	0	0	1	84
2.66	1.97	74.916	43.6	45	0.87	2.04	0	0	15	0	0	1	84
2.68	1.99	76.154	43.6	45.1	0.88	2.08	0	0	14	0	1	1	83
2.7	2.01	77.403	43.7	45.1	0.88	2.09	0	0	14	0	1	1	83
2.72	2.02	78.663	43.7	45.2	0.89	2.11	0	0	14	0	1	1	84
2.74	2.04	79.934	43.8	45.3	0.89	2.09	0	0	14	0	0	1	85
2.76	2.06	81.216	43.9	45.3	0.9	2.11	0	0	14	0	0	1	85
2.78	2.08	82.51	43.9	45.4	0.91	2.13	0	0	14	0	1	1	84
2.8	2.09	83.814	44	45.5	0.91	2.14	0	0	14	0	1	1	84
2.82	2.11	85.13	44	45.5	0.92	2.15	0	0	13	0	0	1	84
2.84	2.13	86.456	44.1	45.6	0.92	2.13	0	0	14	0	0	1	85
2.86	2.14	87.794	44.1	45.7	0.93	2.16	0	0	13	0	0	1	85
2.88	2.16	89.143	44.2	45.8	0.93	2.18	0	0	13	0	0	1	85
2.9	2.18	90.503	44.3	45.8	0.94	2.19	0	0	13	0	0	1	85
2.92	2.2	91.875	44.3	45.9	0.94	2.18	0	0	13	0	0	1	86
2.94	2.21	93.257	44.4	46	0.95	2.2	0	0	13	0	0	1	86
2.96	2.23	94.651	44.4	46	0.95	2.24	0	0	13	0	0	1	85
2.98	2.25	96.056	44.5	46.1	0.96	2.25	0	0	13	0	0	1	85
3	2.27	97.473	44.5	46.2	0.97	2.26	0	0	12	0	0	1	85
3.02	2.28	98.9	44.6	46.2	0.97	2.24	0	0	13	0	0	1	86
3.04	2.3	100.339	44.7	46.4	0.98	2.27	0	0	12	0	0	1	86
3.06	2.31	101.789	44.9	46.5	0.98	2.26	0	0	12	0	0	1	87

Hydraulic parameter							Percentage of width occupied by fish hydraulic habitat						
Maximum Depth (m)	Average Depth (m)	Discharge (m3/s)	Width (m)	Wetted perimeter (m)	Average velocity (m/s)	Velocity 98% (m/s)	SVS	SS	SD	FVS	FS	FI	FD
3.08	2.32	103.25	45	46.7	0.99	2.28	0	0	12	0	0	1	86
3.1	2.33	104.723	45.2	46.8	0.99	2.29	0	0	12	1	1	0	85
3.12	2.35	106.207	45.3	47	1	2.28	0	0	12	1	1	0	86
3.14	2.36	107.703	45.5	47.2	1	2.3	0	0	12	1	1	0	85
3.16	2.37	109.21	45.6	47.3	1.01	2.29	0	0	12	1	1	1	85
3.18	2.38	110.728	45.8	47.5	1.02	2.33	0	0	11	1	1	1	85
3.2	2.39	112.257	45.9	47.6	1.02	2.32	0	0	12	1	1	1	85
3.22	2.41	113.798	46.1	47.8	1.03	2.37	0	0	11	1	1	1	85
3.24	2.42	115.351	46.2	47.9	1.03	2.36	0	0	11	1	1	1	86
3.26	2.43	116.914	46.4	48.1	1.04	2.37	0	0	11	1	1	1	86
3.28	2.44	118.49	46.5	48.3	1.04	2.4	0	0	11	1	1	1	85
3.3	2.45	120.076	46.7	48.4	1.05	2.38	0	0	11	1	1	1	86
3.32	2.46	121.674	46.9	48.6	1.05	2.41	0	0	11	1	1	1	85
3.34	2.48	123.284	47	48.7	1.06	2.42	0	1	11	1	1	1	85
3.36	2.49	124.905	47.2	48.9	1.06	2.41	0	0	11	1	1	1	86
3.38	2.5	126.538	47.3	49.1	1.07	2.43	0	1	10	1	1	1	85
3.4	2.51	128.182	47.5	49.2	1.07	2.42	0	1	10	1	1	1	86
3.42	2.52	129.838	47.6	49.4	1.08	2.45	0	1	10	1	1	1	85
3.44	2.54	131.505	47.8	49.5	1.09	2.46	0	1	10	1	1	1	85
3.46	2.55	133.184	47.9	49.7	1.09	2.43	0	1	10	1	1	1	86
3.48	2.56	134.874	48.1	49.8	1.1	2.46	0	1	10	1	1	1	85
3.5	2.57	136.576	48.2	50	1.1	2.45	0	1	10	1	1	1	86
3.52	2.58	138.289	48.4	50.2	1.11	2.49	0	1	10	1	1	1	86
3.54	2.6	140.015	48.5	50.3	1.11	2.5	0	1	10	1	1	1	87
3.56	2.61	141.751	48.7	50.5	1.12	2.53	0	1	10	1	1	1	86
3.58	2.62	143.5	48.9	50.6	1.12	2.52	0	1	10	1	1	1	87

Hydraulic parameter							Percentage of width occupied by fish hydraulic habitat						
Maximum Depth (m)	Average Depth (m)	Discharge (m3/s)	Width (m)	Wetted perimeter (m)	Average velocity (m/s)	Velocity 98% (m/s)	SVS	SS	SD	FVS	FS	FI	FD
3.6	2.63	145.26	49	50.8	1.13	2.53	0	1	10	1	1	1	87
3.62	2.64	147.031	49.2	51	1.13	2.53	0	1	10	1	1	1	87
3.64	2.65	148.815	49.4	51.2	1.14	2.53	0	1	10	1	1	1	87
3.66	2.66	150.61	49.5	51.3	1.14	2.55	0	1	10	1	1	1	87
3.68	2.67	152.417	49.7	51.5	1.15	2.58	0	1	9	1	1	1	86
3.7	2.69	154.235	49.9	51.7	1.15	2.57	0	1	9	1	1	1	86
3.72	2.7	156.065	50	51.8	1.16	2.57	0	1	9	1	1	1	86
3.74	2.71	157.907	50.2	52	1.16	2.6	0	1	9	2	2	1	85
3.76	2.72	159.761	50.4	52.2	1.17	2.6	0	1	9	2	2	1	85
3.78	2.73	161.626	50.5	52.4	1.17	2.61	0	1	9	2	2	1	85
3.8	2.74	163.503	50.7	52.5	1.18	2.59	0	1	9	1	1	1	86
3.82	2.75	165.392	50.9	52.7	1.18	2.62	0	1	9	2	2	2	85
3.84	2.76	167.293	51	52.9	1.19	2.63	0	1	9	2	2	2	85
3.86	2.77	169.205	51.2	53.1	1.19	2.6	0	1	9	1	1	1	86
3.88	2.78	171.13	51.4	53.2	1.2	2.61	0	1	9	1	1	1	86
3.9	2.79	173.066	51.6	53.4	1.2	2.68	0	1	9	2	2	2	85
3.92	2.8	175.014	51.8	53.6	1.21	2.69	0	1	9	2	2	2	86
3.94	2.81	176.974	52	53.8	1.21	2.67	0	1	9	1	1	1	86
3.96	2.82	178.945	52.2	54	1.22	2.68	0	1	9	1	1	1	87
3.98	2.83	180.929	52.4	54.2	1.22	2.71	0	1	8	2	2	2	86
4	2.84	182.924	52.6	54.4	1.23	2.72	0	1	8	2	2	2	86
4.02	2.85	184.932	52.7	54.6	1.23	2.72	0	1	8	2	2	2	86
4.04	2.86	186.951	52.9	54.8	1.24	2.73	0	1	8	2	2	2	86
4.06	2.87	188.982	53.1	55	1.24	2.74	0	1	8	2	2	2	86
4.08	2.88	191.025	53.3	55.2	1.24	2.72	0	1	8	1	1	1	87
4.1	2.89	193.08	53.5	55.4	1.25	2.72	0	1	8	1	1	1	87

Hydraulic parameter							Percentage of width occupied by fish hydraulic habitat						
Maximum Depth (m)	Average Depth (m)	Discharge (m3/s)	Width (m)	Wetted perimeter (m)	Average velocity (m/s)	Velocity 98% (m/s)	SVS	SS	SD	FVS	FS	FI	FD
4.12	2.9	195.147	53.7	55.6	1.25	2.75	0	1	8	2	2	2	86
4.14	2.91	197.226	53.9	55.8	1.26	2.76	0	1	8	2	2	2	86
4.16	2.92	199.317	54.1	56	1.26	2.77	0	1	8	2	2	2	86
4.18	2.93	201.419	54.3	56.2	1.27	2.75	0	1	8	1	1	1	87
4.2	2.93	203.534	54.5	56.4	1.27	2.78	0	1	8	2	2	2	87
4.22	2.94	205.661	54.7	56.6	1.28	2.78	0	1	8	2	2	2	87
4.24	2.95	207.8	54.9	56.8	1.28	2.76	0	1	8	1	1	1	87
4.26	2.96	209.951	55.1	57	1.29	2.77	0	1	8	1	1	1	87
4.28	2.97	212.114	55.3	57.2	1.29	2.8	0	1	8	2	2	2	87
4.3	2.98	214.288	55.5	57.4	1.3	2.78	0	1	8	1	1	1	88
4.32	2.99	216.475	55.6	57.6	1.3	2.81	0	1	8	2	2	2	87
4.34	3	218.674	55.8	57.8	1.3	2.83	0	1	8	1	1	1	88
4.36	3.01	220.886	56	58	1.31	2.86	0	1	8	2	2	2	87
4.38	3.02	223.109	56.2	58.2	1.31	2.86	0	1	8	2	2	2	87
4.4	3.03	225.344	56.4	58.4	1.32	2.84	0	1	8	1	1	1	88
4.42	3.04	227.591	56.6	58.6	1.32	2.86	0	1	8	1	1	1	88
4.44	3.05	229.851	56.8	58.8	1.33	2.89	0	1	8	2	2	2	87
4.46	3.06	232.123	57	59	1.33	2.86	0	0	8	1	1	1	88
4.48	3.07	234.406	57.2	59.2	1.34	2.9	0	1	7	2	2	2	87
4.5	3.08	236.702	57.4	59.4	1.34	2.87	0	0	8	1	1	1	88
4.52	3.09	239.01	57.6	59.6	1.34	2.91	0	1	7	2	2	2	87
4.54	3.1	241.331	57.8	59.8	1.35	2.91	0	1	7	2	2	2	87
4.56	3.11	243.663	58	60	1.35	2.89	0	0	7	1	1	1	88
4.58	3.12	246.008	58.2	60.2	1.36	2.9	0	0	7	1	1	1	88
4.6	3.13	248.364	58.4	60.4	1.36	2.9	0	0	7	1	1	1	88
4.62	3.14	250.733	58.6	60.6	1.37	2.91	0	0	7	1	1	1	89

Hydraulic parameter							Percentage of width occupied by fish hydraulic habitat						
Maximum Depth (m)	Average Depth (m)	Discharge (m3/s)	Width (m)	Wetted perimeter (m)	Average velocity (m/s)	Velocity 98% (m/s)	SVS	SS	SD	FVS	FS	FI	FD
4.64	3.14	253.115	58.8	60.8	1.37	2.95	0	0	7	1	1	1	88
4.66	3.15	255.508	59.1	61.1	1.37	2.93	0	0	7	1	1	1	89
4.68	3.15	257.914	59.4	61.4	1.38	2.93	0	0	7	1	1	1	89
4.7	3.16	260.332	59.7	61.7	1.38	2.96	0	1	7	1	1	1	88
4.72	3.16	262.762	59.9	62	1.39	2.93	0	0	7	1	1	1	88
4.74	3.17	265.204	60.2	62.3	1.39	2.96	0	1	7	2	2	2	87
4.76	3.17	267.659	60.5	62.6	1.39	2.95	0	0	7	1	1	1	88
4.78	3.18	270.126	60.8	62.8	1.4	2.95	0	0	7	1	1	1	88
4.8	3.18	272.605	61.1	63.1	1.4	2.96	0	0	7	1	1	1	88
4.82	3.19	275.097	61.4	63.4	1.41	2.98	0	1	7	2	2	2	87
4.84	3.19	277.601	61.7	63.7	1.41	2.99	0	1	7	2	2	2	87
4.86	3.2	280.117	61.9	63.9	1.41	2.96	0	0	7	1	1	1	88
4.88	3.21	282.646	62.1	64.1	1.42	3.01	0	1	7	2	2	2	88
4.9	3.22	285.187	62.3	64.3	1.42	3.02	0	1	7	2	2	2	88
4.92	3.23	287.74	62.5	64.5	1.43	3.03	0	1	7	2	2	2	88
4.94	3.24	290.306	62.7	64.8	1.43	3.07	0	1	7	2	2	2	88
4.96	3.25	292.884	62.9	65	1.43	3.04	0	0	7	1	1	1	88
4.98	3.26	295.474	63.1	65.2	1.44	3.05	0	0	7	1	1	1	89
5	3.27	298.077	63.3	65.4	1.44	3.06	0	0	7	1	1	1	89

8.2.2 Limpopo River at Spanwerk (From Monograph)

Hydraulic parameter							Percentage of width occupied by fish hydraulic habitat						
Maximum Depth (m)	Average Depth (m)	Discharge (m3/s)	Width (m)	Wetted perimeter (m)	Average velocity (m/s)	Velocity 98% (m/s)	SVS	SS	SD	FVS	FS	FI	FD
0.6	0.27	0.002	63.1	63.3	0.00	0.00	26	58	15	0	0	0	0

Hydraulic parameter							Percentage of width occupied by fish hydraulic habitat						
Maximum Depth (m)	Average Depth (m)	Discharge (m3/s)	Width (m)	Wetted perimeter (m)	Average velocity (m/s)	Velocity 98% (m/s)	SVS	SS	SD	FVS	FS	FI	FD
0.7	0.30	0.252	80.0	80.2	0.01	0.04	22	56	22	0	0	0	0
0.8	0.35	1.409	95.7	96.0	0.04	0.16	19	50	31	0	0	0	0
0.9	0.42	4.084	101.9	102.4	0.09	0.34	7	53	35	0	1	1	3
1.0	0.51	8.844	105.4	106.2	0.17	0.56	2	44	39	0	1	2	12
1.1	0.59	16.223	108.9	109.9	0.25	0.84	2	27	36	1	1	2	30
1.2	0.67	26.739	112.5	113.7	0.36	1.11	1	12	35	1	2	2	48
1.3	0.75	40.892	115.9	117.3	0.47	1.41	1	5	29	2	2	2	60
1.4	0.80	59.170	122.3	124.0	0.60	1.66	2	3	22	5	1	3	65
1.5	0.86	82.049	128.8	130.6	0.74	1.87	1	3	16	4	3	2	72
1.6	0.94	109.997	131.4	133.4	0.89	2.04	0	2	12	1	5	3	77
1.7	1.02	143.473	134.0	136.1	1.04	2.29	0	1	9	2	1	5	81
0.6	0.27	0.002	63.1	63.3	0.00	0.00	26	58	15	0	0	0	0
0.7	0.30	0.252	80.0	80.2	0.01	0.04	22	56	22	0	0	0	0
0.8	0.35	1.409	95.7	96.0	0.04	0.16	19	50	31	0	0	0	0
0.9	0.42	4.084	101.9	102.4	0.09	0.34	7	53	35	0	1	1	3
1.0	0.51	8.844	105.4	106.2	0.17	0.56	2	44	39	0	1	2	12
1.1	0.59	16.223	108.9	109.9	0.25	0.84	2	27	36	1	1	2	30
1.2	0.67	26.739	112.5	113.7	0.36	1.11	1	12	35	1	2	2	48
1.3	0.75	40.892	115.9	117.3	0.47	1.41	1	5	29	2	2	2	60
1.4	0.80	59.170	122.3	124.0	0.60	1.66	2	3	22	5	1	3	65
1.5	0.86	82.049	128.8	130.6	0.74	1.87	1	3	16	4	3	2	72
1.6	0.94	109.997	131.4	133.4	0.89	2.04	0	2	12	1	5	3	77
1.7	1.02	143.473	134.0	136.1	1.04	2.29	0	1	9	2	1	5	81

8.2.3 Matlabas

Hydraulic parameter							Percentage of width occupied by fish hydraulic habitat						
Maximum Depth (m)	Average Depth (m)	Discharge (m3/s)	Width (m)	Wetted perimeter (m)	Average velocity (m/s)	Velocity 98% (m/s)	SVS	SS	SD	FVS	FS	FI	FD
0.02	0.01	0	0.4	0.4	0.03	0.1	100	0	0	0	0	0	0
0.04	0.02	0.001	1.1	1.1	0.04	0.14	100	0	0	0	0	0	0
0.06	0.02	0.003	2.4	2.4	0.05	0.17	100	0	0	0	0	0	0
0.08	0.03	0.007	3.4	3.4	0.07	0.23	100	0	0	0	0	0	0
0.1	0.04	0.016	4.2	4.2	0.09	0.29	97	0	0	2	0	0	0
0.12	0.06	0.03	4.4	4.4	0.11	0.37	85	9	0	5	1	0	0
0.14	0.08	0.049	4.6	4.6	0.13	0.45	69	22	0	7	2	0	0
0.16	0.1	0.073	4.7	4.8	0.16	0.53	43	44	0	7	7	0	0
0.18	0.11	0.102	4.9	4.9	0.18	0.6	25	58	0	5	12	0	0
0.2	0.13	0.137	5.1	5.1	0.21	0.67	15	62	0	4	19	0	0
0.22	0.14	0.179	5.2	5.3	0.24	0.74	11	59	0	5	23	3	0
0.24	0.16	0.239	5.4	5.5	0.28	0.83	8	52	0	5	26	8	0
0.26	0.18	0.292	5.4	5.5	0.3	0.88	7	47	0	6	20	19	0
0.28	0.2	0.351	5.5	5.6	0.32	0.92	5	45	0	5	14	31	0
0.3	0.21	0.416	5.6	5.7	0.35	0.96	4	41	0	5	9	39	1
0.32	0.23	0.489	5.7	5.9	0.37	0.99	3	39	0	4	8	41	5
0.34	0.24	0.568	5.9	6	0.4	1.03	3	36	0	5	8	38	11
0.36	0.26	0.655	6.000	6.2	0.43	1.08	4	31	0	7	8	26	25
0.38	0.27	0.749	6.2	6.3	0.45	1.1	3	29	0	7	7	17	38
0.4	0.28	0.85	6.3	6.5	0.48	1.14	3	26	0	8	6	11	46
0.42	0.3	0.96	6.4	6.6	0.5	1.17	3	25	0	8	6	9	50
0.44	0.31	1.077	6.6	6.7	0.53	1.2	3	23	0	8	5	10	52
0.46	0.32	1.203	6.7	6.9	0.55	1.23	2	22	0	7	6	8	54

Hydraulic parameter							Percentage of width occupied by fish hydraulic habitat						
Maximum Depth (m)	Average Depth (m)	Discharge (m3/s)	Width (m)	Wetted perimeter (m)	Average velocity (m/s)	Velocity 98% (m/s)	SVS	SS	SD	FVS	FS	FI	FD
0.48	0.34	1.337	6.9	7	0.58	1.27	2	20	0	8	7	8	55
0.5	0.35	1.479	7	7.2	0.6	1.31	2	19	0	7	8	6	58
0.52	0.36	1.631	7.1	7.3	0.63	1.35	2	16	1	8	8	6	59
0.54	0.35	1.791	7.8	8	0.65	1.37	3	12	3	13	8	5	56
0.56	0.32	1.96	9.2	9.4	0.67	1.41	5	8	4	22	7	5	49
0.58	0.32	2.138	9.5	9.7	0.69	1.45	5	6	6	24	6	6	48
0.6	0.33	2.326	9.9	10.1	0.71	1.47	5	5	6	25	5	6	48
0.62	0.34	2.523	10.3	10.6	0.72	1.49	4	4	6	24	7	6	48
0.64	0.34	2.73	10.8	11	0.74	1.51	3	5	6	20	14	5	47
0.66	0.35	2.946	11.2	11.4	0.75	1.53	3	5	6	17	17	5	47
0.68	0.36	3.173	11.6	11.9	0.76	1.57	3	5	5	17	19	5	46
0.7	0.36	3.409	12.1	12.4	0.78	1.58	2	5	5	16	21	5	45
0.72	0.37	3.656	12.6	12.9	0.79	1.62	2	5	5	16	22	5	44
0.74	0.37	3.913	13.1	13.4	0.8	1.63	2	5	5	16	20	8	44
0.76	0.38	4.181	13.6	14	0.81	1.65	2	5	5	16	15	14	44
0.78	0.38	4.46	14.1	14.5	0.82	1.66	2	5	4	15	14	16	43
0.8	0.39	4.749	14.7	15	0.83	1.69	2	5	4	16	13	17	43
0.82	0.4	5.049	15	15.4	0.84	1.7	2	5	4	14	14	16	45
0.84	0.41	5.36	15.3	15.7	0.85	1.73	2	5	4	13	14	13	49
0.86	0.43	5.682	15.6	16	0.86	1.72	1	5	4	10	14	13	52
0.88	0.44	6.016	15.9	16.3	0.87	1.77	1	5	4	10	14	12	53
0.9	0.45	6.361	16.2	16.6	0.87	1.77	1	5	4	8	13	13	55
0.92	0.45	6.717	16.8	17.2	0.88	1.79	1	5	4	10	13	12	56
0.94	0.45	7.086	17.6	18	0.89	1.79	1	5	4	11	12	11	55
0.96	0.45	7.466	18.4	18.8	0.9	1.81	1	5	4	13	11	11	56
0.98	0.45	7.857	19.2	19.7	0.91	1.82	2	5	4	14	9	12	56

Hydraulic parameter							Percentage of width occupied by fish hydraulic habitat						
Maximum Depth (m)	Average Depth (m)	Discharge (m3/s)	Width (m)	Wetted perimeter (m)	Average velocity (m/s)	Velocity 98% (m/s)	SVS	SS	SD	FVS	FS	FI	FD
1	0.45	8.261	20	20.5	0.91	1.85	2	5	3	15	9	11	55
1.02	0.45	8.677	20.8	21.3	0.92	1.86	2	5	3	16	10	10	55
1.04	0.46	9.106	21.7	22.3	0.92	1.87	2	4	4	16	10	9	55
1.06	0.46	9.547	22.7	23.2	0.92	1.87	2	4	4	16	11	9	54
1.08	0.45	10	24.1	24.6	0.92	1.87	2	4	4	19	11	7	53
1.1	0.44	10.466	25.6	26.2	0.92	1.87	2	4	4	20	12	6	52
1.12	0.44	10.944	27.2	27.7	0.92	1.86	2	4	4	21	13	6	50
1.14	0.43	11.435	28.7	29.3	0.92	1.88	2	4	4	22	12	7	49
1.16	0.43	11.94	30.3	30.8	0.92	1.84	2	4	4	20	16	8	47
1.18	0.43	12.457	31.8	32.4	0.92	1.81	2	4	4	18	15	10	47
1.2	0.43	12.988	33.4	34	0.91	1.81	2	4	4	19	15	10	46
1.22	0.43	13.531	34.6	35.2	0.91	1.83	2	4	4	20	16	9	45
1.24	0.44	14.089	35.8	36.5	0.9	1.79	2	5	4	17	17	11	45
1.26	0.41	14.659	39.6	40.2	0.89	1.8	2	4	3	21	17	10	42
1.28	0.43	15.243	40.4	41	0.89	1.78	2	4	4	19	17	12	43
1.3	0.44	15.841	41.2	41.8	0.88	1.76	2	5	4	17	17	12	44
1.32	0.45	16.453	42.1	42.8	0.87	1.78	2	5	4	17	15	14	44
1.34	0.46	17.078	42.8	43.5	0.87	1.76	1	5	4	12	18	14	46
1.36	0.47	17.718	43.4	44	0.86	1.76	1	6	4	10	17	15	48
1.38	0.49	18.372	43.9	44.6	0.86	1.72	1	6	4	7	16	16	50
1.4	0.5	19.039	44.8	45.4	0.85	1.73	1	6	4	7	17	13	52
1.42	0.51	19.721	45.9	46.5	0.85	1.71	1	6	4	6	15	15	53
1.44	0.51	20.418	47	47.6	0.85	1.7	1	6	4	7	11	15	55
1.46	0.52	21.129	48.3	49	0.84	1.69	1	6	4	10	6	17	56
1.48	0.52	21.854	50.1	50.8	0.84	1.71	1	6	4	11	6	15	56
1.5	0.52	22.595	51.9	52.6	0.83	1.7	2	6	5	12	5	14	57

Hydraulic parameter							Percentage of width occupied by fish hydraulic habitat						
Maximum Depth (m)	Average Depth (m)	Discharge (m3/s)	Width (m)	Wetted perimeter (m)	Average velocity (m/s)	Velocity 98% (m/s)	SVS	SS	SD	FVS	FS	FI	FD
1.52	0.52	23.349	53.9	54.6	0.83	1.68	2	6	5	11	7	13	57
1.54	0.52	24.119	56	56.7	0.82	1.68	2	5	5	14	6	11	57
1.56	0.52	24.904	58.1	58.8	0.82	1.68	2	5	5	15	7	10	56
1.58	0.53	25.704	60.2	60.9	0.81	1.65	2	6	5	13	9	6	59
1.6	0.53	26.519	62.2	63	0.81	1.66	2	5	5	14	10	6	57
1.62	0.53	27.349	64.3	65.1	0.8	1.63	2	5	6	14	11	6	57
1.64	0.53	28.194	66.4	67.2	0.8	1.65	2	6	6	13	13	6	55
1.66	0.54	29.055	68.5	69.2	0.79	1.63	2	6	6	12	12	7	56
1.68	0.54	29.932	70.6	71.3	0.78	1.62	2	6	6	12	12	7	55
1.7	0.54	30.824	72.7	73.4	0.78	1.61	2	6	6	11	12	8	55
1.72	0.55	31.731	74.7	75.4	0.77	1.58	2	6	7	10	12	9	55
1.74	0.56	32.655	76.1	76.8	0.77	1.58	2	6	7	10	13	9	54
1.76	0.57	33.594	77.4	78.2	0.76	1.59	2	6	7	9	12	10	54
1.78	0.56	34.549	82.3	83	0.76	1.56	2	6	7	11	11	9	53
1.8	0.54	35.521	87.3	88.1	0.75	1.56	2	6	7	13	11	9	51
1.82	0.55	36.508	90	90.8	0.74	1.52	2	6	7	13	10	9	53
1.84	0.56	37.512	91.3	92	0.74	1.54	2	6	7	13	10	9	52
1.86	0.57	38.532	92.5	93.3	0.73	1.55	2	6	7	12	10	10	52
1.88	0.58	39.568	93.8	94.5	0.72	1.54	2	6	7	12	10	9	54
1.9	0.6	40.621	95	95.8	0.72	1.52	2	7	8	9	10	10	55
1.92	0.61	41.69	96.2	97	0.71	1.52	2	7	8	8	10	10	55
1.94	0.62	42.776	97.5	98.3	0.71	1.49	1	8	8	4	10	11	57
1.96	0.63	43.879	98.7	99.5	0.7	1.52	1	8	8	5	10	11	57
1.98	0.64	44.998	100	100.7	0.7	1.5	1	8	9	4	9	10	60
2	0.66	46.134	101.2	102	0.69	1.52	1	7	9	6	8	9	59
2.02	0.67	47.288	102.5	103.2	0.69	1.53	1	7	9	5	8	9	60

Hydraulic parameter							Percentage of width occupied by fish hydraulic habitat						
Maximum Depth (m)	Average Depth (m)	Discharge (m3/s)	Width (m)	Wetted perimeter (m)	Average velocity (m/s)	Velocity 98% (m/s)	SVS	SS	SD	FVS	FS	FI	FD
2.04	0.68	48.458	103.7	104.5	0.69	1.52	1	7	10	5	7	9	62
2.06	0.69	49.645	104.9	105.7	0.68	1.5	1	7	10	5	6	8	63
2.08	0.7	50.85	106.2	107	0.68	1.51	1	7	11	5	5	6	65
2.1	0.72	52.072	107.4	108.2	0.68	1.5	1	7	11	5	4	5	67
2.12	0.73	53.311	108.7	109.5	0.68	1.51	1	7	11	5	5	5	67
2.14	0.74	54.568	109.9	110.7	0.67	1.5	1	7	12	5	4	5	67
2.16	0.75	55.842	111.2	112	0.67	1.51	1	6	12	4	4	5	67
2.18	0.76	57.134	112.4	113.2	0.67	1.5	1	6	12	4	4	5	68
2.2	0.77	58.443	113.6	114.4	0.67	1.52	1	6	12	5	5	4	67
2.22	0.79	59.771	114.2	115	0.66	1.5	1	5	13	4	4	4	68
2.24	0.81	61.116	114.7	115.5	0.66	1.5	1	5	14	4	4	4	69
2.26	0.82	62.479	115.3	116.1	0.66	1.51	1	5	14	4	4	4	69
2.28	0.84	63.86	115.8	116.6	0.66	1.51	1	5	15	3	3	4	69
2.3	0.85	65.259	116.3	117.2	0.66	1.53	1	5	15	3	3	4	70

8.2.4 Lephalala

Hydraulic parameter							Percentage of width occupied by fish hydraulic habitat						
Maximum Depth (m)	Average Depth (m)	Discharge (m3/s)	Width (m)	Wetted perimeter (m)	Average velocity (m/s)	Velocity 98% (m/s)	SVS	SS	SD	FVS	FS	FI	FD
0.02	0.01	0	0.2	0.2	0.02	0.07	100	0	0	0	0	0	0
0.04	0.02	0	0.5	0.5	0.03	0.11	100	0	0	0	0	0	0
0.06	0.03	0.001	0.7	0.7	0.04	0.14	100	0	0	0	0	0	0
0.08	0.04	0.002	1	1	0.05	0.17	100	0	0	0	0	0	0

Hydraulic parameter							Percentage of width occupied by fish hydraulic habitat						
Maximum Depth (m)	Average Depth (m)	Discharge (m3/s)	Width (m)	Wetted perimeter (m)	Average velocity (m/s)	Velocity 98% (m/s)	SVS	SS	SD	FVS	FS	FI	FD
0.1	0.05	0.003	1.2	1.2	0.06	0.2	99	1	0	0	0	0	0
0.12	0.06	0.006	1.4	1.5	0.06	0.23	83	17	0	0	0	0	0
0.14	0.07	0.009	1.7	1.7	0.07	0.25	71	28	0	1	0	0	0
0.16	0.09	0.013	1.8	1.8	0.08	0.29	58	40	0	1	1	0	0
0.18	0.1	0.017	1.9	2	0.09	0.32	48	48	0	2	2	0	0
0.2	0.08	0.02	2.8	2.9	0.08	0.29	56	42	0	1	1	0	0
0.22	0.08	0.024	3.9	3.9	0.08	0.28	61	37	0	1	1	0	0
0.24	0.08	0.032	4.7	4.8	0.08	0.29	63	35	0	1	1	0	0
0.26	0.09	0.045	5.2	5.3	0.09	0.32	63	33	0	2	1	0	0
0.28	0.11	0.06	5.6	5.7	0.1	0.34	61	34	0	3	1	1	0
0.3	0.12	0.077	6.1	6.2	0.11	0.37	50	44	0	3	2	1	0
0.32	0.13	0.097	6.5	6.7	0.12	0.39	38	55	0	3	2	1	0
0.34	0.14	0.12	7	7.1	0.12	0.41	32	61	0	2	3	1	0
0.36	0.15	0.146	7.400	7.5	0.13	0.43	28	65	0	2	4	1	1
0.38	0.16	0.175	7.8	8	0.14	0.45	25	66	0	2	4	1	1
0.4	0.17	0.208	8.2	8.4	0.15	0.48	24	67	0	3	4	2	1
0.42	0.19	0.244	8.6	8.8	0.15	0.5	22	67	0	3	3	3	2
0.44	0.2	0.284	9.1	9.3	0.16	0.51	19	69	0	3	3	4	2
0.46	0.21	0.328	9.5	9.7	0.17	0.53	18	69	0	3	3	5	2
0.48	0.22	0.376	9.9	10.1	0.17	0.55	18	68	0	3	3	5	3
0.5	0.23	0.428	10.3	10.6	0.18	0.58	17	67	0	3	4	5	4
0.52	0.24	0.484	10.8	11	0.19	0.6	16	64	2	4	4	5	7
0.54	0.25	0.546	11.2	11.4	0.2	0.62	15	61	4	4	4	4	8
0.56	0.26	0.612	11.6	11.9	0.2	0.63	14	60	5	4	4	4	10
0.58	0.27	0.683	12	12.3	0.21	0.66	13	57	6	4	4	4	11
0.6	0.28	0.76	12.4	12.7	0.22	0.67	13	55	8	4	4	4	12

Hydraulic parameter							Percentage of width occupied by fish hydraulic habitat						
Maximum Depth (m)	Average Depth (m)	Discharge (m3/s)	Width (m)	Wetted perimeter (m)	Average velocity (m/s)	Velocity 98% (m/s)	SVS	SS	SD	FVS	FS	FI	FD
0.62	0.3	0.851	12.6	12.9	0.23	0.7	11	54	8	4	5	4	14
0.64	0.31	0.953	12.7	13	0.24	0.72	7	54	9	3	5	5	17
0.66	0.33	1.061	12.8	13.1	0.25	0.74	5	53	9	3	6	6	19
0.68	0.35	1.174	12.9	13.2	0.26	0.78	5	49	10	3	6	6	22
0.7	0.37	1.294	13	13.3	0.27	0.81	2	45	13	2	6	7	25
0.72	0.38	1.42	13.1	13.4	0.28	0.83	2	40	17	1	6	6	27
0.74	0.4	1.553	13.2	13.5	0.29	0.86	2	35	20	1	5	7	30
0.76	0.42	1.692	13.3	13.6	0.3	0.88	2	31	21	1	4	7	33
0.78	0.44	1.837	13.4	13.7	0.32	0.9	1	28	22	1	3	7	36
0.8	0.45	1.99	13.5	13.8	0.33	0.94	2	25	23	2	2	7	39
0.82	0.47	2.149	13.6	13.9	0.34	0.95	1	23	24	1	2	7	41
0.84	0.49	2.316	13.6	14	0.35	0.99	2	20	24	2	2	6	44
0.86	0.5	2.491	13.7	14.1	0.36	1.01	2	19	24	2	2	5	48
0.88	0.52	2.673	13.8	14.2	0.37	1.04	1	17	24	2	2	3	50
0.9	0.54	2.864	13.9	14.3	0.38	1.06	1	16	24	2	2	3	53
0.92	0.55	3.062	14	14.4	0.4	1.09	1	14	24	2	2	2	55
0.94	0.57	3.268	14.1	14.5	0.41	1.11	1	12	25	2	2	2	57
0.96	0.59	3.482	14.1	14.6	0.42	1.13	1	11	25	1	2	2	58
0.98	0.6	3.684	14.2	14.7	0.43	1.14	1	10	25	1	2	2	59
1	0.62	3.856	14.3	14.8	0.43	1.17	1	9	25	2	2	2	59
1.02	0.64	4.032	14.4	14.9	0.44	1.18	1	8	26	2	2	2	60
1.04	0.65	4.212	14.5	15	0.45	1.18	1	7	27	1	2	2	61
1.06	0.67	4.398	14.6	15.1	0.45	1.19	1	6	27	1	2	2	61
1.08	0.69	4.587	14.6	15.2	0.46	1.22	1	5	26	2	2	2	61
1.1	0.7	4.781	14.7	15.2	0.46	1.23	1	4	27	2	1	2	62
1.12	0.72	4.98	14.8	15.3	0.47	1.24	1	4	27	2	1	2	63

Hydraulic parameter							Percentage of width occupied by fish hydraulic habitat						
Maximum Depth (m)	Average Depth (m)	Discharge (m3/s)	Width (m)	Wetted perimeter (m)	Average velocity (m/s)	Velocity 98% (m/s)	SVS	SS	SD	FVS	FS	FI	FD
1.14	0.73	5.183	14.9	15.4	0.47	1.26	1	3	27	2	1	2	63
1.16	0.75	5.39	15	15.5	0.48	1.27	1	3	26	2	1	1	64
1.18	0.77	5.602	15.1	15.6	0.49	1.28	1	3	26	2	2	1	64
1.2	0.78	5.819	15.2	15.8	0.49	1.29	1	3	26	2	2	2	64
1.22	0.79	6.04	15.3	15.9	0.5	1.31	1	3	26	2	2	2	64
1.24	0.81	6.266	15.4	16.1	0.5	1.32	1	3	25	2	2	2	65
1.26	0.82	6.496	15.5	16.2	0.51	1.32	1	3	25	2	2	2	66
1.28	0.84	6.731	15.6	16.4	0.52	1.35	1	3	24	2	2	2	65
1.3	0.85	6.971	15.7	16.5	0.52	1.35	1	3	24	2	2	2	66
1.32	0.87	7.215	15.8	16.7	0.53	1.38	1	3	24	3	3	2	65
1.34	0.88	7.465	15.9	16.8	0.53	1.38	1	3	24	2	3	3	66
1.36	0.89	7.718	16	17	0.54	1.4	1	3	23	2	3	2	67
1.38	0.91	7.977	16.1	17.1	0.54	1.41	1	3	23	2	2	2	67
1.4	0.92	8.24	16.2	17.3	0.55	1.42	1	3	23	2	2	2	67
1.42	0.94	8.509	16.3	17.4	0.56	1.43	1	3	22	2	2	2	67
1.44	0.95	8.781	16.4	17.6	0.56	1.45	1	3	22	2	3	2	68
1.46	0.96	9.059	16.5	17.7	0.57	1.46	1	3	22	2	4	2	68
1.48	0.98	9.342	16.6	17.9	0.57	1.48	1	3	21	2	3	3	67
1.5	0.99	9.629	16.7	18.1	0.58	1.49	1	3	21	2	2	4	67
1.52	1.01	9.921	16.8	18.2	0.59	1.49	0	3	21	1	3	3	68
1.54	1.02	10.218	16.9	18.4	0.59	1.5	0	3	21	1	3	2	69
1.56	1.03	10.52	17	18.5	0.6	1.53	1	3	20	3	2	3	68
1.58	1.05	10.827	17.2	18.7	0.6	1.54	1	3	20	3	2	3	69
1.6	1.06	11.139	17.3	18.8	0.61	1.55	1	3	20	3	3	2	69
1.62	1.07	11.456	17.4	19	0.61	1.55	0	3	20	1	3	2	70
1.64	1.09	11.778	17.5	19.1	0.62	1.55	0	3	20	1	3	3	70

Hydraulic parameter							Percentage of width occupied by fish hydraulic habitat						
Maximum Depth (m)	Average Depth (m)	Discharge (m3/s)	Width (m)	Wetted perimeter (m)	Average velocity (m/s)	Velocity 98% (m/s)	SVS	SS	SD	FVS	FS	FI	FD
1.66	1.1	12.104	17.6	19.3	0.63	1.56	0	3	19	1	2	3	71
1.68	1.11	12.436	17.7	19.4	0.63	1.57	0	3	19	1	2	3	71
1.7	1.13	12.773	17.8	19.6	0.64	1.58	0	3	19	1	3	3	71
1.72	1.14	13.115	17.9	19.7	0.64	1.58	0	3	19	1	2	3	72
1.74	1.16	13.461	17.9	19.8	0.65	1.6	0	3	19	1	2	2	72
1.76	1.17	13.813	18	19.9	0.65	1.61	0	3	18	1	2	2	73
1.78	1.19	14.17	18.1	19.9	0.66	1.62	0	3	18	1	2	2	73
1.8	1.2	14.532	18.2	20	0.66	1.62	0	3	18	1	2	2	74
1.82	1.22	14.899	18.2	20.1	0.67	1.64	0	2	18	1	2	2	74
1.84	1.23	15.271	18.3	20.2	0.68	1.64	0	2	18	1	2	2	75
1.86	1.25	15.648	18.4	20.3	0.68	1.67	0	2	18	1	2	2	74
1.88	1.26	16.031	18.4	20.4	0.69	1.67	0	2	18	1	2	2	75
1.9	1.28	16.418	18.5	20.4	0.69	1.67	0	2	18	1	2	2	76
1.92	1.29	16.811	18.6	20.5	0.7	1.68	0	2	18	1	2	2	76
1.94	1.31	17.209	18.7	20.6	0.7	1.71	0	2	17	1	2	2	76
1.96	1.32	17.612	18.7	20.7	0.71	1.72	0	2	17	1	2	2	76
1.98	1.34	18.02	18.8	20.8	0.72	1.71	0	2	17	1	1	2	77
2	1.35	18.434	18.9	20.9	0.72	1.73	0	2	17	1	1	2	77
2.02	1.37	18.852	19	20.9	0.73	1.75	0	2	17	1	2	2	77
2.04	1.38	19.276	19	21	0.73	1.77	0	2	17	1	2	2	77
2.06	1.4	19.706	19.1	21.1	0.74	1.78	0	2	16	1	2	2	77
2.08	1.41	20.14	19.2	21.2	0.74	1.77	0	2	17	1	1	2	78
2.1	1.43	20.58	19.2	21.3	0.75	1.77	0	2	16	1	1	2	78
2.12	1.44	21.025	19.3	21.4	0.75	1.81	0	1	16	1	1	2	78
2.14	1.46	21.475	19.4	21.4	0.76	1.81	0	1	16	1	1	2	78
2.16	1.47	21.931	19.5	21.5	0.77	1.83	0	1	16	1	1	2	78

Hydraulic parameter							Percentage of width occupied by fish hydraulic habitat						
Maximum Depth (m)	Average Depth (m)	Discharge (m3/s)	Width (m)	Wetted perimeter (m)	Average velocity (m/s)	Velocity 98% (m/s)	SVS	SS	SD	FVS	FS	FI	FD
2.18	1.49	22.392	19.5	21.6	0.77	1.82	0	1	16	1	1	2	79
2.2	1.5	22.859	19.6	21.7	0.78	1.85	0	1	16	1	1	2	79
2.22	1.51	23.33	19.7	21.8	0.78	1.84	0	1	16	1	1	2	80
2.24	1.53	23.808	19.7	21.9	0.79	1.88	0	1	15	1	1	2	79
2.26	1.53	24.29	20	22.2	0.79	1.86	0	1	15	1	1	2	79
2.28	1.52	24.778	20.4	22.6	0.8	1.88	1	1	14	3	2	2	77
2.3	1.51	25.271	20.8	23	0.8	1.87	1	1	14	3	2	1	77
2.32	1.5	25.77	21.2	23.4	0.81	1.89	1	2	14	4	3	2	75
2.34	1.5	26.274	21.5	23.6	0.81	1.9	1	2	13	5	3	2	74
2.36	1.51	26.784	21.6	23.7	0.82	1.91	1	2	13	5	3	2	75
2.38	1.53	27.299	21.7	23.8	0.82	1.91	1	1	13	5	3	2	75
2.4	1.54	27.82	21.7	23.9	0.83	1.9	1	1	13	4	3	2	75
2.42	1.56	28.346	21.8	24	0.83	1.92	1	2	13	4	3	2	76
2.44	1.57	28.877	21.9	24.1	0.84	1.92	1	2	13	3	3	3	76
2.46	1.59	29.414	21.9	24.2	0.84	1.95	0	2	13	3	3	4	76
2.48	1.6	29.957	22	24.2	0.85	1.94	0	2	13	2	2	4	77
2.5	1.62	30.505	22.1	24.3	0.85	1.97	0	2	13	1	2	5	77
2.52	1.63	31.059	22.2	24.4	0.86	1.99	0	2	13	1	2	5	77
2.54	1.65	31.618	22.2	24.5	0.86	2	0	2	12	1	2	5	77
2.56	1.66	32.183	22.3	24.6	0.87	1.99	0	2	13	1	2	5	78
2.58	1.68	32.753	22.4	24.7	0.87	2	0	2	13	0	2	5	78
2.6	1.69	33.329	22.5	24.7	0.88	2.01	0	2	12	0	1	4	79
2.62	1.71	33.911	22.5	24.8	0.88	2.03	0	2	12	1	2	4	79
2.64	1.72	34.498	22.6	24.9	0.89	2.02	0	2	12	0	1	3	81
2.66	1.73	35.09	22.7	25	0.89	2.02	0	2	12	0	1	3	82
2.68	1.75	35.689	22.7	25.1	0.9	2.05	0	2	12	1	1	2	82

Hydraulic parameter							Percentage of width occupied by fish hydraulic habitat						
Maximum Depth (m)	Average Depth (m)	Discharge (m3/s)	Width (m)	Wetted perimeter (m)	Average velocity (m/s)	Velocity 98% (m/s)	SVS	SS	SD	FVS	FS	FI	FD
2.7	1.76	36.293	22.8	25.2	0.9	2.05	0	1	12	1	1	1	83
2.72	1.78	36.903	22.9	25.2	0.91	2.04	0	1	12	0	1	1	84
2.74	1.79	37.518	23	25.3	0.91	2.06	0	1	12	0	1	1	84
2.76	1.81	38.139	23	25.4	0.92	2.06	0	1	12	0	1	1	84
2.78	1.82	38.766	23.1	25.5	0.92	2.11	0	1	12	1	1	1	83
2.8	1.83	39.398	23.2	25.6	0.93	2.12	0	1	12	1	1	1	84
2.82	1.85	40.036	23.3	25.7	0.93	2.15	0	1	11	1	1	1	83
2.84	1.86	40.68	23.3	25.8	0.94	2.15	0	1	12	1	1	1	83
2.86	1.88	41.329	23.4	25.8	0.94	2.14	0	1	12	1	1	1	84
2.88	1.89	41.985	23.5	25.9	0.95	2.15	0	1	12	1	1	1	84
2.9	1.91	42.646	23.6	26	0.95	2.15	0	1	12	1	1	1	84
2.92	1.92	43.313	23.6	26.1	0.96	2.16	0	1	12	1	1	1	84
2.94	1.93	43.985	23.7	26.2	0.96	2.18	0	1	12	1	1	1	83
2.96	1.95	44.663	23.8	26.3	0.96	2.2	0	1	11	2	2	1	83
2.98	1.96	45.348	23.8	26.3	0.97	2.2	0	1	11	2	2	1	83
3	1.97	46.037	24	26.5	0.97	2.2	0	1	11	2	2	1	83
3.02	1.97	46.733	24.2	26.7	0.98	2.2	0	1	11	2	2	1	83
3.04	1.97	47.435	24.5	27	0.98	2.21	0	1	11	2	2	2	83
3.06	1.97	48.142	24.8	27.3	0.99	2.21	0	1	11	2	2	2	83
3.08	1.96	48.855	25	27.6	0.99	2.23	0	1	11	3	3	1	82
3.1	1.96	49.574	25.3	27.9	1	2.24	0	1	11	3	3	1	82
3.12	1.96	50.299	25.6	28.1	1	2.24	0	1	11	3	3	1	82
3.14	1.96	51.03	25.9	28.4	1.01	2.23	0	1	10	3	3	1	81
3.16	1.96	51.767	26.1	28.7	1.01	2.27	0	1	10	4	4	2	79
3.18	1.96	52.509	26.4	29	1.01	2.25	0	1	10	4	4	2	79
3.2	1.96	53.258	26.7	29.2	1.02	2.27	1	1	10	4	4	2	79

Hydraulic parameter							Percentage of width occupied by fish hydraulic habitat						
Maximum Depth (m)	Average Depth (m)	Discharge (m3/s)	Width (m)	Wetted perimeter (m)	Average velocity (m/s)	Velocity 98% (m/s)	SVS	SS	SD	FVS	FS	FI	FD
3.22	1.96	54.012	26.9	29.5	1.02	2.29	1	1	10	5	5	2	78
3.24	1.96	54.772	27.2	29.8	1.03	2.26	1	1	10	4	4	2	78
3.26	1.96	55.538	27.5	30.1	1.03	2.29	1	1	9	4	4	2	78
3.28	1.96	56.31	27.8	30.3	1.03	2.28	1	1	9	4	4	2	78
3.3	1.95	57.088	28.2	30.8	1.04	2.3	1	1	9	5	5	3	77
3.32	1.92	57.872	29	31.6	1.04	2.3	1	2	9	5	5	3	76
3.34	1.89	58.662	29.8	32.4	1.04	2.26	1	2	9	5	5	3	75
3.36	1.86	59.458	30.6	33.2	1.05	2.29	1	2	8	6	6	4	73
3.38	1.83	60.26	31.3	33.9	1.05	2.27	1	2	8	6	6	4	73
3.4	1.81	61.068	32.1	34.7	1.05	2.27	1	2	8	7	7	4	72
3.42	1.79	61.882	32.9	35.5	1.05	2.26	1	2	8	7	7	4	71
3.44	1.78	62.702	33.3	35.9	1.06	2.27	1	2	7	7	7	5	70
3.46	1.78	63.528	33.7	36.4	1.06	2.27	1	2	7	7	7	5	71
3.48	1.78	64.36	34.1	36.8	1.06	2.28	1	2	7	7	7	5	70
3.5	1.78	65.198	34.6	37.3	1.06	2.27	1	2	7	7	7	5	70
3.52	1.78	66.042	35	37.7	1.06	2.27	1	2	7	7	7	5	70
3.54	1.77	66.892	35.4	38.1	1.06	2.29	1	2	7	8	8	5	69
3.56	1.77	67.748	35.8	38.6	1.07	2.3	1	2	7	7	7	5	70
3.58	1.77	68.61	36.2	39	1.07	2.27	1	2	7	6	6	5	72
3.6	1.77	69.478	36.7	39.5	1.07	2.31	1	2	7	6	6	6	72
3.62	1.77	70.353	37.1	39.9	1.07	2.29	1	2	7	6	6	6	73
3.64	1.77	71.233	37.5	40.3	1.07	2.28	1	2	7	5	5	6	74
3.66	1.77	72.12	37.9	40.8	1.07	2.28	1	2	7	5	5	5	75
3.68	1.77	73.012	38.3	41.2	1.07	2.31	1	3	7	5	5	6	74
3.7	1.77	73.911	38.8	41.6	1.08	2.28	1	2	7	5	5	5	75
3.72	1.77	74.816	39.2	42.1	1.08	2.3	1	2	7	5	5	6	74

Hydraulic parameter							Percentage of width occupied by fish hydraulic habitat						
Maximum Depth (m)	Average Depth (m)	Discharge (m3/s)	Width (m)	Wetted perimeter (m)	Average velocity (m/s)	Velocity 98% (m/s)	SVS	SS	SD	FVS	FS	FI	FD
3.74	1.78	75.727	39.6	42.5	1.08	2.29	1	2	7	5	5	5	75
3.76	1.78	76.644	40	43	1.08	2.3	1	3	7	5	5	6	75
3.78	1.78	77.568	40.4	43.4	1.08	2.3	0	3	7	4	4	5	76
3.8	1.78	78.497	40.9	43.8	1.08	2.32	0	3	7	5	5	6	76
3.82	1.78	79.433	41.3	44.3	1.08	2.3	1	2	7	5	5	5	76
3.84	1.79	80.375	41.6	44.6	1.08	2.29	0	2	7	4	4	5	77
3.86	1.8	81.323	41.8	44.8	1.08	2.32	0	2	7	5	5	5	76
3.88	1.81	82.277	42.1	45.1	1.08	2.3	0	2	7	4	4	5	78
3.9	1.82	83.238	42.3	45.3	1.08	2.32	0	2	7	4	4	5	77

8.2.5 Limpopo @ Limpokwena

Hydraulic parameter							Percentage of width occupied by fish hydraulic habitat						
Maximum Depth (m)	Average Depth (m)	Discharge (m3/s)	Width (m)	Wetted perimeter (m)	Average velocity (m/s)	Velocity 98% (m/s)	SVS	SS	SD	FVS	FS	FI	FD
0.02	0.01	0	7.4	7.4	0	0	100	0	0	0	0	0	0
0.04	0.03	0	8.4	8.4	0	0.01	100	0	0	0	0	0	0
0.06	0.04	0.002	9.4	9.5	0	0.02	100	0	0	0	0	0	0
0.08	0.06	0.004	10.3	10.3	0.01	0.03	100	0	0	0	0	0	0
0.1	0.08	0.009	10.7	10.7	0.01	0.04	97	3	0	0	0	0	0
0.12	0.09	0.016	11.2	11.2	0.02	0.06	39	61	0	0	0	0	0
0.14	0.11	0.027	11.6	11.6	0.02	0.08	27	73	0	0	0	0	0
0.16	0.12	0.041	12.1	12.1	0.03	0.1	21	79	0	0	0	0	0
0.18	0.14	0.06	12.5	12.5	0.03	0.13	18	82	0	0	0	0	0
0.2	0.15	0.085	12.9	13	0.04	0.16	17	83	0	0	0	0	0
0.22	0.17	0.115	13.4	13.4	0.05	0.18	16	84	0	0	0	0	0

Hydraulic parameter							Percentage of width occupied by fish hydraulic habitat						
Maximum Depth (m)	Average Depth (m)	Discharge (m3/s)	Width (m)	Wetted perimeter (m)	Average velocity (m/s)	Velocity 98% (m/s)	SVS	SS	SD	FVS	FS	FI	FD
0.24	0.18	0.152	13.8	13.9	0.06	0.22	15	85	0	0	0	0	0
0.26	0.17	0.197	16.8	16.8	0.07	0.25	27	73	0	0	0	0	0
0.28	0.15	0.251	21.7	21.8	0.08	0.28	41	57	0	1	0	1	0
0.3	0.14	0.302	27.2	27.2	0.08	0.29	52	46	0	1	0	1	0
0.32	0.13	0.351	32	32.1	0.08	0.29	56	42	0	1	0	0	0
0.34	0.14	0.416	36.2	36.3	0.08	0.3	60	38	0	2	0	0	1
0.36	0.14	0.492	40.8	40.9	0.09	0.3	56	41	0	2	0	0	1
0.38	0.15	0.583	45.6	45.7	0.09	0.31	50	47	0	2	1	0	1
0.4	0.15	0.688	50.5	50.6	0.09	0.32	43	53	0	2	1	0	1
0.42	0.16	0.811	55.5	55.6	0.09	0.32	39	57	0	2	1	0	1
0.44	0.16	0.959	59.9	60.1	0.1	0.34	36	59	0	2	2	0	1
0.46	0.18	1.154	61.6	61.7	0.1	0.37	29	64	0	2	3	0	1
0.48	0.19	1.369	63.2	63.3	0.11	0.39	24	69	0	2	3	1	2
0.5	0.21	1.604	64.8	65	0.12	0.41	20	70	2	2	3	2	2
0.52	0.23	1.846	66	66.2	0.12	0.44	14	68	8	2	4	3	2
0.54	0.24	2.085	67.1	67.4	0.13	0.46	11	68	11	1	4	4	2
0.56	0.26	2.345	68.3	68.6	0.13	0.47	9	68	12	1	3	4	3
0.58	0.27	2.626	69.5	69.8	0.14	0.48	7	68	13	1	3	4	4
0.6	0.29	2.929	70.7	71	0.14	0.51	7	66	14	1	3	4	5
0.62	0.3	3.256	71.9	72.2	0.15	0.53	8	64	14	1	2	4	7
0.64	0.32	3.607	73.1	73.4	0.16	0.54	5	66	13	1	2	5	7
0.66	0.33	3.983	74.5	74.9	0.16	0.56	6	65	13	1	2	4	9
0.68	0.34	4.386	76.1	76.4	0.17	0.58	7	63	14	1	1	4	10
0.7	0.36	4.816	77.6	78	0.17	0.61	8	60	13	2	2	3	12
0.72	0.37	5.274	80	80.3	0.18	0.62	7	61	14	2	2	3	13
0.74	0.38	5.761	82.3	82.7	0.19	0.64	9	58	14	2	1	2	15

Hydraulic parameter							Percentage of width occupied by fish hydraulic habitat						
Maximum Depth (m)	Average Depth (m)	Discharge (m3/s)	Width (m)	Wetted perimeter (m)	Average velocity (m/s)	Velocity 98% (m/s)	SVS	SS	SD	FVS	FS	FI	FD
0.76	0.38	6.279	84.6	85.1	0.19	0.67	9	53	16	3	2	2	16
0.78	0.39	6.828	87	87.4	0.2	0.69	10	48	19	3	2	1	17
0.8	0.4	7.409	90.5	91	0.21	0.7	10	43	23	3	2	2	17
0.82	0.4	8.023	95.3	95.7	0.21	0.72	11	40	25	3	2	2	17
0.84	0.4	8.634	99.9	100.3	0.22	0.73	12	35	27	4	3	1	17
0.86	0.4	9.209	104.4	104.9	0.22	0.75	13	32	28	5	3	1	18
0.88	0.4	9.833	109	109.5	0.22	0.74	14	28	32	5	3	1	18
0.9	0.4	10.833	114.4	115	0.23	0.79	14	25	31	6	4	2	18
0.92	0.37	11.629	130.7	131.3	0.24	0.8	19	21	29	8	4	2	17
0.94	0.38	12.465	137.1	137.7	0.24	0.82	19	20	30	9	4	2	17
0.96	0.38	13.34	142.6	143.3	0.25	0.84	18	20	28	9	4	2	17
0.98	0.39	14.258	146.7	147.3	0.25	0.83	14	24	29	7	6	3	17
1	0.4	15.218	150.7	151.4	0.25	0.84	13	24	28	7	6	3	18
1.02	0.41	16.222	155	155.6	0.26	0.86	12	26	27	6	7	4	18
1.04	0.42	17.271	159.2	159.9	0.26	0.87	11	26	27	6	7	4	19
1.06	0.43	18.365	163.4	164.1	0.26	0.87	8	29	27	4	7	5	19
1.08	0.44	19.506	166.9	167.6	0.27	0.88	7	30	26	4	7	6	20
1.1	0.45	20.696	168.9	169.7	0.27	0.89	5	31	27	3	8	6	20
1.12	0.47	21.934	170.7	171.5	0.28	0.91	5	31	26	3	8	6	22
1.14	0.48	23.223	173.1	173.9	0.28	0.91	4	31	26	3	6	7	23
1.16	0.49	24.563	175.5	176.3	0.28	0.91	3	32	26	2	5	8	24
1.18	0.51	25.956	177.9	178.7	0.29	0.94	4	30	25	2	4	8	26
1.2	0.52	27.402	180.3	181.1	0.29	0.94	3	30	26	2	4	8	27
1.22	0.53	28.903	182.1	182.9	0.3	0.97	3	29	25	3	3	8	29
1.24	0.55	30.459	183.6	184.4	0.3	0.98	3	28	25	3	3	7	31
1.26	0.57	32.073	185	185.8	0.31	1	3	26	26	3	3	5	34

Hydraulic parameter							Percentage of width occupied by fish hydraulic habitat						
Maximum Depth (m)	Average Depth (m)	Discharge (m3/s)	Width (m)	Wetted perimeter (m)	Average velocity (m/s)	Velocity 98% (m/s)	SVS	SS	SD	FVS	FS	FI	FD
1.28	0.58	33.744	186.3	187.1	0.31	1	2	26	26	2	3	5	36
1.3	0.6	35.475	187.4	188.2	0.32	1.01	2	25	27	2	3	4	37
1.32	0.61	37.266	188.4	189.3	0.32	1.02	1	24	28	1	3	3	39
1.34	0.63	39.118	189.5	190.4	0.33	1.06	2	23	27	2	3	3	41
1.36	0.65	41.033	190.6	191.5	0.33	1.05	1	21	29	1	2	3	42
1.38	0.66	43.011	191.7	192.6	0.34	1.07	2	17	32	2	2	3	43
1.4	0.68	45.055	192.8	193.7	0.34	1.08	1	16	33	1	2	3	44
1.42	0.7	47.164	193.8	194.8	0.35	1.1	1	15	33	1	2	3	45
1.44	0.71	49.341	194.9	195.8	0.36	1.13	1	13	33	2	2	2	47
1.46	0.73	51.586	196	196.9	0.36	1.14	1	13	33	1	1	3	48
1.48	0.74	53.9	197.1	198	0.37	1.15	1	10	35	2	1	2	49
1.5	0.76	56.285	198.2	199.2	0.37	1.17	1	9	35	1	2	2	50
1.52	0.78	58.742	199.3	200.3	0.38	1.18	1	9	35	1	2	2	51
1.54	0.79	61.272	199.7	200.7	0.39	1.21	1	7	35	2	2	2	52
1.56	0.81	63.877	200.2	201.2	0.39	1.22	1	7	35	1	2	2	53
1.58	0.83	66.556	200.6	201.6	0.4	1.23	1	6	35	1	1	2	54
1.6	0.85	69.312	201.1	202.1	0.41	1.25	1	5	35	1	1	2	55
1.62	0.87	72.146	201.5	202.5	0.41	1.27	0	5	35	1	1	2	56
1.64	0.88	75.059	202	203	0.42	1.29	0	5	34	0	1	2	57
1.66	0.9	78.052	202.4	203.5	0.43	1.32	1	4	34	1	1	2	58
1.68	0.92	81.127	202.8	203.9	0.43	1.33	1	4	33	1	1	1	59
1.7	0.94	84.284	203.3	204.4	0.44	1.35	1	4	33	1	1	1	59
1.72	0.96	87.524	203.7	204.8	0.45	1.38	1	3	32	1	1	1	60
1.74	0.97	90.85	204.2	205.3	0.46	1.39	1	3	32	1	1	1	61
1.76	0.99	94.262	204.6	205.7	0.46	1.4	1	3	32	2	0	1	62
1.78	1.01	97.761	205.1	206.2	0.47	1.4	0	3	32	0	1	1	63

Hydraulic parameter							Percentage of width occupied by fish hydraulic habitat						
Maximum Depth (m)	Average Depth (m)	Discharge (m3/s)	Width (m)	Wetted perimeter (m)	Average velocity (m/s)	Velocity 98% (m/s)	SVS	SS	SD	FVS	FS	FI	FD
1.8	1.03	101.349	205.5	206.6	0.48	1.43	0	3	31	0	1	1	63
1.82	1.05	105.026	206	207.1	0.49	1.46	0	3	31	1	1	1	64
1.84	1.06	108.795	206.4	207.6	0.5	1.49	0	2	30	1	1	1	64
1.86	1.08	112.656	206.8	208	0.5	1.51	0	2	30	1	1	1	65
1.88	1.1	116.611	207.3	208.5	0.51	1.52	0	2	29	1	1	1	66
1.9	1.12	120.66	207.7	208.9	0.52	1.53	0	2	29	1	1	1	67
1.92	1.13	124.806	208.2	209.4	0.53	1.55	0	2	29	1	1	1	68
1.94	1.15	129.048	208.6	209.8	0.54	1.57	0	2	28	0	0	1	69
1.96	1.17	133.389	209.1	210.3	0.55	1.58	0	2	28	0	1	1	69
1.98	1.19	137.83	209.5	210.7	0.55	1.62	0	2	27	1	1	1	69
2	1.2	142.372	210	211.2	0.56	1.63	0	1	27	1	1	1	69
2.02	1.22	147.016	210.4	211.7	0.57	1.64	0	1	27	1	1	1	70
2.04	1.24	151.763	210.8	212.1	0.58	1.66	0	1	26	1	1	1	71
2.06	1.26	156.615	211.3	212.6	0.59	1.67	0	1	26	1	1	1	71
2.08	1.27	161.573	211.7	213	0.6	1.69	0	1	25	1	1	1	72
2.1	1.29	166.639	212.2	213.5	0.61	1.71	0	1	25	1	1	1	72
2.12	1.31	171.813	212.6	213.9	0.62	1.74	0	1	24	1	1	1	73
2.14	1.33	177.096	213.1	214.4	0.63	1.78	0	1	23	1	1	1	73
2.16	1.34	182.491	213.5	214.8	0.64	1.79	0	1	23	1	1	1	73
2.18	1.36	187.998	214	215.3	0.65	1.8	0	1	23	1	1	1	74
2.2	1.38	193.619	214.4	215.8	0.66	1.82	0	1	22	1	1	1	73
2.22	1.39	199.355	214.8	216.2	0.67	1.85	0	1	22	1	1	1	74
2.24	1.41	205.207	215.3	216.7	0.68	1.87	0	1	22	2	1	1	74
2.26	1.43	211.176	215.7	217.1	0.69	1.88	0	1	21	1	1	0	76
2.28	1.45	217.264	215.8	217.2	0.7	1.91	0	1	21	2	1	0	76
2.3	1.47	223.472	215.9	217.3	0.71	1.89	0	1	21	0	0	1	77

Hydraulic parameter							Percentage of width occupied by fish hydraulic habitat						
Maximum Depth (m)	Average Depth (m)	Discharge (m3/s)	Width (m)	Wetted perimeter (m)	Average velocity (m/s)	Velocity 98% (m/s)	SVS	SS	SD	FVS	FS	FI	FD
2.32	1.49	229.801	216	217.4	0.72	1.93	0	1	20	1	1	1	77
2.34	1.51	236.253	216.1	217.5	0.73	1.94	0	1	20	0	0	1	78
2.36	1.53	242.829	216.2	217.6	0.74	1.98	0	1	19	1	1	1	78
2.38	1.54	249.53	216.3	217.7	0.75	1.97	0	1	19	0	0	1	79
2.4	1.56	256.358	216.4	217.9	0.76	2.01	0	1	19	0	1	1	78
2.42	1.58	263.313	216.6	218	0.77	2.01	0	1	19	0	0	1	80
2.44	1.6	270.398	216.7	218.1	0.78	2.05	0	1	18	0	0	0	80
2.46	1.62	277.613	216.8	218.3	0.79	2.07	0	1	18	0	0	0	80
2.48	1.64	284.96	216.9	218.4	0.8	2.07	0	0	18	0	0	0	81
2.5	1.66	292.44	217	218.5	0.81	2.08	0	0	17	0	0	0	82
2.52	1.68	300.054	217.1	218.6	0.82	2.1	0	0	17	0	0	0	83
2.54	1.7	307.804	217.2	218.7	0.83	2.14	0	0	16	0	0	0	82
2.56	1.72	315.691	217.3	218.8	0.85	2.14	0	0	16	0	0	0	83
2.58	1.74	323.716	217.4	219	0.86	2.15	0	0	16	0	0	0	84
2.6	1.75	331.881	217.6	219.1	0.87	2.18	0	0	16	0	0	0	84
2.62	1.77	340.187	217.7	219.2	0.88	2.22	0	0	15	0	0	0	83
2.64	1.79	348.635	217.8	219.3	0.89	2.22	0	0	15	0	0	0	84
2.66	1.81	357.227	217.9	219.4	0.9	2.22	0	0	15	0	0	0	85
2.68	1.83	365.964	218	219.5	0.92	2.25	0	0	15	0	0	0	85
2.7	1.85	374.848	218.1	219.7	0.93	2.29	0	0	14	0	0	0	85
2.72	1.87	383.879	218.2	219.8	0.94	2.32	0	0	14	0	0	0	85
2.74	1.89	393.059	218.3	219.9	0.95	2.34	0	0	14	0	0	0	85
2.76	1.91	402.389	218.4	220	0.97	2.33	0	0	13	0	0	0	86
2.78	1.93	411.871	218.5	220.1	0.98	2.33	0	0	13	0	0	0	87
2.8	1.95	421.506	218.6	220.2	0.99	2.36	0	0	13	0	0	0	86
2.82	1.96	431.296	218.8	220.4	1	2.38	0	0	13	0	0	0	86

Hydraulic parameter							Percentage of width occupied by fish hydraulic habitat						
Maximum Depth (m)	Average Depth (m)	Discharge (m3/s)	Width (m)	Wetted perimeter (m)	Average velocity (m/s)	Velocity 98% (m/s)	SVS	SS	SD	FVS	FS	FI	FD
2.84	1.98	441.241	218.9	220.5	1.02	2.38	0	0	13	0	0	0	87
2.86	2	451.344	219	220.6	1.03	2.41	0	0	12	0	0	0	88
2.88	2.02	461.604	219.1	220.7	1.04	2.46	0	0	12	0	0	0	87
2.9	2.04	472.025	219.2	220.8	1.06	2.47	0	0	12	0	0	0	87
2.92	2.06	482.607	219.3	220.9	1.07	2.49	0	0	12	0	0	0	87
2.94	2.08	493.352	219.4	221.1	1.08	2.48	0	0	11	0	0	0	89
2.96	2.1	504.26	219.5	221.2	1.1	2.52	0	0	11	0	0	0	88
2.98	2.12	515.334	219.6	221.3	1.11	2.54	0	0	11	0	0	0	88
3	2.14	526.574	219.7	221.4	1.12	2.57	0	0	11	0	0	0	88
3.02	2.15	537.983	219.9	221.5	1.14	2.58	0	0	11	0	0	0	89
3.04	2.17	549.56	220	221.6	1.15	2.59	0	0	10	0	0	0	90
3.06	2.19	561.309	220.1	221.8	1.16	2.64	0	0	10	0	0	0	89
3.08	2.21	573.23	220.2	221.9	1.18	2.65	0	0	10	0	0	0	89
3.1	2.23	585.324	220.3	222	1.19	2.64	0	0	10	0	0	0	90
3.12	2.25	597.593	220.4	222.1	1.21	2.66	0	0	10	0	0	0	90
3.14	2.27	610.039	220.5	222.2	1.22	2.7	0	0	9	0	0	0	90
3.16	2.29	622.662	220.6	222.3	1.23	2.77	0	0	9	0	0	0	90
3.18	2.31	635.465	220.7	222.5	1.25	2.75	0	0	9	0	0	0	91
3.2	2.32	648.448	220.8	222.6	1.26	2.77	0	0	9	0	0	0	91
3.22	2.34	661.612	220.9	222.7	1.28	2.81	0	0	9	0	0	0	90
3.24	2.36	674.96	221.1	222.8	1.29	2.83	0	0	9	0	0	0	90
3.26	2.38	688.493	221.2	222.9	1.31	2.82	0	0	8	0	0	0	92
3.28	2.4	702.211	221.3	223	1.32	2.83	0	0	8	0	0	0	92
3.3	2.42	716.118	221.4	223.2	1.34	2.85	0	0	8	0	0	0	92
3.32	2.44	730.213	221.5	223.3	1.35	2.94	0	0	8	0	0	0	91
3.34	2.46	744.498	221.6	223.4	1.37	2.97	0	0	8	0	0	0	91

Hydraulic parameter							Percentage of width occupied by fish hydraulic habitat						
Maximum Depth (m)	Average Depth (m)	Discharge (m3/s)	Width (m)	Wetted perimeter (m)	Average velocity (m/s)	Velocity 98% (m/s)	SVS	SS	SD	FVS	FS	FI	FD
3.36	2.47	758.975	221.7	223.5	1.38	2.96	0	0	8	0	0	0	92
3.38	2.49	773.645	221.8	223.6	1.4	2.98	0	0	8	0	0	0	92
3.4	2.51	788.509	221.9	223.7	1.41	3.02	0	0	7	0	0	0	92
3.42	2.53	803.57	222	223.9	1.43	3.04	0	0	7	0	0	0	92
3.44	2.55	818.828	222.2	224	1.45	3.05	0	0	7	0	0	0	92
3.46	2.57	834.284	222.3	224.1	1.46	3.04	0	0	7	0	0	0	93
3.48	2.59	849.941	222.4	224.2	1.48	3.11	0	0	7	0	0	0	92
3.5	2.61	865.799	222.5	224.3	1.49	3.14	0	0	7	0	0	0	92
3.52	2.62	881.86	222.6	224.4	1.51	3.17	0	0	7	0	0	0	92
3.54	2.64	898.125	222.7	224.6	1.53	3.16	0	0	7	0	0	0	93
3.56	2.66	914.597	222.8	224.7	1.54	3.19	0	0	6	0	0	0	94
3.58	2.68	931.275	222.9	224.8	1.56	3.24	0	0	6	0	0	0	93
3.6	2.7	948.163	223	224.9	1.57	3.26	0	0	6	0	0	0	93
3.62	2.72	965.26	223.1	225	1.59	3.25	0	0	6	0	0	0	94
3.64	2.72	982.569	224.9	226.8	1.61	3.29	0	0	6	0	0	0	93
3.66	2.71	1000.091	227.2	229.1	1.62	3.33	0	0	6	1	1	1	91
3.68	2.7	1017.828	229.4	231.3	1.64	3.36	0	0	5	1	1	1	92
3.7	2.7	1035.78	231.7	233.6	1.66	3.39	0	0	5	1	1	1	92
3.72	2.69	1053.949	233.9	235.8	1.67	3.39	0	0	5	2	2	1	91
3.74	2.69	1072.338	236.1	238	1.69	3.45	0	0	5	2	2	1	89
3.76	2.68	1090.946	238.4	240.3	1.71	3.46	0	0	5	2	2	2	89
3.78	2.67	1109.776	240.6	242.5	1.72	3.49	0	0	4	3	3	1	88
3.8	2.67	1128.83	242.8	244.8	1.74	3.54	0	0	4	3	3	2	87
3.82	2.67	1148.107	245.1	247	1.76	3.58	0	0	4	3	3	2	87
3.84	2.66	1167.611	247.3	249.3	1.77	3.59	0	0	4	3	3	2	87
3.86	2.66	1187.342	249.4	251.3	1.79	3.6	0	0	4	4	4	2	86

Hydraulic parameter							Percentage of width occupied by fish hydraulic habitat						
Maximum Depth (m)	Average Depth (m)	Discharge (m3/s)	Width (m)	Wetted perimeter (m)	Average velocity (m/s)	Velocity 98% (m/s)	SVS	SS	SD	FVS	FS	FI	FD
3.88	2.66	1207.302	250.8	252.8	1.81	3.63	0	0	4	4	4	2	86
3.9	2.67	1227.492	252.2	254.2	1.82	3.66	0	0	4	4	4	2	86
3.92	2.67	1247.914	253.6	255.6	1.84	3.74	0	0	3	4	4	3	85
3.94	2.68	1268.569	255	257	1.86	3.78	0	0	3	4	4	3	85
3.96	2.68	1289.459	256.4	258.4	1.87	3.79	0	0	3	3	3	3	87
3.98	2.69	1310.586	257.8	259.8	1.89	3.82	0	0	3	3	3	3	88
4	2.7	1331.949	259.2	261.3	1.91	3.89	0	0	3	4	4	3	86
4.02	2.7	1353.552	260.7	262.7	1.92	3.88	0	0	3	3	3	3	88
4.04	2.71	1375.396	262.1	264.1	1.94	3.92	0	0	3	3	3	3	89
4.06	2.71	1397.481	263.5	265.5	1.96	3.97	0	0	3	3	3	3	87
4.08	2.72	1419.81	264.9	266.9	1.97	4.02	0	0	3	3	3	3	87
4.1	2.73	1442.384	265.9	268	1.99	4.07	0	0	3	3	3	3	88
4.12	2.74	1465.204	266.7	268.7	2.01	4.07	0	0	3	2	2	2	90
4.14	2.75	1488.272	267.4	269.4	2.02	4.1	0	0	3	2	2	2	90
4.16	2.76	1511.59	268.1	270.2	2.04	4.17	0	0	3	2	2	2	90
4.18	2.78	1535.158	268.8	270.9	2.06	4.18	0	0	3	2	2	2	90
4.2	2.79	1558.979	269.5	271.6	2.07	4.2	0	0	3	2	2	2	91
4.22	2.8	1583.054	270.2	272.3	2.09	4.26	0	0	3	2	2	2	90
4.24	2.81	1607.384	271	273	2.11	4.3	0	0	3	2	2	2	90
4.26	2.83	1631.97	271.7	273.8	2.12	4.28	0	0	3	1	1	2	92
4.28	2.84	1656.815	272.4	274.5	2.14	4.33	0	0	3	2	2	2	91
4.3	2.85	1681.92	273.1	275.2	2.16	4.41	0	0	3	2	2	2	92

8.2.6 Mogalakwena

Hydraulic parameter							Percentage of width occupied by fish hydraulic habitat						
Maximum Depth (m)	Average Depth (m)	Discharge (m3/s)	Width (m)	Wetted perimeter (m)	Average velocity (m/s)	Velocity 98% (m/s)	SVS	SS	SD	FVS	FS	FI	FD
0.02	0.01	0	0.3	0.3	0.01	0.02	100	0	0	0	0	0	0
0.04	0.02	0	0.6	0.6	0.01	0.03	100	0	0	0	0	0	0
0.06	0.03	0	0.9	0.9	0.01	0.05	100	0	0	0	0	0	0
0.08	0.04	0.001	1.2	1.2	0.02	0.06	100	0	0	0	0	0	0
0.1	0.05	0.001	1.5	1.5	0.02	0.07	99	1	0	0	0	0	0
0.12	0.06	0.002	1.8	1.8	0.02	0.08	83	17	0	0	0	0	0
0.14	0.07	0.004	2.1	2.1	0.03	0.09	71	29	0	0	0	0	0
0.16	0.08	0.006	2.4	2.5	0.03	0.1	62	38	0	0	0	0	0
0.18	0.09	0.008	2.7	2.8	0.03	0.12	55	45	0	0	0	0	0
0.2	0.1	0.011	3	3	0.04	0.13	49	51	0	0	0	0	0
0.22	0.04	0.001	10.4	10.4	0	0	82	18	0	0	0	0	0
0.24	0.04	0.003	16.8	16.9	0	0.01	87	13	0	0	0	0	0
0.26	0.06	0.007	16.9	17	0.01	0.02	85	15	0	0	0	0	0
0.28	0.08	0.014	17	17.1	0.01	0.04	84	16	0	0	0	0	0
0.3	0.1	0.023	17.1	17.2	0.01	0.05	80	20	0	0	0	0	0
0.32	0.12	0.036	17.2	17.3	0.02	0.06	39	61	0	0	0	0	0
0.34	0.14	0.051	17.2	17.4	0.02	0.07	2	98	0	0	0	0	0
0.36	0.16	0.07	17.300	17.4	0.02	0.09	2	98	0	0	0	0	0
0.38	0.18	0.092	17.4	17.5	0.03	0.1	2	98	0	0	0	0	0
0.4	0.2	0.117	17.5	17.6	0.03	0.12	1	99	0	0	0	0	0
0.42	0.22	0.146	17.6	17.7	0.04	0.13	1	99	0	0	0	0	0
0.44	0.24	0.179	17.7	17.8	0.04	0.15	1	99	0	0	0	0	0
0.46	0.26	0.216	17.7	17.9	0.05	0.17	1	99	0	0	0	0	0
0.48	0.28	0.256	17.8	18	0.05	0.18	1	99	0	0	0	0	0
0.5	0.29	0.301	17.9	18.1	0.06	0.2	1	99	0	0	0	0	0
0.52	0.31	0.35	18	18.2	0.06	0.22	1	97	1	0	0	0	0

Hydraulic parameter							Percentage of width occupied by fish hydraulic habitat						
Maximum Depth (m)	Average Depth (m)	Discharge (m3/s)	Width (m)	Wetted perimeter (m)	Average velocity (m/s)	Velocity 98% (m/s)	SVS	SS	SD	FVS	FS	FI	FD
0.54	0.33	0.403	18.1	18.3	0.07	0.24	1	95	4	0	0	0	0
0.56	0.35	0.461	18.2	18.4	0.07	0.25	2	92	5	0	0	0	1
0.58	0.37	0.523	18.2	18.5	0.08	0.27	2	90	7	0	0	0	1
0.6	0.39	0.589	18.3	18.6	0.08	0.29	2	87	9	0	0	0	2
0.62	0.4	0.66	18.4	18.7	0.09	0.31	2	85	10	0	0	0	3
0.64	0.42	0.735	18.5	18.8	0.09	0.33	2	83	11	0	0	0	4
0.66	0.44	0.816	18.6	18.8	0.1	0.34	2	81	13	0	0	0	4
0.68	0.46	0.901	18.6	18.9	0.11	0.36	2	75	18	0	0	0	5
0.7	0.48	0.991	18.7	19	0.11	0.37	1	51	42	0	0	0	5
0.72	0.49	1.086	18.8	19.1	0.12	0.39	1	30	63	0	0	0	6
0.74	0.51	1.185	18.9	19.2	0.12	0.41	1	11	81	0	0	0	7
0.76	0.53	1.29	19	19.3	0.13	0.43	1	8	83	0	0	0	8
0.78	0.55	1.4	19.1	19.4	0.13	0.45	1	8	82	0	0	0	9
0.8	0.57	1.515	19.1	19.5	0.14	0.47	1	8	82	0	0	0	9
0.82	0.58	1.636	19.2	19.6	0.15	0.49	1	7	81	0	0	0	10
0.84	0.6	1.761	19.3	19.7	0.15	0.5	1	8	80	0	0	0	11
0.86	0.62	1.892	19.4	19.8	0.16	0.51	2	8	79	0	0	0	11
0.88	0.64	2.029	19.5	19.9	0.16	0.53	1	8	78	0	0	0	12
0.9	0.65	2.171	19.6	20	0.17	0.55	1	7	77	0	0	0	13
0.92	0.67	2.318	19.6	20.1	0.18	0.57	1	7	76	0	0	0	15
0.94	0.69	2.471	19.7	20.2	0.18	0.6	1	7	75	0	0	0	16
0.96	0.7	2.629	19.8	20.3	0.19	0.62	2	7	72	0	0	0	18
0.98	0.72	2.793	19.9	20.3	0.19	0.64	2	6	71	1	1	0	20
1	0.74	2.963	20	20.4	0.2	0.66	2	6	70	1	1	0	21
1.02	0.75	3.139	20	20.5	0.21	0.67	1	6	69	0	1	0	22
1.04	0.77	3.32	20.1	20.6	0.21	0.7	1	6	68	0	1	0	24

Hydraulic parameter							Percentage of width occupied by fish hydraulic habitat						
Maximum Depth (m)	Average Depth (m)	Discharge (m3/s)	Width (m)	Wetted perimeter (m)	Average velocity (m/s)	Velocity 98% (m/s)	SVS	SS	SD	FVS	FS	FI	FD
1.06	0.79	3.507	20.2	20.7	0.22	0.72	1	6	67	0	1	0	25
1.08	0.81	3.7	20.3	20.8	0.23	0.73	1	5	65	0	1	0	27
1.1	0.77	3.899	21.7	22.2	0.23	0.75	5	6	60	2	1	1	26
1.12	0.72	4.104	23.9	24.5	0.24	0.76	11	5	53	5	0	1	25
1.14	0.68	4.315	26.2	26.7	0.24	0.76	15	4	49	7	0	1	23
1.16	0.64	4.532	28.4	29	0.25	0.75	19	5	45	9	1	1	22
1.18	0.62	4.756	30.6	31.2	0.25	0.76	20	6	40	10	1	0	21
1.2	0.59	4.985	32.9	33.5	0.26	0.77	20	9	37	10	3	0	20
1.22	0.58	5.22	34.9	35.5	0.26	0.77	18	11	36	10	5	1	20
1.24	0.57	5.462	36.7	37.3	0.26	0.78	17	14	33	9	6	0	19
1.26	0.56	5.71	38.5	39.1	0.26	0.8	17	15	31	10	8	1	19
1.28	0.56	5.964	40.3	40.9	0.27	0.79	15	19	30	8	8	2	18
1.3	0.56	6.225	41.2	41.8	0.27	0.81	13	20	29	8	8	3	18
1.32	0.58	6.492	41.3	41.9	0.27	0.82	10	23	28	6	9	4	19
1.34	0.6	6.766	41.4	42.1	0.27	0.83	7	25	28	5	9	6	19
1.36	0.62	7.045	41.5	42.2	0.27	0.83	5	27	28	3	9	8	19
1.38	0.64	7.332	41.7	42.3	0.28	0.84	2	30	28	1	9	9	20
1.4	0.66	7.625	41.8	42.5	0.28	0.84	1	30	28	1	7	10	22
1.42	0.67	7.924	41.9	42.6	0.28	0.85	1	30	28	1	6	10	24
1.44	0.69	8.23	42	42.7	0.28	0.86	1	30	28	1	4	10	26
1.46	0.71	8.543	42.2	42.9	0.29	0.88	1	30	27	1	3	10	28
1.48	0.73	8.863	42.3	43	0.29	0.89	1	29	27	1	1	9	31
1.5	0.75	9.189	42.4	43.1	0.29	0.9	1	29	27	1	0	8	33
1.52	0.76	9.522	42.5	43.3	0.29	0.91	1	28	27	1	0	7	36
1.54	0.78	9.861	42.7	43.4	0.3	0.92	1	27	27	1	0	6	38
1.56	0.8	10.208	42.8	43.6	0.3	0.93	1	26	28	1	0	4	40

Hydraulic parameter							Percentage of width occupied by fish hydraulic habitat						
Maximum Depth (m)	Average Depth (m)	Discharge (m3/s)	Width (m)	Wetted perimeter (m)	Average velocity (m/s)	Velocity 98% (m/s)	SVS	SS	SD	FVS	FS	FI	FD
1.58	0.82	10.561	42.9	43.7	0.3	0.93	1	25	29	0	0	3	42
1.6	0.83	10.922	43	43.8	0.3	0.94	1	24	30	0	0	2	43
1.62	0.85	11.289	43.2	44	0.31	0.95	0	22	31	0	0	0	45
1.64	0.87	11.663	43.3	44.1	0.31	0.96	0	20	33	0	0	0	45
1.66	0.89	12.044	43.4	44.2	0.31	0.96	0	18	35	0	0	1	46
1.68	0.9	12.432	43.5	44.4	0.32	0.98	1	15	37	1	0	1	46
1.7	0.92	12.827	43.7	44.5	0.32	0.98	1	12	38	1	0	1	46
1.72	0.94	13.229	43.8	44.6	0.32	0.99	1	10	40	1	0	1	47
1.74	0.96	13.639	43.9	44.8	0.33	1	1	8	42	1	0	1	47
1.76	0.97	14.055	44.1	45	0.33	1	0	6	44	0	1	1	47
1.78	0.98	14.479	44.7	45.6	0.33	1	1	4	45	1	1	1	47
1.8	0.99	14.91	45.3	46.2	0.33	1	2	4	44	2	1	1	47
1.82	0.99	15.348	45.9	46.8	0.34	1.01	2	4	44	2	1	1	47
1.84	1	15.793	46.4	47.4	0.34	1.01	2	3	44	2	1	1	47
1.86	1.01	16.245	47	48	0.34	1.02	2	3	44	2	1	1	47
1.88	1.01	16.705	47.6	48.6	0.35	1.04	3	3	42	3	1	1	47
1.9	1.02	17.173	48.2	49.2	0.35	1.04	3	4	41	3	1	1	47
1.92	1.03	17.647	48.8	49.8	0.35	1.05	3	4	41	3	2	1	46
1.94	1.04	18.129	49.4	50.4	0.35	1.06	3	4	40	3	2	1	46
1.96	1.04	18.619	50	51	0.36	1.06	2	5	39	3	3	2	46
1.98	1.06	19.116	50.3	51.3	0.36	1.06	2	5	39	3	2	1	47
2	1.08	19.62	50.5	51.5	0.36	1.08	2	5	39	2	2	2	47
2.02	1.09	20.132	50.6	51.6	0.36	1.1	2	5	38	2	3	2	47
2.04	1.11	20.651	50.8	51.8	0.37	1.11	2	6	37	2	3	3	48
2.06	1.13	21.178	50.9	52	0.37	1.1	1	6	38	1	2	3	49
2.08	1.14	21.713	51.1	52.1	0.37	1.11	1	6	38	1	2	3	50

Hydraulic parameter							Percentage of width occupied by fish hydraulic habitat						
Maximum Depth (m)	Average Depth (m)	Discharge (m3/s)	Width (m)	Wetted perimeter (m)	Average velocity (m/s)	Velocity 98% (m/s)	SVS	SS	SD	FVS	FS	FI	FD
2.1	1.16	22.255	51.2	52.3	0.38	1.13	1	6	37	1	2	3	50
2.12	1.17	22.805	51.4	52.5	0.38	1.13	1	6	37	1	2	3	51
2.14	1.19	23.363	51.5	52.6	0.38	1.13	0	6	37	0	2	3	52
2.16	1.21	23.928	51.7	52.8	0.38	1.14	0	6	37	0	1	2	52
2.18	1.22	24.501	51.8	52.9	0.39	1.15	1	6	36	1	1	2	53
2.2	1.24	25.082	52	53.1	0.39	1.16	1	6	36	1	1	2	54
2.22	1.26	25.671	52.1	53.3	0.39	1.16	0	6	36	0	1	2	55
2.24	1.27	26.267	52.3	53.4	0.39	1.17	0	5	36	0	1	2	55
2.26	1.29	26.871	52.5	53.6	0.4	1.19	1	5	35	1	1	1	56
2.28	1.31	27.483	52.6	53.8	0.4	1.2	1	5	35	1	1	1	57
2.3	1.32	28.103	52.8	53.9	0.4	1.21	1	5	35	1	1	1	57
2.32	1.34	28.731	52.9	54.1	0.41	1.21	0	4	36	0	1	1	58
2.34	1.35	29.367	53.1	54.2	0.41	1.22	0	4	36	0	1	1	58
2.36	1.37	30.01	53.2	54.4	0.41	1.24	0	4	35	1	1	1	58
2.38	1.38	30.662	53.6	54.8	0.41	1.23	0	3	36	0	1	1	59
2.4	1.38	31.322	54.4	55.6	0.42	1.25	1	3	35	1	1	1	58
2.42	1.38	31.99	55.2	56.4	0.42	1.24	1	3	35	2	1	1	58
2.44	1.38	32.665	55.9	57.1	0.42	1.26	1	3	34	2	1	1	57
2.46	1.38	33.349	56.7	57.9	0.43	1.27	2	3	33	3	2	1	57
2.48	1.38	34.041	57.5	58.7	0.43	1.28	2	3	33	3	2	1	56
2.5	1.39	34.741	58.2	59.4	0.43	1.27	2	3	33	3	2	1	56
2.52	1.39	35.45	59	60.2	0.43	1.28	2	3	32	3	3	1	56
2.54	1.39	36.166	59.8	61	0.44	1.3	2	3	31	4	3	1	55
2.56	1.39	36.891	60.5	61.7	0.44	1.3	2	3	31	4	3	1	55
2.58	1.39	37.624	61.3	62.5	0.44	1.29	2	4	31	4	3	1	56
2.6	1.4	38.365	61.9	63.1	0.44	1.31	2	4	30	4	3	1	55

Hydraulic parameter							Percentage of width occupied by fish hydraulic habitat						
Maximum Depth (m)	Average Depth (m)	Discharge (m3/s)	Width (m)	Wetted perimeter (m)	Average velocity (m/s)	Velocity 98% (m/s)	SVS	SS	SD	FVS	FS	FI	FD
2.62	1.42	39.114	62.1	63.3	0.44	1.31	2	4	31	3	3	2	56
2.64	1.43	39.872	62.2	63.4	0.45	1.32	2	4	30	3	3	2	56
2.66	1.45	40.638	62.4	63.6	0.45	1.33	2	5	29	3	3	3	56
2.68	1.47	41.412	62.5	63.8	0.45	1.33	1	5	30	2	2	3	57
2.7	1.48	42.195	62.7	63.9	0.45	1.35	1	5	29	2	2	3	57
2.72	1.5	42.986	62.8	64.1	0.46	1.35	1	5	29	2	2	3	58
2.74	1.51	43.785	63	64.3	0.46	1.37	1	5	29	2	2	4	57
2.76	1.53	44.593	63.2	64.4	0.46	1.37	1	5	29	1	1	4	59
2.78	1.55	45.409	63.3	64.6	0.46	1.37	0	5	29	1	1	4	60
2.8	1.56	46.234	63.5	64.8	0.47	1.39	1	5	29	1	1	3	60
2.82	1.58	47.067	63.6	64.9	0.47	1.39	0	5	29	1	1	3	61
2.84	1.6	47.909	63.8	65.1	0.47	1.4	1	5	29	1	1	3	61
2.86	1.61	48.76	64	65.3	0.47	1.4	0	4	29	1	1	3	62
2.88	1.63	49.618	64.1	65.4	0.48	1.41	1	4	29	1	1	2	62
2.9	1.64	50.486	64.3	65.6	0.48	1.42	0	4	29	1	1	2	62
2.92	1.66	51.362	64.4	65.7	0.48	1.41	0	4	30	1	1	2	63
2.94	1.68	52.247	64.6	65.9	0.48	1.44	1	4	29	1	1	1	63
2.96	1.69	53.14	64.8	66.1	0.49	1.43	0	4	29	1	1	1	64
2.98	1.71	54.042	64.9	66.2	0.49	1.45	0	3	29	1	1	1	64
3	1.72	54.952	65.1	66.4	0.49	1.44	0	3	30	1	1	1	65
3.02	1.74	55.872	65.2	66.6	0.49	1.46	0	3	29	1	1	1	65
3.04	1.75	56.8	65.4	66.7	0.5	1.47	0	3	29	1	1	1	65
3.06	1.77	57.736	65.5	66.9	0.5	1.47	0	2	30	1	1	1	66
3.08	1.79	58.682	65.7	67.1	0.5	1.49	0	2	29	1	1	1	65
3.1	1.8	59.636	65.9	67.2	0.5	1.48	0	2	30	1	1	1	66
3.12	1.82	60.599	66	67.4	0.51	1.49	0	2	30	1	1	1	66

Hydraulic parameter							Percentage of width occupied by fish hydraulic habitat						
Maximum Depth (m)	Average Depth (m)	Discharge (m3/s)	Width (m)	Wetted perimeter (m)	Average velocity (m/s)	Velocity 98% (m/s)	SVS	SS	SD	FVS	FS	FI	FD
3.14	1.83	61.571	66.2	67.6	0.51	1.51	0	2	29	1	1	1	66
3.16	1.85	62.552	66.4	67.7	0.51	1.5	0	2	30	1	1	1	66
3.18	1.86	63.542	66.5	67.9	0.51	1.52	0	2	29	1	1	1	66
3.2	1.88	64.54	66.7	68.1	0.52	1.52	0	1	30	1	1	1	67
3.22	1.89	65.548	66.9	68.3	0.52	1.54	0	2	29	1	1	1	66
3.24	1.91	66.564	67	68.4	0.52	1.53	0	1	29	1	1	1	67
3.26	1.92	67.589	67.2	68.6	0.52	1.55	0	1	29	1	1	1	67
3.28	1.94	68.623	67.4	68.8	0.53	1.55	0	1	29	1	1	1	67
3.3	1.95	69.667	67.5	68.9	0.53	1.56	0	1	29	1	1	1	68
3.32	1.97	70.719	67.7	69.1	0.53	1.58	0	1	28	1	1	1	67
3.34	1.98	71.78	68	69.4	0.53	1.57	0	1	29	1	1	1	68
3.36	1.99	72.85	68.3	69.8	0.54	1.59	0	2	28	1	1	1	67
3.38	2	73.93	68.7	70.1	0.54	1.58	0	1	28	1	1	1	67
3.4	2.01	75.018	69	70.4	0.54	1.59	0	1	28	1	1	1	68
3.42	2.02	76.115	69.3	70.7	0.54	1.59	0	2	28	1	1	1	68
3.44	2.03	77.222	69.7	71.1	0.55	1.6	0	1	28	1	1	1	68
3.46	2.04	78.338	70	71.4	0.55	1.62	1	2	27	2	2	1	67
3.48	2.05	79.463	70.3	71.7	0.55	1.62	1	2	27	2	2	1	67
3.5	2.06	80.597	70.6	72.1	0.55	1.63	1	2	27	2	2	1	67
3.52	2.07	81.74	71	72.4	0.56	1.64	1	2	26	2	2	1	67
3.54	2.09	82.892	71.3	72.7	0.56	1.64	1	2	26	1	1	1	67
3.56	2.1	84.054	71.6	73.1	0.56	1.65	1	2	26	2	2	1	67
3.58	2.11	85.225	71.9	73.4	0.56	1.66	1	1	26	1	1	1	67
3.6	2.12	86.405	72.3	73.7	0.56	1.65	1	2	26	1	1	1	67
3.62	2.13	87.594	72.6	74	0.57	1.65	1	2	26	1	1	1	67
3.64	2.14	88.793	72.9	74.4	0.57	1.65	1	2	26	1	1	1	68

Hydraulic parameter							Percentage of width occupied by fish hydraulic habitat						
Maximum Depth (m)	Average Depth (m)	Discharge (m3/s)	Width (m)	Wetted perimeter (m)	Average velocity (m/s)	Velocity 98% (m/s)	SVS	SS	SD	FVS	FS	FI	FD
3.66	2.15	90.001	73.2	74.7	0.57	1.66	1	2	26	1	1	1	68
3.68	2.16	91.218	73.6	75	0.57	1.67	1	2	26	1	1	1	68
3.7	2.17	92.445	73.9	75.4	0.58	1.69	1	2	25	2	2	1	67
3.72	2.18	93.681	74.2	75.7	0.58	1.69	1	2	25	2	2	1	67
3.74	2.19	94.927	74.5	76	0.58	1.68	1	2	25	1	1	1	68
3.76	2.2	96.181	74.8	76.2	0.58	1.69	1	2	25	2	2	1	68
3.78	2.22	97.446	75	76.5	0.59	1.68	1	2	25	1	1	1	68
3.8	2.23	98.719	75.3	76.8	0.59	1.68	0	2	25	1	1	1	69
3.82	2.24	100	75.5	77	0.59	1.69	0	2	25	1	1	1	69
3.84	2.25	101.3	75.8	77.3	0.59	1.7	0	2	25	1	1	1	69
3.86	2.27	102.6	76	77.5	0.6	1.71	1	2	24	1	1	1	69
3.88	2.28	103.91	76.3	77.8	0.6	1.72	1	2	24	1	1	1	69
3.9	2.29	105.23	76.5	78	0.6	1.7	0	2	25	1	1	1	69

8.2.7 Limpopo @ Poachers Corner

Hydraulic parameter							Percentage of width occupied by fish hydraulic habitat						
Maximum Depth (m)	Average Depth (m)	Discharge (m3/s)	Width (m)	Wetted perimeter (m)	Average velocity (m/s)	Velocity 98% (m/s)	SVS	SS	SD	FVS	FS	FI	FD
0.02	0.01	0	6.2	6.2	0	0.01	100	0	0	0	0	0	0
0.04	0.03	0.001	6.5	6.5	0.01	0.02	100	0	0	0	0	0	0
0.06	0.05	0.004	6.7	6.8	0.01	0.04	100	0	0	0	0	0	0
0.08	0.07	0.01	7	7.1	0.02	0.07	100	0	0	0	0	0	0
0.1	0.08	0.019	7.3	7.4	0.03	0.11	94	6	0	0	0	0	0
0.12	0.1	0.033	7.6	7.7	0.04	0.15	22	78	0	0	0	0	0
0.14	0.12	0.053	7.9	8	0.06	0.19	18	82	0	0	0	0	0

Hydraulic parameter							Percentage of width occupied by fish hydraulic habitat						
Maximum Depth (m)	Average Depth (m)	Discharge (m3/s)	Width (m)	Wetted perimeter (m)	Average velocity (m/s)	Velocity 98% (m/s)	SVS	SS	SD	FVS	FS	FI	FD
0.16	0.12	0.079	8.9	8.9	0.07	0.24	23	76	0	0	1	0	0
0.18	0.12	0.113	10.8	10.9	0.09	0.28	35	63	0	1	1	0	0
0.2	0.12	0.155	13.2	13.3	0.1	0.32	43	54	0	1	2	0	0
0.22	0.11	0.207	17.4	17.5	0.11	0.36	53	42	0	2	1	1	0
0.24	0.11	0.269	20.6	20.7	0.12	0.38	58	37	0	3	0	2	0
0.26	0.13	0.343	21	21.1	0.13	0.4	54	40	0	3	1	2	0
0.28	0.14	0.43	21.4	21.5	0.14	0.42	45	48	0	3	1	2	0
0.3	0.16	0.53	21.8	21.9	0.15	0.46	35	57	0	3	2	3	0
0.32	0.18	0.644	22.1	22.4	0.16	0.49	18	71	0	2	5	1	3
0.34	0.19	0.774	22.5	22.8	0.18	0.53	11	75	0	2	8	1	4
0.36	0.21	0.92	22.9	23.3	0.19	0.56	8	74	0	2	9	2	5
0.38	0.23	1.084	23.3	23.7	0.2	0.59	7	71	0	2	9	4	7
0.4	0.24	1.266	23.7	24.2	0.22	0.62	6	69	0	2	8	7	8
0.42	0.26	1.468	24.1	24.6	0.24	0.66	5	64	0	2	6	12	9
0.44	0.27	1.691	24.5	25.1	0.25	0.69	4	61	0	2	4	17	11
0.46	0.29	1.934	24.9	25.5	0.27	0.73	4	57	0	3	4	19	14
0.48	0.31	2.201	25.3	25.9	0.29	0.77	4	53	0	3	4	19	18
0.5	0.32	2.49	25.7	26.4	0.3	0.79	4	48	2	3	4	15	25
0.52	0.34	2.805	26.1	26.8	0.32	0.83	3	38	9	3	4	9	33
0.54	0.35	3.145	26.5	27.3	0.34	0.86	3	32	11	4	4	5	40
0.56	0.36	3.511	26.9	27.8	0.36	0.9	3	28	11	5	5	4	45
0.58	0.38	3.905	27.1	28	0.38	0.94	3	26	10	4	5	4	47
0.6	0.39	4.317	27.9	29	0.4	0.96	3	24	10	6	4	5	49
0.62	0.31	4.002	36.9	38	0.35	0.84	13	22	9	16	3	3	33
0.64	0.27	3.925	46.2	47.4	0.32	0.79	21	19	9	22	2	3	24
0.66	0.25	4.086	53.8	55.1	0.31	0.76	26	16	9	25	1	1	21

Hydraulic parameter							Percentage of width occupied by fish hydraulic habitat						
Maximum Depth (m)	Average Depth (m)	Discharge (m3/s)	Width (m)	Wetted perimeter (m)	Average velocity (m/s)	Velocity 98% (m/s)	SVS	SS	SD	FVS	FS	FI	FD
0.68	0.23	4.275	63.2	64.6	0.29	0.72	31	14	10	26	1	2	17
0.7	0.22	4.55	73.3	74.8	0.29	0.72	34	11	11	27	2	1	14
0.72	0.19	4.66	92.9	94.4	0.27	0.65	36	15	12	22	5	0	10
0.74	0.19	5.322	100.6	102.3	0.27	0.67	32	16	13	21	8	0	10
0.76	0.2	6.146	106.2	107.9	0.28	0.7	28	16	11	22	10	1	11
0.78	0.19	6.705	123.2	125	0.28	0.69	28	20	10	21	11	2	9
0.8	0.21	7.928	124.7	126.6	0.3	0.72	21	23	9	18	16	2	10
0.82	0.23	9.262	126.2	128.1	0.32	0.76	15	25	9	15	21	4	11
0.84	0.25	11.996	127.5	129.5	0.38	0.83	8	24	7	12	27	8	13
0.86	0.26	12.882	128.8	130.8	0.38	0.85	7	25	7	10	25	13	13
0.88	0.28	13.812	130.1	132.2	0.38	0.87	5	27	7	8	23	17	13
0.9	0.3	14.785	131.4	133.6	0.38	0.87	2	30	7	3	20	24	14
0.92	0.32	15.803	132	134.2	0.38	0.87	2	31	8	3	16	24	17
0.94	0.34	16.867	132	134.3	0.38	0.89	1	31	8	2	13	24	22
0.96	0.36	17.979	132.1	134.4	0.38	0.9	1	31	8	2	7	26	26
0.98	0.38	19.138	132.2	134.6	0.38	0.91	1	31	8	1	3	24	32
1	0.4	20.346	132.3	134.7	0.39	0.94	0	31	7	1	2	21	37
1.02	0.42	21.604	132.3	134.8	0.39	0.96	0	30	7	0	2	18	41
1.04	0.44	22.914	132.4	135	0.4	0.98	0	30	7	0	2	15	45
1.06	0.46	24.275	132.5	135.1	0.4	0.98	0	29	8	0	2	7	54
1.08	0.48	25.69	132.6	135.2	0.41	1	0	28	8	0	1	5	57
1.1	0.5	27.159	132.6	135.4	0.41	1.01	0	27	9	0	0	3	60
1.12	0.51	28.683	132.7	135.5	0.42	1.04	0	25	10	0	0	2	62
1.14	0.53	30.263	132.8	135.6	0.43	1.06	0	22	12	0	0	2	63
1.16	0.55	31.901	132.9	135.8	0.43	1.08	0	20	14	0	0	1	65
1.18	0.57	33.597	132.9	135.9	0.44	1.08	0	16	17	0	0	1	66

Hydraulic parameter							Percentage of width occupied by fish hydraulic habitat						
Maximum Depth (m)	Average Depth (m)	Discharge (m3/s)	Width (m)	Wetted perimeter (m)	Average velocity (m/s)	Velocity 98% (m/s)	SVS	SS	SD	FVS	FS	FI	FD
1.2	0.59	35.353	133	136	0.45	1.09	0	12	20	0	0	1	66
1.22	0.61	37.169	133.1	136.2	0.46	1.12	0	10	22	0	0	0	68
1.24	0.63	39.046	133.2	136.3	0.46	1.14	0	7	24	0	0	0	69
1.26	0.65	40.986	133.2	136.4	0.47	1.16	0	6	24	0	0	0	70
1.28	0.67	42.989	133.3	136.5	0.48	1.18	0	4	25	0	0	0	70
1.3	0.69	45.057	133.4	136.7	0.49	1.2	0	2	27	0	0	0	71
1.32	0.71	47.19	133.5	136.8	0.5	1.22	0	1	27	0	0	0	71
1.34	0.73	49.391	133.5	136.9	0.51	1.23	0	1	27	0	0	0	72
1.36	0.75	51.659	133.6	137.1	0.52	1.24	0	1	27	0	0	0	72
1.38	0.77	53.995	133.7	137.2	0.52	1.26	0	1	26	0	0	0	73
1.4	0.79	56.402	133.8	137.3	0.53	1.29	0	1	26	0	0	0	74
1.42	0.81	58.879	133.8	137.5	0.54	1.31	0	0	25	0	0	0	74
1.44	0.83	61.428	133.9	137.6	0.55	1.33	0	0	25	0	0	1	74
1.46	0.85	64.05	134	137.7	0.56	1.34	0	0	24	0	0	1	75
1.48	0.87	66.746	134.1	137.9	0.57	1.37	0	0	24	0	0	1	75
1.5	0.89	69.517	134.1	138	0.58	1.39	0	0	23	0	0	1	76
1.52	0.91	72.364	134.2	138.1	0.59	1.41	0	0	23	0	0	1	77
1.54	0.93	75.288	134.3	138.3	0.61	1.42	0	0	22	0	0	1	77
1.56	0.95	78.29	134.4	138.4	0.62	1.45	0	0	22	0	1	0	77
1.58	0.97	81.371	134.4	138.5	0.63	1.47	0	0	21	0	1	0	78
1.6	0.98	84.533	134.5	138.6	0.64	1.49	0	0	21	0	1	0	78
1.62	1	87.775	134.6	138.8	0.65	1.51	0	0	20	0	1	0	79
1.64	1.02	91.1	134.7	138.9	0.66	1.53	0	0	20	0	1	0	79
1.66	1.04	94.509	134.7	139	0.67	1.55	0	0	19	0	1	0	80
1.68	1.06	98.002	134.8	139.2	0.68	1.56	0	0	19	0	1	0	80
1.7	1.08	101.58	134.9	139.3	0.7	1.58	0	0	18	0	1	0	81

Hydraulic parameter							Percentage of width occupied by fish hydraulic habitat						
Maximum Depth (m)	Average Depth (m)	Discharge (m3/s)	Width (m)	Wetted perimeter (m)	Average velocity (m/s)	Velocity 98% (m/s)	SVS	SS	SD	FVS	FS	FI	FD
1.72	1.1	105.245	135	139.4	0.71	1.6	0	0	18	1	0	0	81
1.74	1.12	108.997	135	139.6	0.72	1.65	0	0	17	1	0	0	82
1.76	1.14	112.838	135.1	139.7	0.73	1.67	0	0	17	1	0	0	82
1.78	1.16	116.769	135.5	140.1	0.74	1.69	0	0	16	1	0	0	83
1.8	1.17	120.79	135.9	140.6	0.76	1.7	0	0	16	1	0	0	83
1.82	1.19	124.903	136.3	141	0.77	1.71	0	0	16	1	0	0	83
1.84	1.21	129.109	136.7	141.5	0.78	1.75	0	0	15	1	0	0	83
1.86	1.22	133.409	137.1	141.9	0.8	1.78	0	0	15	1	0	0	83
1.88	1.24	137.803	137.5	142.4	0.81	1.79	0	0	14	1	0	0	84
1.9	1.26	142.294	137.9	142.8	0.82	1.81	0	0	14	1	0	0	84
1.92	1.27	146.882	138.3	143.3	0.83	1.82	0	0	14	1	1	0	83
1.94	1.29	151.567	138.7	143.7	0.85	1.85	0	0	13	1	1	0	84
1.96	1.3	156.352	139.1	144.1	0.86	1.85	0	0	13	1	1	0	85
1.98	1.32	161.237	139.4	144.5	0.88	1.89	0	0	12	1	1	1	84
2	1.34	166.223	139.8	144.9	0.89	1.92	0	0	12	1	1	1	84
2.02	1.35	171.311	140.2	145.3	0.9	1.91	0	0	12	1	1	1	85
2.04	1.36	176.503	141.3	146.3	0.92	1.93	0	0	12	1	1	1	85
2.06	1.37	181.799	142.4	147.4	0.93	1.97	0	0	11	2	2	1	84
2.08	1.38	187.201	143.4	148.5	0.94	2.02	0	0	10	3	1	1	84
2.1	1.39	192.708	144.5	149.5	0.96	2.04	0	0	10	3	2	1	84
2.12	1.4	198.324	145.5	150.6	0.97	2.03	0	0	10	3	1	1	85
2.14	1.41	204.048	146.6	151.7	0.99	2.05	0	0	10	3	2	1	84
2.16	1.42	209.882	147.6	152.7	1	2.05	0	1	9	2	2	1	84
2.18	1.43	215.826	148.7	153.8	1.01	2.09	0	1	9	3	2	2	83
2.2	1.44	221.883	149.7	154.9	1.03	2.11	0	1	9	2	2	2	84
2.22	1.45	228.052	150.8	155.9	1.04	2.16	0	1	8	4	3	2	83

Hydraulic parameter							Percentage of width occupied by fish hydraulic habitat						
Maximum Depth (m)	Average Depth (m)	Discharge (m3/s)	Width (m)	Wetted perimeter (m)	Average velocity (m/s)	Velocity 98% (m/s)	SVS	SS	SD	FVS	FS	FI	FD
2.24	1.46	234.335	151.8	157	1.06	2.19	0	1	8	3	3	2	83
2.26	1.47	240.732	152.7	157.9	1.07	2.2	0	1	8	2	2	2	84
2.28	1.49	247.246	153.3	158.5	1.08	2.22	0	1	8	2	2	2	84
2.3	1.5	253.877	153.9	159.1	1.1	2.28	0	1	7	3	3	3	83
2.32	1.52	260.626	154.5	159.7	1.11	2.28	0	1	7	2	3	3	84
2.34	1.53	267.494	155.1	160.3	1.13	2.31	0	1	7	2	3	4	83
2.36	1.54	274.483	155.7	160.9	1.14	2.32	0	1	7	2	3	3	84
2.38	1.56	281.592	156.3	161.5	1.16	2.34	0	1	7	2	3	3	84
2.4	1.55	288.824	159.1	164.3	1.17	2.38	0	1	6	3	3	2	85
2.42	1.54	296.18	162.4	167.6	1.19	2.4	0	1	6	3	3	3	83
2.44	1.53	303.66	165.7	171	1.2	2.45	0	1	6	5	4	3	82
2.46	1.54	311.265	167.1	172.4	1.21	2.45	0	1	6	4	4	3	83
2.48	1.55	318.997	167.2	172.5	1.23	2.49	0	1	6	4	4	2	83
2.5	1.57	326.857	167.3	172.6	1.24	2.51	0	1	5	4	4	2	83
2.52	1.59	334.845	167.4	172.7	1.26	2.52	0	1	5	4	3	2	84
2.54	1.61	342.963	167.5	172.8	1.27	2.59	0	1	5	4	4	2	84
2.56	1.63	351.212	167.6	172.9	1.29	2.6	0	1	5	3	3	2	86
2.58	1.65	359.593	167.7	173	1.3	2.66	0	1	5	3	3	2	86
2.6	1.67	368.107	167.8	173.1	1.31	2.66	0	1	5	1	2	3	88
2.62	1.69	376.754	167.9	173.2	1.33	2.69	0	1	5	0	1	4	89
2.64	1.71	385.537	168	173.3	1.34	2.73	0	1	5	1	1	4	88
2.66	1.73	394.456	168	173.4	1.36	2.75	0	1	5	0	1	4	89
2.68	1.75	403.512	168.1	173.5	1.38	2.81	0	1	5	1	1	4	89
2.7	1.76	412.707	168.2	173.6	1.39	2.81	0	1	5	0	1	4	90
2.72	1.78	422.04	168.3	173.7	1.41	2.85	0	1	5	0	1	3	91
2.74	1.8	431.515	168.4	173.8	1.42	2.89	0	1	5	1	1	3	90

Hydraulic parameter							Percentage of width occupied by fish hydraulic habitat						
Maximum Depth (m)	Average Depth (m)	Discharge (m3/s)	Width (m)	Wetted perimeter (m)	Average velocity (m/s)	Velocity 98% (m/s)	SVS	SS	SD	FVS	FS	FI	FD
2.76	1.82	441.13	168.5	173.9	1.44	2.92	0	0	5	1	1	3	91
2.78	1.84	450.888	168.5	174	1.45	2.93	0	0	5	0	0	2	93
2.8	1.86	460.79	168.6	174.1	1.47	2.97	0	0	5	1	1	1	93
2.82	1.88	470.836	168.7	174.1	1.49	2.98	0	0	5	0	0	1	94
2.84	1.9	481.028	168.7	174.2	1.5	3.02	0	0	5	0	0	0	95
2.86	1.92	491.367	168.8	174.3	1.52	3.08	0	0	5	0	0	0	94
2.88	1.94	501.854	168.9	174.4	1.53	3.08	0	0	4	0	0	0	95
2.9	1.96	512.489	168.9	174.4	1.55	3.15	0	0	4	0	0	0	94
2.92	1.98	523.275	169	174.5	1.57	3.2	0	0	4	0	0	0	94
2.94	1.99	534.211	169.1	174.6	1.58	3.21	0	0	4	0	0	0	95
2.96	2.01	545.3	169.1	174.7	1.6	3.26	0	0	4	0	0	0	95
2.98	2.03	556.542	169.2	174.8	1.62	3.28	0	0	4	0	0	0	95
3	2.05	567.938	169.3	174.8	1.63	3.27	0	0	4	0	0	0	96
3.02	2.07	579.489	169.3	174.9	1.65	3.35	0	0	4	0	0	0	95
3.04	2.09	591.196	169.4	175	1.67	3.36	0	0	4	0	0	0	96
3.06	2.11	603.062	169.5	175.1	1.69	3.43	0	0	4	0	0	0	95
3.08	2.13	615.085	169.6	175.3	1.7	3.47	0	0	4	0	0	0	95
3.1	2.15	627.268	169.7	175.4	1.72	3.51	0	0	4	0	0	0	95
3.12	2.17	639.612	169.8	175.5	1.74	3.53	0	0	4	0	0	0	95
3.14	2.19	652.118	169.8	175.7	1.76	3.57	0	0	4	0	0	0	95
3.16	2.2	664.786	169.9	175.8	1.77	3.63	0	0	4	0	0	0	96
3.18	2.22	677.618	170	175.9	1.79	3.67	0	0	4	0	0	0	96
3.2	2.24	690.615	170.1	176.1	1.81	3.7	0	0	4	0	0	0	96
3.22	2.26	703.778	170.2	176.2	1.83	3.74	0	0	4	0	0	0	96
3.24	2.28	717.108	170.3	176.3	1.85	3.75	0	0	4	0	0	0	96
3.26	2.3	730.606	170.4	176.5	1.87	3.79	0	0	4	0	0	0	96

Hydraulic parameter							Percentage of width occupied by fish hydraulic habitat						
Maximum Depth (m)	Average Depth (m)	Discharge (m3/s)	Width (m)	Wetted perimeter (m)	Average velocity (m/s)	Velocity 98% (m/s)	SVS	SS	SD	FVS	FS	FI	FD
3.28	2.32	744.274	170.4	176.6	1.88	3.85	0	0	4	0	0	0	96
3.3	2.34	758.111	170.5	176.7	1.9	3.89	0	0	4	0	0	0	96
3.32	2.35	772.12	170.6	176.9	1.92	3.93	0	0	4	0	0	0	96
3.34	2.37	786.301	170.7	177	1.94	3.97	0	0	4	0	0	0	96
3.36	2.39	800.656	170.8	177.2	1.96	4	0	0	4	0	0	0	96
3.38	2.41	815.185	170.9	177.3	1.98	4.01	0	0	4	0	0	0	96
3.4	2.43	829.89	171	177.4	2	4.07	0	0	4	0	0	1	96
3.42	2.45	844.772	171	177.6	2.02	4.12	0	0	3	0	0	1	96
3.44	2.47	859.831	171.1	177.7	2.04	4.15	0	0	3	0	0	1	96
3.46	2.49	875.069	171.2	177.8	2.06	4.2	0	0	3	0	0	1	96
3.48	2.51	890.487	171.3	178	2.08	4.24	0	0	3	0	0	1	96
3.5	2.52	906.086	171.4	178.1	2.09	4.27	0	0	3	0	0	1	96
3.52	2.54	921.867	171.5	178.2	2.11	4.3	0	0	3	0	0	1	96
3.54	2.56	937.831	171.6	178.4	2.13	4.35	0	0	3	0	0	0	96
3.56	2.58	953.98	171.7	178.5	2.15	4.4	0	0	3	0	0	0	96
3.58	2.6	970.313	171.7	178.6	2.17	4.44	0	0	3	0	0	0	96
3.6	2.62	986.833	171.8	178.8	2.19	4.49	0	0	3	0	0	0	96
3.62	2.64	1003.54	171.9	178.9	2.21	4.53	0	0	3	0	0	0	96
3.64	2.65	1020.436	172	179	2.23	4.56	0	0	3	0	0	0	96
3.66	2.67	1037.521	172.1	179.2	2.26	4.57	0	0	3	0	0	0	96
3.68	2.69	1054.797	172.1	179.3	2.28	4.61	0	0	3	0	0	0	96
3.7	2.71	1072.264	172.2	179.4	2.3	4.65	0	0	3	0	0	0	96
3.72	2.73	1089.925	172.3	179.5	2.32	4.69	0	0	3	0	0	0	97
3.74	2.75	1107.779	172.4	179.6	2.34	4.73	0	0	3	0	0	0	97
3.76	2.77	1125.828	172.4	179.8	2.36	4.77	0	0	3	0	0	0	97
3.78	2.79	1144.073	172.5	179.9	2.38	4.81	0	0	3	0	0	0	97

Hydraulic parameter							Percentage of width occupied by fish hydraulic habitat						
Maximum Depth (m)	Average Depth (m)	Discharge (m3/s)	Width (m)	Wetted perimeter (m)	Average velocity (m/s)	Velocity 98% (m/s)	SVS	SS	SD	FVS	FS	FI	FD
3.8	2.81	1162.515	172.6	180	2.4	4.83	0	0	3	0	0	0	97
3.82	2.82	1181.155	172.6	180.1	2.42	4.89	0	0	3	0	0	0	97
3.84	2.84	1199.994	172.7	180.3	2.44	4.94	0	0	3	0	0	0	97
3.86	2.86	1219.034	172.8	180.4	2.47	5.01	0	0	3	0	0	0	97
3.88	2.88	1238.275	172.8	180.5	2.49	5.05	0	0	3	0	0	0	97
3.9	2.9	1257.718	172.9	180.6	2.51	5.1	0	0	3	0	0	0	97
3.92	2.92	1277.365	173	180.7	2.53	5.14	0	0	3	0	0	0	97
3.94	2.94	1297.217	173.1	180.9	2.55	5.16	0	0	3	0	0	0	97
3.96	2.96	1317.274	173.1	181	2.57	5.22	0	0	3	0	0	0	97
3.98	2.98	1337.537	173.2	181.1	2.6	5.25	0	0	3	0	0	0	97
4	2.99	1358.009	173.3	181.2	2.62	5.29	0	0	3	0	0	0	97
4.02	3.01	1378.69	173.3	181.3	2.64	5.32	0	0	3	0	0	0	97
4.04	3.03	1399.58	173.4	181.5	2.66	5.37	0	0	3	0	0	0	97
4.06	3.05	1420.682	173.5	181.6	2.68	5.42	0	0	3	0	0	0	97
4.08	3.07	1441.995	173.5	181.7	2.71	5.45	0	0	3	0	0	0	97
4.1	3.09	1463.522	173.6	181.8	2.73	5.47	0	0	3	0	0	0	97
4.12	3.11	1485.263	173.7	181.9	2.75	5.54	0	0	3	0	0	0	96
4.14	3.13	1507.22	173.8	182.1	2.78	5.61	0	0	3	1	1	1	95
4.16	3.14	1529.392	173.8	182.2	2.8	5.67	0	0	3	1	1	1	95
4.18	3.16	1551.783	173.9	182.3	2.82	5.72	0	0	2	1	1	1	96
4.2	3.18	1574.391	174	182.4	2.84	5.78	0	0	2	1	1	1	96
4.22	3.2	1597.22	174	182.6	2.87	5.83	0	0	2	1	1	1	96
4.24	3.22	1620.269	174.1	182.7	2.89	5.88	0	0	2	1	1	1	96
4.26	3.24	1643.54	174.2	182.8	2.91	5.9	0	0	2	1	1	1	96
4.28	3.26	1667.034	174.3	182.9	2.94	5.94	0	0	2	1	1	1	96
4.3	3.27	1690.752	174.3	183	2.96	6	0	0	2	1	1	1	96

Hydraulic parameter							Percentage of width occupied by fish hydraulic habitat						
Maximum Depth (m)	Average Depth (m)	Discharge (m3/s)	Width (m)	Wetted perimeter (m)	Average velocity (m/s)	Velocity 98% (m/s)	SVS	SS	SD	FVS	FS	FI	FD
4.32	3.29	1714.695	174.4	183.2	2.99	6.1	0	0	2	1	1	1	96
4.34	3.31	1738.864	174.5	183.3	3.01	6.16	0	0	2	1	1	1	96
4.36	3.33	1763.26	174.5	183.4	3.03	6.21	0	0	2	1	1	1	96
4.38	3.35	1787.885	174.6	183.5	3.06	6.27	0	0	2	1	1	1	96
4.4	3.37	1812.738	174.7	183.6	3.08	6.32	0	0	2	1	1	1	96
4.42	3.39	1837.823	174.7	183.8	3.11	6.33	0	0	2	1	1	1	96
4.44	3.41	1863.138	174.8	183.9	3.13	6.4	0	0	2	1	1	1	96
4.46	3.42	1888.687	174.9	184	3.15	6.47	0	0	2	1	1	1	96
4.48	3.44	1914.469	175	184.1	3.18	6.54	0	0	2	1	1	1	96
4.5	3.46	1940.485	175	184.2	3.2	6.59	0	0	2	1	1	1	96
4.52	3.48	1966.738	175.1	184.4	3.23	6.65	0	0	2	1	1	1	96
4.54	3.5	1993.227	175.2	184.5	3.25	6.69	0	0	2	1	1	1	96
4.56	3.52	2019.955	175.2	184.6	3.28	6.74	0	0	2	1	1	1	96
4.58	3.54	2046.921	175.3	184.7	3.3	6.74	0	0	2	1	1	1	96
4.6	3.55	2074.128	175.4	184.9	3.33	6.74	0	0	2	0	0	0	97
4.62	3.57	2101.576	175.5	185	3.35	6.8	0	0	2	0	0	0	97
4.64	3.59	2129.266	175.5	185.1	3.38	6.87	0	0	2	0	0	0	97
4.66	3.61	2157.2	175.6	185.2	3.4	6.94	0	0	2	0	0	0	97
4.68	3.63	2185.378	175.7	185.3	3.43	7	0	0	2	0	0	0	97
4.7	3.65	2213.802	175.7	185.5	3.45	7.06	0	0	2	0	0	0	97
4.72	3.67	2242.472	175.8	185.6	3.48	7.1	0	0	2	0	0	0	97
4.74	3.68	2271.39	175.9	185.7	3.51	7.15	0	0	2	0	0	0	97
4.76	3.7	2300.556	175.9	185.8	3.53	7.17	0	0	2	0	0	0	97
4.78	3.72	2329.973	176	185.9	3.56	7.25	0	0	2	0	0	0	97
4.8	3.74	2359.641	176.1	186.1	3.58	7.32	0	0	2	0	0	0	97
4.82	3.76	2389.56	176.2	186.2	3.61	7.39	0	0	2	0	0	0	97

Hydraulic parameter							Percentage of width occupied by fish hydraulic habitat						
Maximum Depth (m)	Average Depth (m)	Discharge (m3/s)	Width (m)	Wetted perimeter (m)	Average velocity (m/s)	Velocity 98% (m/s)	SVS	SS	SD	FVS	FS	FI	FD
4.84	3.77	2419.733	176.3	186.4	3.64	7.46	0	0	2	0	0	0	97
4.86	3.79	2450.16	176.4	186.6	3.66	7.52	0	0	2	0	0	0	97
4.88	3.81	2480.842	176.6	186.7	3.69	7.57	0	0	2	0	0	0	97
4.9	3.83	2511.781	176.7	186.9	3.71	7.61	0	0	2	0	0	0	97
4.92	3.84	2542.977	176.8	187.1	3.74	7.66	0	0	2	0	0	0	97
4.94	3.86	2574.432	176.9	187.2	3.77	7.67	0	0	2	0	0	0	97
4.96	3.88	2606.146	177	187.4	3.79	7.75	0	0	2	0	0	0	97
4.98	3.9	2638.121	177.1	187.5	3.82	7.83	0	0	2	0	0	0	97
5	3.91	2670.357	177.3	187.7	3.85	7.89	0	0	2	0	0	0	97

8.2.8 Sand

Hydraulic parameter							Percentage of width occupied by fish hydraulic habitat						
Maximum Depth (m)	Average Depth (m)	Discharge (m3/s)	Width (m)	Wetted perimeter (m)	Average velocity (m/s)	Velocity 98% (m/s)	SVS	SS	SD	FVS	FS	FI	FD
0.02	0.01	0	0.5	0.5	0.01	0.04	100	0	0	0	0	0	0
0.04	0.02	0	1	1	0.02	0.07	100	0	0	0	0	0	0
0.06	0.03	0.001	1.6	1.6	0.03	0.09	100	0	0	0	0	0	0
0.08	0.04	0.003	2.1	2.1	0.03	0.12	100	0	0	0	0	0	0
0.1	0.04	0.005	3	3	0.04	0.14	99	1	0	0	0	0	0
0.12	0.05	0.009	4	4	0.05	0.16	87	13	0	0	0	0	0
0.14	0.06	0.044	4.9	4.9	0.15	0.5	70	19	0	9	2	0	0
0.16	0.07	0.066	5.8	5.9	0.16	0.53	63	24	0	9	4	0	0
0.18	0.08	0.093	6.8	6.8	0.18	0.58	58	26	0	11	5	0	0
0.2	0.09	0.126	7.7	7.7	0.19	0.62	49	32	0	12	7	0	0
0.22	0.1	0.167	8.6	8.7	0.2	0.65	41	37	0	11	9	1	0

Hydraulic parameter							Percentage of width occupied by fish hydraulic habitat						
Maximum Depth (m)	Average Depth (m)	Discharge (m3/s)	Width (m)	Wetted perimeter (m)	Average velocity (m/s)	Velocity 98% (m/s)	SVS	SS	SD	FVS	FS	FI	FD
0.24	0.11	0.216	9.5	9.5	0.21	0.7	36	40	0	12	10	3	0
0.26	0.12	0.274	10.2	10.3	0.23	0.74	31	41	0	12	12	4	0
0.28	0.13	0.34	11	11	0.24	0.78	26	43	0	12	13	6	0
0.3	0.14	0.417	11.6	11.7	0.25	0.83	22	43	0	12	14	9	0
0.32	0.15	0.504	12.2	12.3	0.27	0.87	19	44	0	11	14	11	2
0.34	0.16	0.602	13.1	13.2	0.28	0.91	17	43	0	11	14	12	3
0.36	0.17	0.712	14.0	14.1	0.3	0.95	16	42	0	11	13	14	4
0.38	0.18	0.835	14.9	15	0.31	1	15	40	0	12	12	14	7
0.4	0.19	0.971	15.8	15.9	0.32	1.03	14	40	0	12	12	14	9
0.42	0.2	1.121	16.7	16.8	0.34	1.09	14	37	0	13	11	14	12
0.44	0.21	1.285	17.6	17.7	0.35	1.12	12	36	0	13	11	14	14
0.46	0.22	1.465	18.5	18.6	0.36	1.15	11	36	0	13	11	12	17
0.48	0.23	1.66	19.5	19.7	0.38	1.2	11	35	0	13	11	12	19
0.5	0.23	1.872	20.8	21	0.39	1.23	10	34	0	13	12	11	21
0.52	0.23	2.101	22.4	22.6	0.4	1.24	10	32	1	13	12	10	22
0.54	0.24	2.348	24	24.2	0.41	1.28	11	29	2	15	11	9	24
0.56	0.24	2.613	25.7	25.9	0.42	1.31	11	27	2	16	11	9	24
0.58	0.25	2.897	27.3	27.5	0.43	1.34	11	26	3	16	11	9	24
0.6	0.26	3.2	28.1	28.4	0.44	1.37	10	25	4	15	11	10	25
0.62	0.28	3.524	28.5	28.8	0.45	1.4	8	25	5	13	12	10	27
0.64	0.29	3.869	28.9	29.2	0.46	1.44	6	25	6	10	14	10	28
0.66	0.31	4.236	29.3	29.6	0.47	1.45	4	25	8	7	16	11	30
0.68	0.32	4.625	29.7	30	0.48	1.47	3	25	8	5	17	10	33
0.7	0.34	5.036	30.1	30.4	0.49	1.51	2	23	9	5	15	11	35
0.72	0.34	5.471	31.4	31.7	0.51	1.55	3	21	9	7	13	12	36
0.74	0.34	5.93	33.4	33.7	0.52	1.56	4	19	9	9	10	14	35

Hydraulic parameter							Percentage of width occupied by fish hydraulic habitat						
Maximum Depth (m)	Average Depth (m)	Discharge (m3/s)	Width (m)	Wetted perimeter (m)	Average velocity (m/s)	Velocity 98% (m/s)	SVS	SS	SD	FVS	FS	FI	FD
0.76	0.34	6.414	35.4	35.7	0.53	1.58	5	17	9	11	7	14	36
0.78	0.34	6.924	37.5	37.8	0.54	1.6	6	16	9	13	6	13	37
0.8	0.34	7.459	39.8	40.1	0.55	1.63	7	14	9	16	3	12	37
0.82	0.35	8.021	41.9	42.3	0.55	1.64	7	14	9	16	6	11	37
0.84	0.35	8.61	43.2	43.6	0.56	1.67	6	14	9	16	8	8	39
0.86	0.37	9.227	44.3	44.7	0.57	1.67	5	14	9	13	10	6	42
0.88	0.37	9.872	46	46.5	0.58	1.69	5	14	9	13	12	4	43
0.9	0.36	10.547	49.6	50.1	0.58	1.69	6	13	9	15	12	4	41
0.92	0.36	11.251	52.9	53.4	0.59	1.69	6	13	9	15	13	5	39
0.94	0.37	11.986	55	55.4	0.59	1.73	6	12	9	17	12	6	38
0.96	0.37	12.751	57	57.5	0.6	1.71	5	13	9	14	13	8	38
0.98	0.38	13.549	59.4	59.9	0.6	1.72	5	13	9	13	13	9	38
1	0.38	14.378	61.8	62.3	0.61	1.73	5	12	9	15	11	11	37
1.02	0.38	15.24	64.8	65.4	0.61	1.75	5	12	9	15	14	8	38
1.04	0.39	16.136	68.1	68.7	0.61	1.77	5	11	9	16	11	11	37
1.06	0.39	17.066	71	71.7	0.62	1.76	5	12	9	14	14	9	37
1.08	0.4	18.03	72.7	73.4	0.62	1.74	4	12	10	12	14	10	39
1.1	0.41	19.03	74.8	75.4	0.62	1.72	4	12	10	11	13	10	41
1.12	0.4	20.066	80.1	80.8	0.63	1.74	4	12	9	13	13	9	39
1.14	0.41	21.138	82.7	83.4	0.63	1.73	4	12	9	13	12	10	40
1.16	0.42	22.248	85.2	85.9	0.63	1.77	4	12	8	13	12	11	39
1.18	0.43	23.395	87.2	87.9	0.63	1.76	4	12	8	12	10	12	41
1.2	0.44	24.58	89.1	89.8	0.63	1.75	3	13	8	9	13	12	41
1.22	0.45	25.805	90.9	91.7	0.63	1.78	3	13	8	10	12	11	42
1.24	0.46	27.069	92.7	93.5	0.64	1.75	3	13	8	8	12	11	44
1.26	0.47	28.373	94.6	95.4	0.64	1.74	2	13	9	7	11	10	47

Hydraulic parameter							Percentage of width occupied by fish hydraulic habitat						
Maximum Depth (m)	Average Depth (m)	Discharge (m3/s)	Width (m)	Wetted perimeter (m)	Average velocity (m/s)	Velocity 98% (m/s)	SVS	SS	SD	FVS	FS	FI	FD
1.28	0.48	29.718	96.4	97.2	0.64	1.77	2	12	9	8	11	9	48
1.3	0.49	31.105	98	98.8	0.64	1.74	2	12	10	6	11	11	49
1.32	0.5	32.533	99.6	100.5	0.65	1.73	2	12	10	5	8	12	50
1.34	0.52	34.005	101.2	102.1	0.65	1.77	2	11	10	7	7	12	51
1.36	0.53	35.519	102.8	103.8	0.65	1.75	2	11	11	5	8	11	53
1.38	0.54	37.077	104.1	105.1	0.66	1.76	2	11	11	5	7	12	54
1.4	0.56	38.68	105.1	106.1	0.66	1.75	1	10	11	4	6	10	57
1.42	0.57	40.328	106	107	0.67	1.75	1	10	11	4	5	9	60
1.44	0.59	42.022	106.8	107.8	0.67	1.79	1	10	11	4	7	6	61
1.46	0.61	43.761	107	108	0.68	1.79	0	10	11	2	9	6	62
1.48	0.62	45.548	107.2	108.3	0.68	1.8	0	9	12	2	6	7	63
1.5	0.64	47.382	107.4	108.5	0.69	1.81	1	9	12	2	5	6	66
1.52	0.66	49.265	107.6	108.7	0.69	1.82	0	8	13	1	5	7	66
1.54	0.68	51.196	107.8	108.9	0.7	1.82	0	8	13	1	3	8	68
1.56	0.7	53.176	108	109.1	0.7	1.82	0	7	13	1	3	6	69
1.58	0.72	55.206	108.2	109.3	0.71	1.82	0	6	14	1	2	6	71
1.6	0.74	57.287	108.4	109.5	0.72	1.83	0	6	14	0	1	6	73
1.62	0.76	59.418	108.5	109.7	0.72	1.83	0	5	15	0	1	5	75
1.64	0.78	61.602	108.7	109.9	0.73	1.86	0	5	14	1	1	4	76
1.66	0.79	63.838	108.8	110	0.74	1.88	0	4	14	1	0	3	77
1.68	0.81	66.126	108.9	110.2	0.75	1.86	0	4	15	0	0	3	78
1.7	0.83	68.469	109.1	110.3	0.75	1.87	0	3	15	0	0	2	79
1.72	0.85	70.865	109.2	110.5	0.76	1.9	0	3	15	1	0	1	79
1.74	0.87	73.316	109.4	110.6	0.77	1.92	0	3	15	1	1	1	79
1.76	0.89	75.822	109.5	110.8	0.78	1.91	0	2	16	0	1	1	81
1.78	0.91	78.385	109.7	110.9	0.79	1.91	0	2	15	0	1	0	82

Hydraulic parameter							Percentage of width occupied by fish hydraulic habitat						
Maximum Depth (m)	Average Depth (m)	Discharge (m3/s)	Width (m)	Wetted perimeter (m)	Average velocity (m/s)	Velocity 98% (m/s)	SVS	SS	SD	FVS	FS	FI	FD
1.8	0.93	81.003	109.8	111.1	0.8	1.95	0	2	15	1	1	0	81
1.82	0.94	83.679	110	111.2	0.81	1.97	0	1	15	1	1	0	82
1.84	0.96	86.413	110.1	111.4	0.81	1.97	0	1	15	0	1	0	83
1.86	0.98	89.204	110.3	111.5	0.82	1.97	0	1	15	0	1	0	83
1.88	1	92.055	110.4	111.7	0.83	2.01	0	1	15	1	1	0	82
1.9	1.02	94.965	110.6	111.8	0.84	2.03	0	1	15	1	1	0	83
1.92	1.04	97.935	111	112.3	0.85	2.02	0	1	15	0	0	0	84
1.94	1.05	100.966	111.6	112.8	0.86	2.03	0	0	14	1	0	0	83
1.96	1.06	104.059	112.1	113.4	0.87	2.04	0	0	14	1	1	0	83
1.98	1.08	107.213	112.7	114	0.88	2.06	0	0	14	1	1	1	83
2	1.09	110.429	113.3	114.6	0.89	2.06	0	0	14	1	0	0	84
2.02	1.11	113.709	113.9	115.2	0.9	2.1	0	1	13	2	1	0	83
2.04	1.12	117.052	114.5	115.8	0.91	2.1	0	0	13	2	1	0	83
2.06	1.14	120.459	115	116.4	0.92	2.13	0	0	13	2	1	0	82
2.08	1.12	123.931	119.3	120.7	0.93	2.14	1	1	12	4	2	0	80
2.1	1.09	127.469	124.3	125.6	0.94	2.12	1	1	11	6	3	1	78
2.12	1.08	131.073	128	129.4	0.95	2.14	1	1	11	7	4	1	76
2.14	1.1	134.743	128.2	129.5	0.96	2.17	1	1	11	7	4	1	75
2.16	1.12	138.48	128.3	129.6	0.97	2.18	1	1	10	7	4	1	75
2.18	1.14	142.286	128.4	129.8	0.98	2.19	1	1	10	7	4	2	76
2.2	1.15	146.159	128.5	129.9	0.99	2.2	1	1	10	7	4	2	76
2.22	1.17	150.102	128.7	130	0.99	2.21	1	1	10	6	4	2	76
2.24	1.19	154.114	128.8	130.2	1	2.25	0	1	10	3	4	4	77
2.26	1.21	158.196	128.9	130.3	1.01	2.24	0	2	10	1	3	6	78
2.28	1.23	162.349	129	130.4	1.02	2.25	0	2	10	0	3	7	78
2.3	1.25	166.574	129.2	130.6	1.03	2.26	0	2	10	0	3	6	80

Hydraulic parameter							Percentage of width occupied by fish hydraulic habitat						
Maximum Depth (m)	Average Depth (m)	Discharge (m3/s)	Width (m)	Wetted perimeter (m)	Average velocity (m/s)	Velocity 98% (m/s)	SVS	SS	SD	FVS	FS	FI	FD
2.32	1.27	170.87	129.3	130.7	1.04	2.28	0	1	10	0	3	6	80
2.34	1.29	175.239	129.4	130.8	1.05	2.3	0	1	9	0	3	6	80
2.36	1.3	179.681	129.6	131	1.06	2.32	0	1	9	0	2	6	81
2.38	1.32	184.196	129.7	131.1	1.07	2.37	0	1	9	1	3	6	81
2.4	1.34	188.786	129.8	131.3	1.08	2.35	0	1	9	0	2	4	84
2.42	1.36	193.45	130	131.4	1.09	2.42	0	1	9	1	1	2	86
2.44	1.38	198.19	130.1	131.5	1.1	2.42	0	1	8	1	0	0	89
2.46	1.4	203.007	130.3	131.7	1.12	2.42	0	1	9	0	0	0	90
2.48	1.42	207.899	130.4	131.8	1.13	2.45	0	1	8	1	0	0	89
2.5	1.43	212.869	130.5	132	1.14	2.44	0	1	8	0	0	0	90
2.52	1.45	217.917	130.7	132.1	1.15	2.47	0	1	8	1	0	0	90
2.54	1.47	223.043	130.8	132.3	1.16	2.47	0	1	8	0	0	0	91
2.56	1.49	228.248	131	132.4	1.17	2.51	0	1	8	1	0	0	90
2.58	1.51	233.532	131.1	132.6	1.18	2.5	0	1	8	0	0	0	91
2.6	1.53	238.897	131.2	132.7	1.19	2.58	0	1	8	1	1	1	90
2.62	1.54	244.342	131.4	132.9	1.2	2.56	0	0	8	0	0	1	91
2.64	1.56	249.869	131.5	133	1.22	2.6	0	0	8	1	1	1	90
2.66	1.58	255.478	131.7	133.2	1.23	2.59	0	0	8	0	0	1	91
2.68	1.6	261.169	131.8	133.3	1.24	2.61	0	0	8	0	0	1	91
2.7	1.62	266.943	131.9	133.4	1.25	2.65	0	0	8	1	1	1	90
2.72	1.64	272.8	132.1	133.6	1.26	2.67	0	0	8	1	1	1	90
2.74	1.65	278.742	132.2	133.7	1.27	2.68	0	0	8	0	0	0	91
2.76	1.67	284.769	132.4	133.9	1.29	2.67	0	0	8	0	0	1	92
2.78	1.69	290.881	132.5	134	1.3	2.72	0	0	7	0	0	0	91
2.8	1.71	297.079	132.7	134.2	1.31	2.73	0	0	7	0	0	0	92
2.82	1.73	303.363	132.8	134.3	1.32	2.76	0	0	7	0	0	0	92

Hydraulic parameter							Percentage of width occupied by fish hydraulic habitat						
Maximum Depth (m)	Average Depth (m)	Discharge (m3/s)	Width (m)	Wetted perimeter (m)	Average velocity (m/s)	Velocity 98% (m/s)	SVS	SS	SD	FVS	FS	FI	FD
2.84	1.74	309.735	133	134.5	1.34	2.81	0	0	7	0	0	0	91
2.86	1.76	316.194	133.1	134.7	1.35	2.78	0	0	7	0	0	0	92
2.88	1.78	322.742	133.3	134.8	1.36	2.82	0	0	7	0	0	0	91
2.9	1.8	329.378	133.4	135	1.37	2.8	0	0	7	0	0	1	92
2.92	1.82	336.104	133.6	135.1	1.39	2.81	0	0	7	0	0	1	92
2.94	1.83	342.92	133.7	135.3	1.4	2.83	0	0	7	0	0	1	92
2.96	1.85	349.827	133.9	135.5	1.41	2.9	0	0	6	0	0	1	91
2.98	1.87	356.824	134	135.6	1.42	2.91	0	0	6	0	0	1	93
3	1.89	363.914	134.2	135.8	1.44	2.97	0	0	6	0	0	1	92
3.02	1.91	371.096	134.3	135.9	1.45	3.01	0	0	6	0	0	1	92
3.04	1.92	378.371	134.5	136.1	1.46	3.01	0	0	6	0	0	1	93
3.06	1.94	385.739	134.6	136.2	1.48	3.04	0	0	6	0	0	1	93
3.08	1.96	393.201	134.8	136.4	1.49	3.09	0	0	6	0	0	1	92
3.1	1.98	400.758	135	136.6	1.5	3.11	0	0	6	0	0	1	92
3.12	1.99	408.41	135.2	136.8	1.52	3.1	0	0	6	0	0	1	93
3.14	2.01	416.158	135.4	137.1	1.53	3.11	0	0	6	0	0	1	94
3.16	2.03	424.003	135.7	137.3	1.54	3.13	0	0	5	0	0	1	94
3.18	2.04	431.944	135.9	137.5	1.56	3.15	0	0	5	0	0	1	94
3.2	2.06	439.983	136.1	137.7	1.57	3.18	0	0	5	0	0	1	94
3.22	2.08	448.12	136.3	137.9	1.58	3.2	0	0	5	0	0	1	94
3.24	2.09	456.356	136.5	138.1	1.6	3.23	0	0	5	0	0	1	94
3.26	2.11	464.691	136.7	138.3	1.61	3.27	0	0	5	0	0	0	94
3.28	2.13	473.126	136.9	138.6	1.62	3.33	0	0	5	1	1	1	93
3.3	2.14	481.661	137.1	138.8	1.64	3.36	0	0	5	1	1	1	93
3.32	2.16	490.298	137.3	139	1.65	3.39	0	0	4	1	1	1	93
3.34	2.18	499.036	137.6	139.2	1.67	3.4	0	0	4	1	1	1	93

Hydraulic parameter							Percentage of width occupied by fish hydraulic habitat						
Maximum Depth (m)	Average Depth (m)	Discharge (m3/s)	Width (m)	Wetted perimeter (m)	Average velocity (m/s)	Velocity 98% (m/s)	SVS	SS	SD	FVS	FS	FI	FD
3.36	2.19	507.876	137.8	139.4	1.68	3.43	0	0	4	1	1	1	93
3.38	2.21	516.819	138	139.6	1.69	3.46	0	0	4	1	1	1	93
3.4	2.23	525.865	138.2	139.8	1.71	3.49	0	0	4	1	1	1	94
3.42	2.24	535.015	138.4	140.1	1.72	3.46	0	0	4	0	0	1	94
3.44	2.26	544.269	138.6	140.3	1.74	3.51	0	0	4	0	0	1	94
3.46	2.28	553.629	138.9	140.6	1.75	3.57	0	0	4	1	1	1	93
3.48	2.29	563.094	139.1	140.8	1.77	3.56	0	0	4	0	0	1	94
3.5	2.31	572.665	139.4	141.1	1.78	3.62	0	0	4	1	1	1	94
3.52	2.32	582.344	139.6	141.3	1.79	3.64	0	0	4	1	1	1	94
3.54	2.34	592.129	139.9	141.5	1.81	3.66	0	0	4	1	1	1	94
3.56	2.36	602.022	140.1	141.8	1.82	3.7	0	0	4	1	1	1	94
3.58	2.37	612.024	140.3	142	1.84	3.72	0	0	4	1	1	1	94
3.6	2.39	622.135	140.6	142.3	1.85	3.73	0	0	4	0	0	1	95
3.62	2.4	632.356	140.8	142.5	1.87	3.77	0	0	4	0	0	1	95
3.64	2.42	642.686	141.1	142.8	1.88	3.8	0	0	4	0	0	1	95
3.66	2.44	653.128	141.3	143	1.9	3.83	0	0	4	0	0	1	95
3.68	2.45	663.681	141.6	143.3	1.91	3.86	0	0	4	0	0	1	95
3.7	2.47	674.345	141.8	143.5	1.93	3.93	0	0	4	1	1	1	94
3.72	2.48	685.123	142	143.8	1.94	3.97	0	0	4	1	1	1	94
3.74	2.5	696.013	142.3	144	1.96	3.98	0	0	4	1	1	1	94
3.76	2.51	707.017	142.5	144.3	1.97	4.02	0	0	4	1	1	1	94
3.78	2.53	718.135	142.8	144.5	1.99	4.02	0	0	4	0	0	1	95
3.8	2.55	729.368	143	144.8	2	4.06	0	0	3	0	0	1	95
3.82	2.56	740.716	143.3	145	2.02	4.1	0	0	3	0	0	1	95
3.84	2.58	752.18	143.5	145.2	2.03	4.13	0	0	3	0	0	1	95
3.86	2.59	763.761	143.8	145.5	2.05	4.21	0	0	3	1	1	1	94

Hydraulic parameter							Percentage of width occupied by fish hydraulic habitat						
Maximum Depth (m)	Average Depth (m)	Discharge (m3/s)	Width (m)	Wetted perimeter (m)	Average velocity (m/s)	Velocity 98% (m/s)	SVS	SS	SD	FVS	FS	FI	FD
3.88	2.61	775.459	144	145.8	2.07	4.24	0	0	3	1	1	1	94
3.9	2.62	787.274	144.3	146	2.08	4.22	0	0	3	0	0	1	95
3.92	2.64	799.208	144.5	146.3	2.1	4.26	0	0	3	1	1	1	94
3.94	2.65	811.26	144.8	146.5	2.11	4.25	0	0	3	0	0	0	95
3.96	2.67	823.432	145	146.8	2.13	4.33	0	0	3	1	1	1	94
3.98	2.68	835.724	145.3	147	2.14	4.35	0	0	3	1	1	1	94
4	2.7	848.136	145.5	147.3	2.16	4.36	0	0	3	1	1	1	94
4.02	2.72	860.669	145.8	147.6	2.17	4.43	0	0	3	1	1	1	94
4.04	2.73	873.324	146	147.8	2.19	4.45	0	0	3	1	1	1	94
4.06	2.75	886.101	146.3	148.1	2.21	4.44	0	0	3	1	1	1	95
4.08	2.76	899.001	146.5	148.3	2.22	4.46	0	0	3	1	1	1	95
4.1	2.78	912.024	146.8	148.6	2.24	4.52	0	0	3	1	1	1	94
4.12	2.79	925.171	147	148.8	2.25	4.53	0	0	3	1	1	1	95
4.14	2.81	938.443	147.3	149.1	2.27	4.57	0	0	3	1	1	1	95
4.16	2.82	951.839	147.6	149.3	2.29	4.61	0	0	3	1	1	1	95
4.18	2.84	965.361	147.8	149.6	2.3	4.65	0	0	3	1	1	1	95
4.2	2.85	979.01	148.1	149.9	2.32	4.69	0	0	3	1	1	1	95
4.22	2.87	992.785	148.3	150.1	2.33	4.72	0	0	3	1	1	1	95
4.24	2.88	1006.687	148.6	150.4	2.35	4.76	0	0	3	1	1	1	95
4.26	2.9	1020.718	148.8	150.6	2.37	4.84	0	0	3	1	1	1	94
4.28	2.91	1034.876	149.1	150.9	2.38	4.79	0	0	3	1	1	1	95
4.3	2.93	1049.164	149.3	151.1	2.4	4.84	0	0	3	1	1	1	95

8.2.9 Levuvhu

Hydraulic parameter							Percentage of width occupied by fish hydraulic habitat						
Maximum Depth (m)	Average Depth (m)	Discharge (m3/s)	Width (m)	Wetted perimeter (m)	Average velocity (m/s)	Velocity 98% (m/s)	SVS	SS	SD	FVS	FS	FI	FD
0.02	0.01	0	0.3	0.3	0.03	0.12	100	0	0	0	0	0	0
0.04	0.01	0.002	5	5	0.03	0.11	100	0	0	0	0	0	0
0.06	0.02	0.011	7.1	7.1	0.06	0.21	100	0	0	0	0	0	0
0.08	0.03	0.027	9.7	9.7	0.08	0.27	98	0	0	2	0	0	0
0.1	0.05	0.053	12.4	12.4	0.1	0.32	96	0	0	4	0	0	0
0.12	0.06	0.093	14.6	14.7	0.11	0.38	90	4	0	6	0	0	0
0.14	0.07	0.147	16.7	16.8	0.13	0.43	67	25	0	6	2	0	0
0.16	0.08	0.215	18.8	18.9	0.14	0.48	55	35	0	6	4	0	0
0.18	0.09	0.299	20.9	21	0.16	0.53	47	40	0	7	6	0	0
0.2	0.1	0.401	23	23.1	0.17	0.57	39	46	0	7	8	0	0
0.22	0.11	0.513	26.1	26.1	0.18	0.6	37	46	0	8	9	1	0
0.24	0.12	0.662	28.1	28.1	0.2	0.65	33	46	0	9	9	3	0
0.26	0.13	0.844	29.3	29.4	0.21	0.7	25	51	0	8	10	6	0
0.28	0.14	1.031	31.5	31.6	0.23	0.75	25	47	0	10	10	9	0
0.3	0.15	1.241	34	34.1	0.24	0.77	21	49	0	9	10	11	0
0.32	0.16	1.478	36.5	36.6	0.25	0.82	19	48	0	9	11	13	1
0.34	0.16	1.685	41.5	41.6	0.25	0.82	22	44	0	11	9	9	4
0.36	0.17	2.011	43.7	43.8	0.27	0.87	20	43	0	12	9	10	6
0.38	0.18	2.374	45.9	46	0.28	0.92	19	41	0	13	9	10	9
0.4	0.19	2.718	49.9	50	0.29	0.95	19	39	0	13	9	9	10
0.42	0.2	3.144	53	53.1	0.3	0.98	16	40	0	13	10	9	12
0.44	0.21	3.637	55.5	55.7	0.32	1.03	15	39	0	13	10	10	14
0.46	0.22	4.18	58.1	58.2	0.33	1.07	13	39	0	12	11	9	15
0.48	0.23	4.82	59.7	59.8	0.35	1.12	11	39	0	11	13	9	18
0.5	0.25	5.517	61.2	61.4	0.37	1.18	8	38	0	9	14	9	20
0.52	0.26	6.312	62.1	62.3	0.39	1.25	7	36	1	9	14	10	23

Hydraulic parameter							Percentage of width occupied by fish hydraulic habitat						
Maximum Depth (m)	Average Depth (m)	Discharge (m3/s)	Width (m)	Wetted perimeter (m)	Average velocity (m/s)	Velocity 98% (m/s)	SVS	SS	SD	FVS	FS	FI	FD
0.54	0.28	7.171	62.9	63.1	0.41	1.3	5	35	2	7	14	11	25
0.56	0.3	8.098	63.6	63.8	0.43	1.36	3	33	4	5	13	14	28
0.58	0.31	9.09	64.3	64.5	0.45	1.43	3	29	6	5	13	14	31
0.6	0.33	10.149	65	65.2	0.48	1.48	2	26	7	4	11	16	34
0.62	0.34	11.276	65.7	65.9	0.5	1.52	2	25	7	3	9	17	37
0.64	0.36	12.474	66.4	66.6	0.52	1.56	2	22	8	3	7	15	42
0.66	0.38	13.78	66.8	67.1	0.54	1.61	2	20	8	3	6	13	47
0.68	0.4	15.195	67	67.3	0.57	1.64	1	18	9	2	5	13	51
0.7	0.42	16.693	67.3	67.5	0.6	1.7	1	16	9	3	4	12	55
0.72	0.43	23.126	67.5	67.7	0.79	1.97	0	11	7	2	4	10	66
0.74	0.45	24.511	67.7	67.9	0.8	1.97	0	10	7	2	3	9	69
0.76	0.47	25.939	67.9	68.1	0.81	1.98	0	9	7	2	3	6	72
0.78	0.49	27.409	68.1	68.3	0.82	1.96	0	9	8	1	2	6	74
0.8	0.51	28.923	68.2	68.5	0.83	1.99	0	8	8	2	2	5	75
0.82	0.53	30.48	68.3	68.6	0.84	1.98	0	7	8	1	2	5	77
0.84	0.55	32.08	68.4	68.7	0.86	1.99	0	6	9	1	1	4	79
0.86	0.57	33.723	68.5	68.8	0.87	2.02	0	5	9	1	1	3	80
0.88	0.59	35.41	68.6	68.9	0.88	2.01	0	4	10	0	1	3	81
0.9	0.61	37.141	68.7	69	0.89	2.04	0	4	10	0	1	2	83
0.92	0.63	38.915	68.8	69.1	0.91	2.08	0	3	10	1	1	2	83
0.94	0.64	40.733	68.9	69.2	0.92	2.07	0	2	11	0	1	2	84
0.96	0.66	42.595	69	69.3	0.93	2.1	0	2	11	1	1	1	84
0.98	0.68	44.501	69	69.4	0.94	2.11	0	2	11	1	1	1	85
1	0.7	46.451	69.1	69.5	0.96	2.1	0	1	11	0	1	0	87
1.02	0.72	48.446	69.2	69.6	0.97	2.1	0	1	11	0	1	0	87
1.04	0.74	50.485	69.3	69.7	0.98	2.17	0	1	10	1	1	0	87

Hydraulic parameter							Percentage of width occupied by fish hydraulic habitat						
Maximum Depth (m)	Average Depth (m)	Discharge (m3/s)	Width (m)	Wetted perimeter (m)	Average velocity (m/s)	Velocity 98% (m/s)	SVS	SS	SD	FVS	FS	FI	FD
1.06	0.76	52.569	69.4	69.9	1	2.19	0	1	10	1	1	0	87
1.08	0.78	54.697	69.5	70	1.01	2.19	0	1	10	0	1	0	88
1.1	0.8	56.87	69.6	70.1	1.03	2.21	0	1	10	0	1	0	88
1.12	0.82	59.087	69.7	70.2	1.04	2.25	0	1	10	1	1	0	88
1.14	0.83	61.35	69.8	70.3	1.05	2.26	0	0	10	1	1	0	88
1.16	0.85	63.658	69.9	70.4	1.07	2.25	0	0	10	0	1	0	89
1.18	0.87	66.011	70	70.5	1.08	2.28	0	0	9	0	0	0	89
1.2	0.89	68.409	70.1	70.6	1.1	2.34	0	0	9	1	0	0	89
1.22	0.91	70.852	70.1	70.7	1.11	2.36	0	0	9	1	0	1	89
1.24	0.93	73.341	70.2	70.8	1.12	2.36	0	0	9	0	0	1	90
1.26	0.95	75.875	70.3	70.9	1.14	2.4	0	0	8	1	0	1	89
1.28	0.97	78.455	70.4	70.9	1.15	2.39	0	0	8	0	0	1	90
1.3	0.99	81.08	70.4	71	1.17	2.43	0	0	8	1	0	1	90
1.32	1.01	83.752	70.4	71.1	1.18	2.44	0	0	8	0	0	1	91
1.34	1.03	86.469	70.5	71.1	1.2	2.47	0	0	8	0	0	1	91
1.36	1.04	89.232	70.5	71.2	1.21	2.52	0	0	8	1	0	1	90
1.38	1.06	92.041	70.6	71.2	1.23	2.53	0	0	8	0	0	1	91
1.4	1.08	94.896	70.6	71.3	1.24	2.58	0	0	7	1	0	0	91
1.42	1.1	97.797	70.6	71.3	1.26	2.61	0	0	7	1	0	0	92
1.44	1.12	100.75	70.7	71.4	1.27	2.61	0	0	7	0	0	0	93
1.46	1.14	103.74	70.7	71.5	1.28	2.67	0	0	7	1	0	0	92
1.48	1.16	106.78	70.8	71.5	1.3	2.66	0	0	7	0	0	0	93
1.5	1.18	109.87	70.8	71.6	1.31	2.68	0	0	7	0	0	0	93
1.52	1.2	113	70.8	71.6	1.33	2.72	0	0	6	1	0	0	93
1.54	1.22	116.18	70.9	71.7	1.34	2.72	0	0	6	0	0	0	94
1.56	1.24	119.41	70.9	71.7	1.36	2.73	0	0	6	0	0	0	94

Hydraulic parameter							Percentage of width occupied by fish hydraulic habitat						
Maximum Depth (m)	Average Depth (m)	Discharge (m3/s)	Width (m)	Wetted perimeter (m)	Average velocity (m/s)	Velocity 98% (m/s)	SVS	SS	SD	FVS	FS	FI	FD
1.58	1.26	122.68	71	71.8	1.37	2.79	0	0	6	0	0	0	94
1.6	1.28	126	71	71.9	1.39	2.84	0	0	6	1	0	0	93
1.62	1.3	129.37	71.1	71.9	1.4	2.86	0	0	6	1	0	0	93
1.64	1.32	132.78	71.1	72	1.42	2.88	0	0	6	0	0	0	94
1.66	1.33	136.24	71.1	72	1.44	2.92	0	0	5	1	0	0	94
1.68	1.35	139.75	71.2	72.1	1.45	2.91	0	0	5	0	0	0	95
1.7	1.37	143.31	71.2	72.1	1.47	2.97	0	0	5	1	0	0	94
1.72	1.39	146.91	71.3	72.2	1.48	3.01	0	0	5	1	0	0	94
1.74	1.41	150.56	71.3	72.3	1.5	3.01	0	0	5	0	0	0	95
1.76	1.43	154.26	71.3	72.3	1.51	3.05	0	0	5	0	0	0	95
1.78	1.45	158.01	71.4	72.4	1.53	3.07	0	0	5	0	0	0	95
1.8	1.47	161.8	71.4	72.4	1.54	3.13	0	0	5	1	0	0	94
1.82	1.49	165.64	71.5	72.5	1.56	3.14	0	0	5	1	0	0	94
1.84	1.51	169.53	71.5	72.5	1.57	3.15	0	0	5	0	0	0	95
1.86	1.53	173.47	71.5	72.6	1.59	3.19	0	0	5	0	0	0	95
1.88	1.55	177.45	71.6	72.7	1.6	3.23	0	0	5	0	0	0	95
1.9	1.56	181.48	71.6	72.7	1.62	3.3	0	0	4	1	0	0	95
1.92	1.58	185.56	71.7	72.8	1.64	3.34	0	0	4	1	0	0	95
1.94	1.6	189.69	71.7	72.8	1.65	3.33	0	0	4	0	0	0	96
1.96	1.62	193.87	71.8	72.9	1.67	3.35	0	0	4	0	0	0	96
1.98	1.64	198.09	71.8	72.9	1.68	3.39	0	0	4	0	0	0	96
2	1.66	202.36	71.8	73	1.7	3.46	0	0	4	1	0	0	95
2.02	1.68	206.68	71.9	73.1	1.71	3.49	0	0	4	1	0	0	95
2.04	1.7	211.05	71.9	73.1	1.73	3.53	0	0	4	1	0	0	95
2.06	1.72	215.47	72	73.2	1.74	3.52	0	0	4	0	0	0	96
2.08	1.74	219.93	72	73.2	1.76	3.55	0	0	4	0	0	0	96

Hydraulic parameter							Percentage of width occupied by fish hydraulic habitat						
Maximum Depth (m)	Average Depth (m)	Discharge (m3/s)	Width (m)	Wetted perimeter (m)	Average velocity (m/s)	Velocity 98% (m/s)	SVS	SS	SD	FVS	FS	FI	FD
2.1	1.75	224.45	72	73.3	1.78	3.59	0	0	4	1	0	0	95
2.12	1.77	229.01	72.1	73.4	1.79	3.63	0	0	4	1	0	0	95
2.14	1.79	233.62	72.1	73.4	1.81	3.67	0	0	4	1	0	0	95
2.16	1.81	238.28	72.2	73.5	1.82	3.67	0	0	4	0	0	0	96
2.18	1.83	242.99	72.2	73.5	1.84	3.71	0	0	4	0	0	0	96
2.2	1.85	247.75	72.2	73.6	1.85	3.78	0	0	4	1	0	0	95
2.22	1.87	252.55	72.3	73.6	1.87	3.82	0	0	4	1	0	0	95
2.24	1.89	257.41	72.3	73.7	1.89	3.85	0	0	4	1	0	0	95
2.26	1.91	262.31	72.4	73.8	1.9	3.82	0	0	4	0	0	0	96
2.28	1.93	267.27	72.4	73.8	1.92	3.85	0	0	4	0	0	0	96
2.3	1.94	272.27	72.4	73.9	1.93	3.93	0	0	4	1	0	0	95
2.32	1.96	277.32	72.5	73.9	1.95	3.93	0	0	4	0	0	0	96
2.34	1.98	282.42	72.5	74	1.96	4	0	0	4	1	0	0	95
2.36	2	287.57	72.6	74	1.98	4	0	0	4	0	0	0	96
2.38	2.02	292.77	72.6	74.1	2	4.03	0	0	4	0	0	0	96
2.4	2.04	298.02	72.7	74.2	2.01	4.09	0	0	4	1	0	0	95
2.42	2.06	303.31	72.7	74.2	2.03	4.11	0	0	4	1	0	0	95
2.44	2.08	308.66	72.7	74.3	2.04	4.15	0	0	3	1	0	0	96
2.46	2.1	314.06	72.8	74.3	2.06	4.15	0	0	4	0	0	0	96
2.48	2.11	319.5	72.8	74.4	2.08	4.18	0	0	3	0	0	0	97
2.5	2.13	325	72.9	74.4	2.09	4.26	0	0	3	1	0	0	96
2.52	2.15	330.54	72.9	74.5	2.11	4.3	0	0	3	1	0	0	96
2.54	2.17	336.14	72.9	74.6	2.12	4.33	0	0	3	1	0	0	96
2.56	2.19	341.78	73	74.6	2.14	4.32	0	0	3	0	0	0	97
2.58	2.21	347.48	73	74.7	2.16	4.32	0	0	3	0	0	0	97
2.6	2.23	353.22	73.1	74.7	2.17	4.37	0	0	3	0	0	0	97

Hydraulic parameter							Percentage of width occupied by fish hydraulic habitat						
Maximum Depth (m)	Average Depth (m)	Discharge (m3/s)	Width (m)	Wetted perimeter (m)	Average velocity (m/s)	Velocity 98% (m/s)	SVS	SS	SD	FVS	FS	FI	FD
2.62	2.25	359.01	73.1	74.8	2.19	4.46	0	0	3	1	0	0	96
2.64	2.26	364.86	73.1	74.9	2.2	4.5	0	0	3	1	0	0	96
2.66	2.28	370.75	73.2	74.9	2.22	4.49	0	0	3	0	0	0	97
2.68	2.3	376.69	73.2	75	2.23	4.51	0	0	3	0	0	0	97
2.7	2.32	382.69	73.3	75	2.25	4.55	0	0	3	0	0	0	97
2.72	2.34	388.73	73.3	75.1	2.27	4.62	0	0	3	1	0	0	96
2.74	2.36	394.83	73.4	75.1	2.28	4.6	0	0	3	0	0	0	97
2.76	2.38	400.97	73.4	75.2	2.3	4.6	0	0	3	0	0	0	97
2.78	2.4	407.16	73.4	75.3	2.31	4.64	0	0	3	0	0	0	97
2.8	2.41	413.41	73.5	75.3	2.33	4.73	0	0	3	1	0	0	96
2.82	2.43	419.7	73.5	75.4	2.35	4.73	0	0	3	0	0	0	97
2.84	2.45	426.05	73.6	75.4	2.36	4.76	0	0	3	0	0	0	97
2.86	2.47	432.44	73.6	75.5	2.38	4.8	0	0	3	0	0	0	97
2.88	2.49	438.89	73.6	75.5	2.4	4.84	0	0	3	0	0	0	97
2.9	2.51	445.38	73.7	75.6	2.41	4.87	0	0	3	0	0	0	97
2.92	2.53	451.93	73.7	75.7	2.43	4.94	0	0	3	0	0	0	96
2.94	2.54	458.53	73.8	75.7	2.44	4.97	0	0	3	0	0	0	96
2.96	2.56	465.18	73.8	75.8	2.46	4.99	0	0	3	0	0	0	96
2.98	2.58	471.87	73.8	75.8	2.48	5.03	0	0	3	0	0	0	96
3	2.6	478.62	73.9	75.9	2.49	5.08	0	0	3	0	0	0	96
3.02	2.62	485.42	73.9	75.9	2.51	5.12	0	0	3	0	0	0	96
3.04	2.64	492.27	74	76	2.52	5.16	0	0	3	0	0	0	96
3.06	2.66	499.18	74	76.1	2.54	5.2	0	0	3	0	0	0	96
3.08	2.67	506.13	74	76.1	2.56	5.23	0	0	3	0	0	0	96
3.1	2.69	513.13	74.1	76.2	2.57	5.26	0	0	3	0	0	0	96
3.12	2.71	520.19	74.1	76.2	2.59	5.28	0	0	3	0	0	0	96

Hydraulic parameter							Percentage of width occupied by fish hydraulic habitat						
Maximum Depth (m)	Average Depth (m)	Discharge (m3/s)	Width (m)	Wetted perimeter (m)	Average velocity (m/s)	Velocity 98% (m/s)	SVS	SS	SD	FVS	FS	FI	FD
3.14	2.73	527.29	74.2	76.3	2.6	5.26	0	0	3	0	0	0	97
3.16	2.75	534.45	74.2	76.3	2.62	5.26	0	0	3	0	0	0	97
3.18	2.77	541.65	74.2	76.4	2.64	5.31	0	0	3	0	0	0	97
3.2	2.79	548.91	74.3	76.5	2.65	5.35	0	0	3	0	0	0	97
3.22	2.8	556.22	74.3	76.5	2.67	5.39	0	0	3	0	0	0	97
3.24	2.82	563.58	74.4	76.6	2.69	5.42	0	0	3	0	0	0	97
3.26	2.84	570.99	74.4	76.6	2.7	5.46	0	0	3	0	0	0	97
3.28	2.86	578.46	74.4	76.7	2.72	5.5	0	0	3	0	0	0	97
3.3	2.88	585.97	74.5	76.7	2.73	5.52	0	0	3	0	0	0	97
3.32	2.9	593.54	74.5	76.8	2.75	5.55	0	0	3	0	0	0	97
3.34	2.91	601.15	74.6	76.9	2.77	5.58	0	0	3	0	0	0	97
3.36	2.93	608.82	74.6	76.9	2.78	5.67	0	0	3	0	0	0	96
3.38	2.95	616.54	74.6	77	2.8	5.68	0	0	3	0	0	0	96
3.4	2.97	624.31	74.7	77	2.81	5.72	0	0	3	0	0	0	96
3.42	2.99	632.14	74.7	77.1	2.83	5.76	0	0	3	0	0	0	96
3.44	3.01	640.01	74.8	77.1	2.85	5.8	0	0	2	0	0	0	96
3.46	3.02	647.94	74.8	77.2	2.86	5.78	0	0	3	0	0	0	97
3.48	3.04	655.92	74.8	77.3	2.88	5.87	0	0	2	0	0	0	97
3.5	3.06	663.94	74.9	77.3	2.9	5.91	0	0	2	0	0	0	97
3.52	3.08	672.03	74.9	77.4	2.91	5.94	0	0	2	0	0	0	97
3.54	3.1	680.16	75	77.4	2.93	5.97	0	0	2	0	0	0	97
3.56	3.12	688.34	75	77.5	2.94	6	0	0	2	0	0	0	97
3.58	3.13	696.58	75.1	77.5	2.96	5.98	0	0	2	0	0	0	98
3.6	3.15	704.87	75.1	77.6	2.98	5.97	0	0	2	0	0	0	98
3.62	3.17	713.21	75.1	77.7	2.99	6.01	0	0	2	0	0	0	98
3.64	3.19	721.6	75.2	77.7	3.01	6.05	0	0	2	0	0	0	98

Hydraulic parameter							Percentage of width occupied by fish hydraulic habitat						
Maximum Depth (m)	Average Depth (m)	Discharge (m3/s)	Width (m)	Wetted perimeter (m)	Average velocity (m/s)	Velocity 98% (m/s)	SVS	SS	SD	FVS	FS	FI	FD
3.66	3.21	730.04	75.2	77.8	3.03	6.08	0	0	2	0	0	0	98
3.68	3.23	738.54	75.3	77.8	3.04	6.12	0	0	2	0	0	0	98
3.7	3.24	747.09	75.3	77.9	3.06	6.16	0	0	2	0	0	0	98
3.72	3.26	755.69	75.3	77.9	3.07	6.19	0	0	2	0	0	0	98
3.74	3.28	764.34	75.4	78	3.09	6.23	0	0	2	0	0	0	98
3.76	3.3	773.04	75.4	78.1	3.11	6.27	0	0	2	0	0	0	98
3.78	3.32	781.8	75.5	78.1	3.12	6.3	0	0	2	0	0	0	98
3.8	3.34	790.61	75.5	78.2	3.14	6.38	0	0	2	0	0	0	97
3.82	3.35	799.47	75.5	78.2	3.16	6.41	0	0	2	0	0	0	97
3.84	3.37	808.38	75.6	78.3	3.17	6.4	0	0	2	0	0	0	97
3.86	3.39	817.35	75.6	78.3	3.19	6.45	0	0	2	0	0	0	97
3.88	3.41	826.36	75.7	78.4	3.2	6.49	0	0	2	0	0	0	97
3.9	3.43	835.43	75.7	78.5	3.22	6.54	0	0	2	0	0	0	97
3.92	3.44	844.56	75.7	78.5	3.24	6.58	0	0	2	0	0	0	97
3.94	3.46	853.73	75.8	78.6	3.25	6.61	0	0	2	0	0	0	97
3.96	3.48	862.96	75.8	78.6	3.27	6.65	0	0	2	0	0	0	97
3.98	3.5	872.24	75.9	78.7	3.29	6.69	0	0	2	0	0	0	97
4	3.52	881.57	75.9	78.7	3.3	6.72	0	0	2	0	0	0	97
4.02	3.54	890.95	75.9	78.8	3.32	6.69	0	0	2	0	0	0	98
4.04	3.55	900.39	76	78.9	3.33	6.72	0	0	2	0	0	0	98
4.06	3.57	909.88	76	78.9	3.35	6.75	0	0	2	0	0	0	98
4.08	3.59	919.42	76.1	79	3.37	6.78	0	0	2	0	0	0	98
4.1	3.61	929.02	76.1	79	3.38	6.77	0	0	2	0	0	0	98
4.12	3.63	938.67	76.1	79.1	3.4	6.82	0	0	2	0	0	0	98
4.14	3.64	948.37	76.2	79.1	3.42	6.87	0	0	2	0	0	0	98
4.16	3.66	958.12	76.2	79.2	3.43	6.91	0	0	2	0	0	0	98

Hydraulic parameter							Percentage of width occupied by fish hydraulic habitat						
Maximum Depth (m)	Average Depth (m)	Discharge (m3/s)	Width (m)	Wetted perimeter (m)	Average velocity (m/s)	Velocity 98% (m/s)	SVS	SS	SD	FVS	FS	FI	FD
4.18	3.68	967.93	76.3	79.3	3.45	6.95	0	0	2	0	0	0	98
4.2	3.7	977.79	76.3	79.3	3.46	6.99	0	0	2	0	0	0	98
4.22	3.72	987.7	76.3	79.4	3.48	7.02	0	0	2	0	0	0	98
4.24	3.73	997.67	76.4	79.4	3.5	7.12	0	0	2	0	0	0	97
4.26	3.75	1007.7	76.4	79.5	3.51	7.16	0	0	2	0	0	0	97
4.28	3.77	1017.8	76.5	79.5	3.53	7.19	0	0	2	0	0	0	97
4.3	3.79	1027.9	76.5	79.6	3.55	7.23	0	0	2	0	0	0	97
4.32	3.81	1038.1	76.5	79.7	3.56	7.26	0	0	2	0	0	0	97
4.34	3.82	1048.3	76.6	79.7	3.58	7.29	0	0	2	0	0	0	97
4.36	3.84	1058.6	76.6	79.8	3.6	7.32	0	0	2	0	0	0	97
4.38	3.86	1068.9	76.7	79.8	3.61	7.3	0	0	2	0	0	0	97
4.4	3.88	1079.3	76.7	79.9	3.63	7.35	0	0	2	0	0	0	97
4.42	3.9	1089.7	76.8	79.9	3.64	7.32	0	0	2	0	0	0	98
4.44	3.91	1100.2	76.8	80	3.66	7.37	0	0	2	0	0	0	98
4.46	3.93	1110.8	76.9	80.1	3.68	7.42	0	0	2	0	0	0	98
4.48	3.95	1121.4	76.9	80.2	3.69	7.54	0	0	2	0	0	0	97
4.5	3.96	1132	77	80.2	3.71	7.57	0	0	2	0	0	0	97
4.52	3.98	1142.7	77.1	80.3	3.73	7.61	0	0	2	0	0	0	97
4.54	4	1153.5	77.1	80.4	3.74	7.64	0	0	2	0	0	0	97
4.56	4.01	1164.3	77.2	80.5	3.76	7.68	0	0	2	0	0	0	97
4.58	4.03	1175.2	77.2	80.5	3.77	7.63	0	0	2	0	0	0	98
4.6	4.05	1186.1	77.3	80.6	3.79	7.76	0	0	2	0	0	0	97
4.62	4.06	1197.1	77.4	80.8	3.81	7.79	0	0	2	0	0	0	97
4.64	4.08	1208.1	77.5	80.9	3.82	7.82	0	0	2	0	0	0	97
4.66	4.1	1219.2	77.5	81	3.84	7.84	0	0	2	0	0	0	97
4.68	4.11	1230.3	77.6	81.2	3.86	7.82	0	0	2	0	0	0	97

Hydraulic parameter							Percentage of width occupied by fish hydraulic habitat						
Maximum Depth (m)	Average Depth (m)	Discharge (m3/s)	Width (m)	Wetted perimeter (m)	Average velocity (m/s)	Velocity 98% (m/s)	SVS	SS	SD	FVS	FS	FI	FD
4.7	4.13	1241.5	77.7	81.3	3.87	7.86	0	0	2	0	0	0	97
4.72	4.14	1252.8	77.7	81.4	3.89	7.9	0	0	2	0	0	0	97
4.74	4.16	1264.1	77.8	81.6	3.9	7.95	0	0	2	0	0	0	97
4.76	4.18	1275.4	77.9	81.7	3.92	8.01	0	0	2	0	0	0	97
4.78	4.19	1286.8	78	81.9	3.94	8.05	0	0	2	0	0	0	97
4.8	4.21	1298.3	78	82	3.95	8.08	0	0	2	0	0	0	97
4.82	4.23	1309.8	78.1	82.1	3.97	8.12	0	0	2	0	0	0	97
4.84	4.24	1321.4	78.2	82.3	3.99	8.15	0	0	2	0	0	0	97
4.86	4.26	1333	78.2	82.4	4	8.18	0	0	2	0	0	0	97
4.88	4.27	1344.7	78.3	82.6	4.02	8.21	0	0	2	0	0	0	97
4.9	4.29	1356.4	78.4	82.7	4.03	8.24	0	0	2	0	0	0	97
4.92	4.31	1368.2	78.5	82.8	4.05	8.26	0	0	2	0	0	0	97
4.94	4.32	1380	78.5	83	4.07	8.28	0	0	2	0	0	0	97
4.96	4.34	1391.9	78.6	83.1	4.08	8.32	0	0	2	0	0	0	97
4.98	4.35	1403.8	78.7	83.2	4.1	8.35	0	0	2	0	0	0	97
5	4.37	1415.8	78.8	83.4	4.11	8.34	0	0	2	0	0	0	97

U.S. Agency for International Development

1300 Pennsylvania Avenue, NW

Washington, D.C. 20523

Tel.: (202) 712-0000

Fax: (202) 216-3524