E-FLOWS FOR THE LIMPOPO RIVER BASIN:

INCEPTION REPORT

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(Submitted in fulfilment of Milestone 1: E-flows Inception Report)

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About IWMI

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

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Collaborators:

IWMI International Water Management Institute

International Water Management Institute, Colombo, Sri Lanka

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LIMCOM LIMPOPO WATERCOURSE COMMISSION

Limpopo River Commission, Mozambique

UNIVERSITY OF MPUMALANGA
Rivers of Life Aquatic Health Services

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

South African NATIONAL PARKS

South African National Parks, Kruger National Park, South Africa

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

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

Cover photo: Cross-sectional survey in process: e-flow assessment of the lower Limpopo during the dry season survey for the Monograph study in 2013. Credit: Martin Kleynhans, Aurecon.

PROJECT TITLE:

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

REPORT TITLE:

E-flows for the Limpopo River Basin: Inception Report.

PROJECT OBJECTIVES:

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

TERMS OF REFERENCE:

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

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

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

This report presents the "Environmental flow determination for the Limpopo Basin." This report focuses on the approach adopted to establish e-flows for the basin.

CONTENTS

Acronyms

BN	Bayesian Network
CPT	Conditional Probability Table
DWS	Department of Water and Sanitation South Africa (=DWA)
DRM	Desktop Reserve Model (Hughes, 1999)
E-flow	The quantity, timing, and quality of freshwater flows and levels necessary to sustain aquatic ecosystems which, in turn, support human cultures, economies, livelihoods, and well-being (Arthington et al., 2018).
EF	Environmental flows (=E-flow)
EI	Ecological importance
ES	Ecological sensitivity
EWR	Environmental Water Requirement (=E-flow)
GW	Groundwater
IWMI	International Water Management Institute
LIMCOM	Limpopo Watercourse Commission
LoE	Line of Evidence
MAR	Mean Annual Runoff
PES	Present Ecological State
PROBFLO	E-flow method (O'Brien et al, 2018)
RW	Resilient Waters Program of USAID
SW	Surface water
VEGRAI	Riparian Vegetation Response Assessment Index

1 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 stream-flow resulting from basin activities and climate change.

1.2 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 as it proved to be a wetland lacking a main channel. In addition, nine (9) sites were established in the estuary. The Monograph also summarizes the second source of e-flow data in the Limpopo Basin, i.e., the many e-flow assessments that have been carried out by the South African Department of Water and Sanitation (DWS) for tributaries located in South Africa. Subsequent to that report, further surveys have been carried out in South Africa, but have avoided the main-stem river because of its transboundary nature. There are no other documented Limpopo Basin e-flow studies from the other countries.

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

An approach to e-flows that embraces the connection between the flow of river water and the water requirements of stakeholders, including rural stakeholders, requirements that will include such things as water for riparian irrigation, for domestic use, fish for food, and reeds for construction etc., will be applied. These requirements will be determined at project initiation. Rural stakeholders rely to a greater degree on immediate ecosystem services from the river, and are most vulnerable when these flows are diverted elsewhere, or when climate changes causes overall long-term and seasonal flow patterns to change. The e-flow assessment done in this project will consider the requirements of rural stakeholders for flow-related ecosystem services, and will document the quantities of water required in the river that will provide the services they require, and the risks to failure of this provision. As groundwater is becoming an increasingly critical resource for stakeholders in the basin, and groundwater abstraction close to the river is prevalent and indirectly influencing river flows, water requirements from both groundwater and surface water need to be understood. Management of 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 link stream flow to the requirements of stakeholders. Greater evidence on the ecological requirements will be gained as this project will focus much of its efforts on the wet-season situation, something that was missed during the Monograph study. It will also carry out more intensive field investigations, and most importantly, will introduce a probabilistic approach to the e-flow investigation, thus enabling the results to be interpreted with greater understanding.

2 APPROACH TO THIS PROJECT:

In the process of contracting this project, the world was struck down by the COVID-19 pandemic. A number of changes to the schedule have had to be made as a result, but the project will continue to be delivered in the same original time limit, but with some deliverables altered. The project response to COVID can be viewed in Annexure C. There does remain a risk however, that the virus will not clear sufficiently to enable travel, both to the field and between countries. This will have to be managed as the situation arises.

2.1 OWNERSHIP BY LIMCOM:

Resilient Waters have been clear that the ultimate beneficiary of this project is LIMCOM (Minutes of the Inception Meeting held between RW, IWMI and LIMCOM on 30/04/2020), and that LIMCOM need to be part of project development, investing in the results that will be produced, and implementing them in their management of the Limpopo River basin. In order to achieve this, the following engagement process will be followed during the project (see table 2.1):

TABLE 2.1: ACTIVITIES FOR LIMCOM PARTICIPATION

PHASE	COMMENT	OPPORTUNITY FOR LIMCOM TO PARTICIPATE	DATE OF PARTICIPATION
Inception	Invitation to review the Inception Report and to provide guidance.	Review of inception report and provide inputs	01/04/2020 – 15/05/2020
Livelihoods and ecosystem services	Preliminary livelihoods and ecosystem service-use survey and report, based on literature, stakeholder representatives and limited direct stakeholder consultation	LIMCOM provide guidance	01/05/2020 – 30/08/2020
Vision	Negotiation of the vision and management objectives for the basin, a combination based largely on the new Vision exercise carried out for LIMCOM but where necessary reverting to country policy, management plans etc.	Team members consult with LIMCOM and with key country stakeholders – mostly online consultation	01/06/2020 to 25/09/2020
Vision workshop	Final workshopping and acceptance of the vision and management objectives and Endpoints for all Risk Regions	Ideally face-to-face workshop hosted by RW	18/09/2020
Groundwater field workshop and field survey	The team of specialists will visit the groundwater sites in the basin. Approximately two days will be spent at each site collecting groundwater-related data. A one-day workshop will be held at the Tuli Karoo site.	Specialist staff from LIMCOM or member states invited to join at their own cost	Jan-March 2021
Wet season field survey surface water	The team of specialists will visit all primary sites in the basin. Approximately two days will be spent at each site collecting ecological data. A summary of dates and locations is given in Annexure B.	Specialist staff from LIMCOM or member states invited to join at their own cost	Jan-March 2021
E-flow training	At the end of the project, a one or two day face-to-face training workshop will be provided.	LIMCOM and nominated representatives invited to a workshop	14 September 2021

2.2 UPGRADE OF EARLIER E-FLOW ASSESSMENTS:

The e-flow results in the 2013 Monograph that were based on eight sites, will be upgraded to provide evidence of the risks to the livelihoods of communities resulting from changes in flow and as mitigated by provision of e-flows. Additional sites on the Luvuvhu and Olifants/Elefantes Rivers will be surveyed for the first time (see Table 2.2) and the results integrated with the updated e-flow assessment of the Limpopo River. This comprehensive assessment will include e-flows for the main stem river and important tributaries, including a total of twelve survey sites, at a greater level of confidence than was contained in the Monograph. It will also include the groundwater contribution to e-flows, with detailed data from two of the twelve sites, one ephemeral and one perennial. The risks to flow-related ecosystem services will also be a new assessment, as described below.

2.3 INCLUDING THE GROUNDWATER CONTRIBUTION TO E-FLOWS:

A problematic aspect of e-flow determination in the Limpopo Basin is that many of the rivers are becoming seasonal and the Limpopo River itself at times dries out. Furthermore, abstraction of groundwater from the riverbank or the river bed is common in the basin, thus indirectly affecting the river flow and complicating the estimation of e-flows. Integration of groundwater aspects into the e-flow assessment is an innovation, with little precedent, that will be addressed in this project.

Groundwater is generally a critical component of environmental flows. It contributes significantly to baseflows of rivers, which are critical to river flows (and hence e-flows), especially in dry seasons. In arid areas, rivers may, reversely, drain to groundwater, if groundwater levels decline, e.g. by groundwater being pumped in the vicinity of the river. Hence, to manage e-flows and set realistic targets for e-flows, it is critical to understand the dynamic connection between a river and the underlying groundwater and to manage surface water and groundwater resources and their abstractions conjunctively.

This project will include for the first time the groundwater resource as part of the assessment of e-flows for the Limpopo River, which is essentially an ephemeral 'sand' river. It is already known that there are substantial flows in the unconfined sandy aquifer below the riverbed. The project will identify one or two hotspots along the river with critical linkages between groundwater and surface flow and will model the hydraulic interactions between surface water and groundwater as a function of season and water abstractions. Some fieldwork will be carried out to better understand this groundwater component.

Two relevant references are available that describe e-flow methods[1,2] for non-perennial rivers and groundwater. However, in this project, best-practice surface water e-flow models will be applied, with the groundwater influence on the hydrology and also on the maintenance of instream and riparian habitats being the main focus.

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1 https://www.researchgate.net/publication/266492910_Investigations_into_the_methodology_for_setting_environmental_water_requirements_in_non-perennial_rivers

2 https://www.sciencedirect.com/science/article/pii/S2214581818301125

2.4 LEVERAGING OF THIS PROJECT:

Two water resource studies in the Limpopo Basin have been established by the University of Mpumalanga (UMP) that will leverage the outputs of this USAID/Resilient Waters funded project. These two projects will run concurrently with the RW project, and will contribute by collecting evidence for the e-flows assessment described above, in particular as related to the Olifants/Elefantes River, and will also contribute skills to the e-flow assessment at all of the other sites. The two projects are the JAF - BRICS Multilateral Joint Science and Technology Research Collaboration study, and a Western Indian Ocean Marine Science Association (WIOMSA) study, descriptions of which follow.

The JAF - BRICS Multilateral Joint Science and Technology Research Collaboration has awarded the international study titled: *Global and local water quality monitoring by multimodal sensor systems (GLOWSENS).* The three-year study from January 2019 to December 2021 will be undertaken by representatives from the BRICS nations. The South African lead team is based at the UMP and will undertake an evaluation of the socio-ecological consequences of multiple stressors to the Olifants/Elefantes and Limpopo (the lower reaches) Rivers, and Massingir dam (in South Africa and Mozambique). The study is proposed to include a series of bio-physical surveys linked to water quality in the Olifants/ Elefantes and Limpopo (below the confluence with the Elefantes) Rivers from 2019 to 2021 with additional laboratory experimentation at the UMP and North West University. The study will make a considerable contribution to the documentation of stressors in the lower Olifants/Elefantes and Limpopo Rivers and will contribute to achievement of a sustainable balance between the use and protection of the resources of the system. The data collected by this project will be incorporated into the PROBFLO assessment of the Limpopo Basin as a whole.

The WIOMSA study has been awarded to UMP and is titled: Slippery resource in peril: ecology of Western Indian Ocean (WIO) Anguillid eels and their contribution to sustainable fisheries and livelihood along the east coast of Africa. The aim of this study is to elucidate aspects of the biology, ecology and risk of multiple stressors to the sustainable use and protection of this species. The objectives include; (1) a synthesis and review of existing knowledge regarding the biology, ecology, use and threats of eels in the WIO, (2) characterize the recruitment and escapement ecology in selected estuaries throughout the WIO, (3) evaluate the contribution of eels to local fisheries and livelihood and finally (4) undertake a regional scale ecological risk assessment of multiple stressors affecting populations that includes recommendations for sustainable management and conservation. The study includes resources for the collection of bio-physical data and flow-ecosystem relationship information for the Anguillid eels in the Limpopo Basin. This study, and the resources available for the research team will make a considerable contribution to the Limpopo e-flows study, the results being taken up directly into the holistic models planned for this project. Eels are particularly important for this e-flows assessment, as they are able to migrate up-river and can pass both waterfalls and some dams, thus making them the only fish-connection to the sea that moves both up and downstream over such obstacles.

The BRICS and WIOMSA studies will provide finance for the involved staff, for equipment, water sample and ecotoxicology analyses and associated transport and fieldwork.

A third leveraging project is the Water Land & Ecosystems (WLE) programme of the CGIAR. WLE has as one of its Flagships, a programme called "Enhancing Sustainability across Agricultural Systems" (https://wle.cgiar.org/research/themes/enhancing-sustainability-across-agricultural-systems). This programme has a number of case studies that are considering various models for assessment of sustainability in relation to agriculture. The e-flows approach in the Limpopo could be considered as one such case study. Inclusion of this project as an adjunct to the RW Project would require that the endpoints of the e-flows assessment include those that allow evaluation of the sustainability of agricultural beneficiaries. Thus, from the WLE perspective, the e-flows project would provide a measure of the contribution of water flows to sustainable agriculture, food security and livelihoods. This project has recently been approved by WLE so will be going ahead but the budget has not been included here.

3 PROCEDURE:

The original Monograph e-flow study was undertaken using a low-confidence rapid e-flow assessment method. Following the addition of the wet-season data during this project, and also the contributions of groundwater, the confidence in the results will be improved by using the state-of-the-art e-flows tool PROBFLO[3] that is the product of the proposing team. PROBFLO results in two outputs including an evaluation of acceptable risk trade-off considerations for a range of environmental management options and e-flow requirements. The approach incorporates regional scale ecological risk assessment methods to evaluate multiple sources of stressors, multiple stressors and diverse ecosystems that address multiple social and ecological endpoints. Endpoints have been defined as "*specific entities and their attributes that are at risk and that are expressions of a management goal*" (USEPA, 2003). PROBFLO is based on a Bayesian Network-Relative Risk Model established to evaluate a range of natural and anthropogenic stressors including water withdrawal, seasonality of flow, changes in groundwater level, pollution, diseases, alien species and a range of altered environmental states.

The application of the ten PROBFLO procedural steps in an e-flow assessment is illustrated in Figure 3.2 and is explained in detail in the Task descriptions below. By implementing PROBFLO, we will gain a quantitative perspective of the flow-related risks to the resilience of ecosystems and communities. Thus, we will be able to link socioeconomic endpoints, for example, food security needs being met by fisheries, with sustainable e-flows. The tool's modular structure quantitatively shows the causal linkages between change drivers (e.g., climate, pollution, water withdrawal from both surface and groundwater) and ecosystem service degradation. It allows users to evaluate the drivers of change and the impact of mitigation measures (e.g. re-establishing flows in tributaries) on the provision of ecosystem services to users. These results can be integrated with water allocation models (not done in this project but see previous IWMI work in the Olifants [4]), whereupon the e-flows become the baseline for understanding trade-offs and for optimizing resilience of both the ecosystem and local communities. They also provide a linkage between surface water resources and groundwater allocation and management.

3.1 THE FOLLOWING PROCEDURAL STEPS WILL BE FOLLOWED IN THIS PROJECT:

[3] O'Brien, G. C., Dickens, C., Hines, E., Wepener, V., Stassen, R., Quayle, L., Fouchy, K., Mackenzie, J., Graham, M. and Landis, W. G. (2018). A regional scale ecological risk framework for environmental flow evaluations, Hydrol. Earth Syst. Sci., 22, 957–975. PROBFLO is a regional scale ecological risk based holistic E-flow assessment approach that has been established to achieve the principles of best E-flow management practice. PROBFLO is transparent and adaptable, and makes use of available data and expert opinion, and explicitly addresses uncertainty. It is scenario based and allows for the evaluation of the socio-ecological consequences of altered flows with consideration of the synergistic effects of non-flow drivers of ecosystem impairment. PROBFLO has previously been used for Phase 2 of the Lesotho Highlands Water Project, in the Inner Niger Delta in Mali, and forms the basis of the E-flows Framework for the Nile Basin Initiative.

[4] McCartney, M. P.; Arranz, R. 2007. Evaluation of historic, current and future water demand in the Olifants River Catchment, South Africa. Colombo, Sri Lanka: International Water Management Institute. 48p. (IWMI Research Report 118)

3.2 TASK 1: BASIN DESCRIPTION:

Data describing the basin, its peoples and ecosystem will be collected and will include information on water resources, hydrology, groundwater, ecosystem types, ecoregions, land use, land cover, dams and associated infrastructure. Existing data from the Limpopo Monograph (2013) e-flows assessment of eight sites spanning Botswana, Zimbabwe, South African and Mozambique, and from the Shashe in Zimbabwe[5] is available for use. Prior and subsequent data from the Department of Water and Sanitation (DWS) in South Africa, who have determined e-flows on the tributaries in the South African part of the basin, will be collected and collated.

The condition of the ecosystem and its ecoregions will also be described using existing data that will include the DWS Present Ecological Status database for South Africa as well as its ecoregions data, but in other countries it will be necessary to use relevant data and reports including the Monograph itself. Lastly, the basin will be divided into Risk Regions (Figure 3.1) i.e. major sub-basin regions as determined by a combination of socio-economic and biophysical characters including transboundary issues. Hotspot areas for groundwater - surface water interactions, e.g. where heavy groundwater pumping is occurring close to the river for intensive agriculture, will be identified.

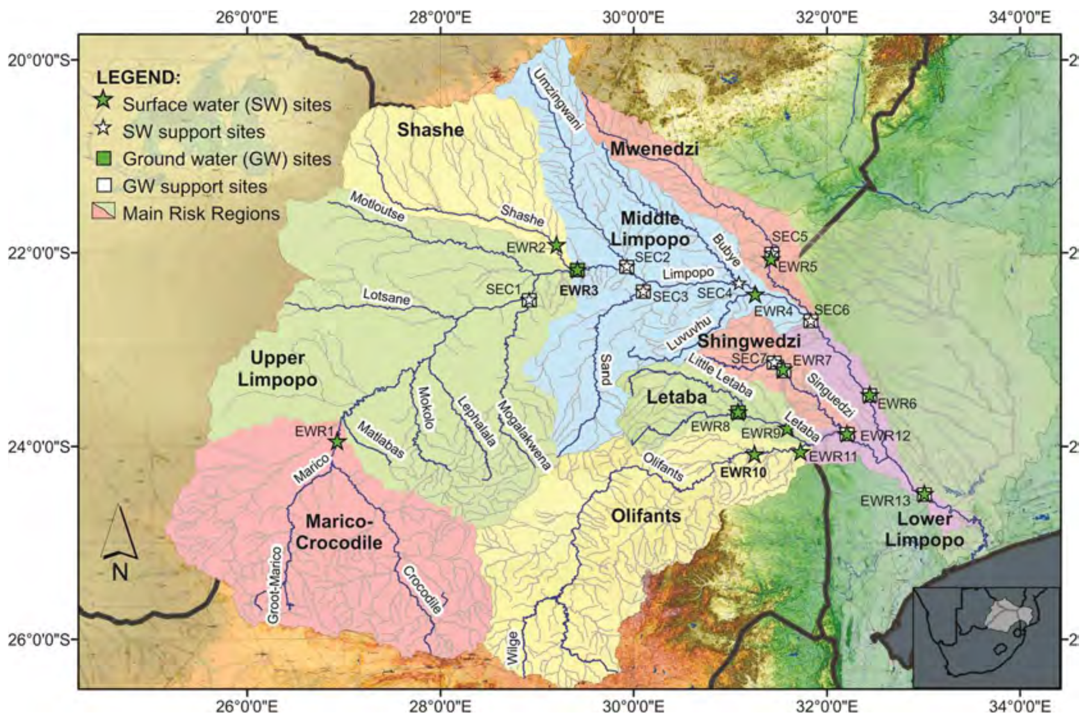

FIGURE 3. 1: LOCATION OF SITES TO BE STUDIED. THE BASIN IS DIVIDED INTO DRAFT RISK REGIONS (TO BE FINALISED IN 2ND PHASE)

[5] King, J (2001) DRIFT and environmental flows in Zimbabwe (Pungwe, Odze and Shashe Rivers). UK Dept of International Development via Mott McDonald, UK

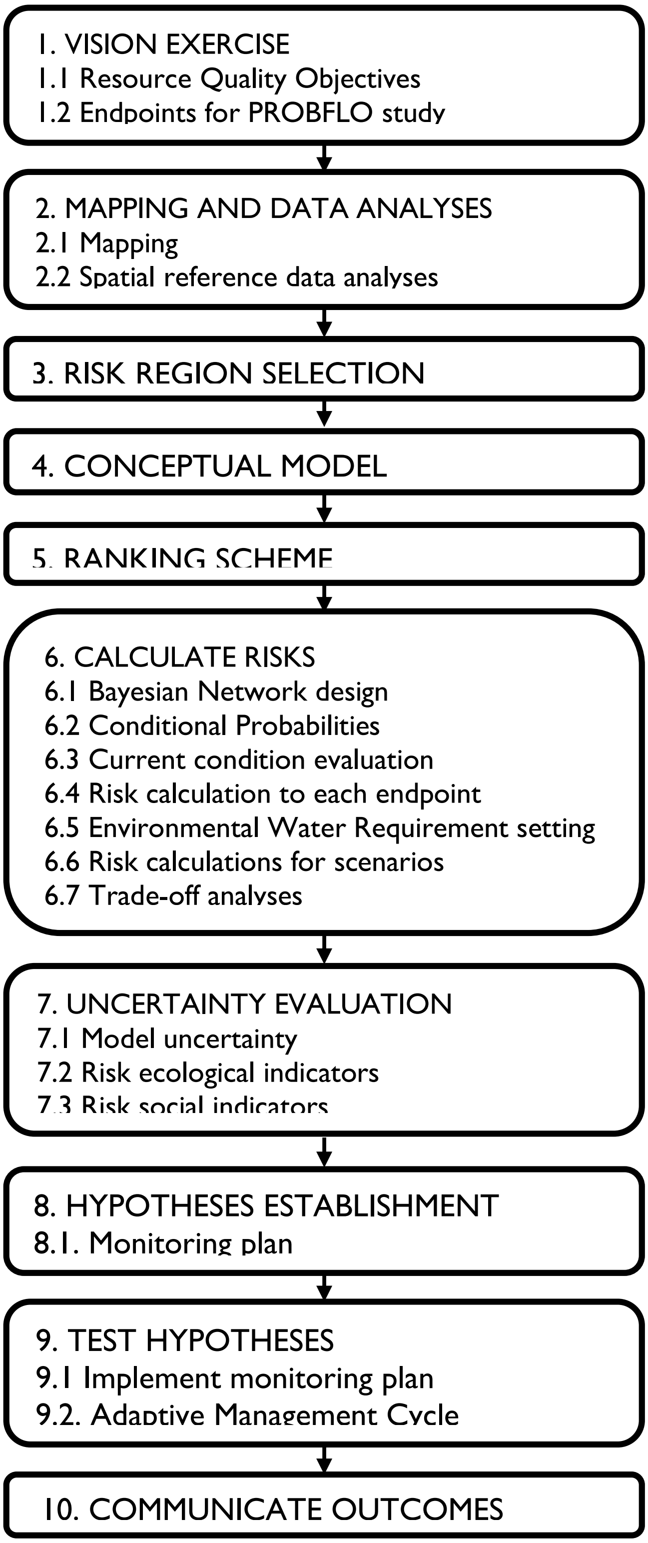

FIGURE 3. 2: THE PROBFLO FRAMEWORK INCLUDING THE 10 PROCEDURAL STEPS THAT WILL BE IMPLEMENTED IN THE LIMPOPO RIVER STUDY

3.3 TASK 2: VISION AND MANAGEMENT OBJECTIVES FOR THE BASIN:

E-flows can only be set in relation to a vision and management objective for the condition of the river within the basin and for the communities that the river supports. This already exists in different styles for the different parts of the basin as part of policy, strategies and resource objectives within riparian governments and LIMCOM have just completed a study on the vision for the basin. For this project, these will be harmonized into a format that provides the vision for different sub-sections of the basin and thus a context for the e-flows evaluation to follow. A vision and objectives will be established separately for each Risk Region and will be considered from both a surface and groundwater perspective and taking into account the reality that the river today is ephemeral in places, and critically along the main stem. If the existing vision or objectives are inadequate for the task, then the e-flows will be determined for the present-day flows and modelled for an improved ecological condition. This will be done largely at a desktop level with only VIP consultation where the project team will work with existing initiatives of Resilient Waters and important stakeholders, in particular LIMCOM to clarify the vision. Setting a vision or objectives that is at odds with the new LIMCOM vision and also what is in present day policy will not be possible in this project as such changes would require extensive consultation.

3.4 TASK 3: ECOSYSTEM SERVICE ENDPOINTS.

Endpoints have been defined as "*specific entities and their attributes that are at risk and that are expressions of a management goal*" (USEPA, 2003).

The vision and objectives clarified in the above task, will be matched to the requirements of local stakeholders for flow-related ecosystem services (as derived from both surface and groundwater systems). In order to do this, a process will be followed where the vision and objectives in policy are tested with key stakeholder representatives in order to establish the following:

a. The activities occurring in the basin that threaten the flow-related ecosystem services to communities along the river
b. The requirements these communities have for flow-related ecosystem services, and the relative dependence on groundwater and surface water for these services.
c. The above requirements become the endpoints of the e-flows study, the endpoints that the e-flows must deliver, in order to continue to provide flow-related ecosystem services. The project facilitates consideration of trade-offs between these endpoints.

Endpoints will be coupled with a preliminary economics and livelihoods assessment related to streamflow, based largely on literature and limited stakeholder representative consultation, consultation with NGOs and riparian government agencies and also with LIMCOM.

3.5 TASK 4: FIELD SURVEY:

To complement the 2013 Limpopo Monograph dry period e-flow assessment, during the October 2019 dry season period, a two-week survey was undertaken to the four new sites positioned on the Luvuvhu, Olifants/Elefantes Rivers. This added to the existing data that was previously collected during the dry season survey of the

Limpopo Monograph study. During the wet season (~ February/March) in 2021, a second three-week survey will be undertaken to all of the 12 sites. Confidence of the study will be improved by re-calculating the Monograph e-flows based on historical samples and the new data. Sites selected for the study will represent 12 Risk Regions that represent the different flow, socio-ecological use, and protection scenarios of the Limpopo Basin. Ecological components of the basin that will be evaluated in the survey will include the basin hydraulic habitats (based on cross and longitudinal surveys at the sites), water and sediment physico-chemical characteristics and associated geomorphology, aquatic vegetation, riparian vegetation, fish, benthic macroinvertebrates and indicator mammals and reptiles as components of the ecosystem and associated ecosystem processes. Single water quality samples that only provide a single snapshot sample will be taken by staff from the University of Northwest and combined with historical data to consider trends in water quality conditions. Additional ecotoxicology analyses of water, sediment and fish tissues will be undertaken by the BRICS study to contribute to the evaluation of the chemical stressors affecting ecosystem components. Note that this study focuses on the e-flows for the rivers of the Limpopo Basin, however the estuary is not included in this assessment. The Monograph study did document the e-flows for the estuary, so this information will inform the interpretation of the e-flows in the river entering the estuary for this new study.

As groundwater is key to e-flows, key data on the interaction between groundwater and surface water will be collected from at least two sites that represent typical settings for this interaction, including perennial and ephemeral conditions (Table 3.1). At these sites, the movement of sub-surface water will be documented over the seasons, and the interaction with surface water and surface ecosystems described. It will also be investigated how human abstraction of groundwater influences the flow in the river and in the subsurface to inform understanding of the disturbance of the natural system and the level of human dependence on groundwater and variability over the year.

Table 3.1 shows river surface water sites used in the Monograph study (Indicated as 2012) and new sites that will be added. The abbreviated name (ABBR) indicates whether the site is a full e-flows site (EWR) or is a secondary site (SEC). The site on the Changane will not be repeated as in the first survey it was found to be hyper saline and also largely a wetland with minimal flow, thus not suitable for an e-flows assessment.

TABLE 3.1: E-FLOW SITES. EWR REFERS TO A MAIN E-FLOW SURVEY; SEC IS A SECONDARY SITE FOR QUICK ASSESSMENT

NAME	ABBR.	DESCRIPTION	LATITUDE	LONGITUDE
Limpopo R. @ Spanwerk	EWR1-LIM	LmEWR1r (2012) - Limpopo at Spanwerk below confluence of Marico and Crocodile Rivers.	-23.944700	26.930800
Mogalakwena R.	SEC1-MOG	Mogalakwena R. upstream of confluence with Limpopo River. *No data available.*	-22.481807	28.918637
Shashe R.	EWR2-SHA	Shahe River upstream of confluence with Limpopo River. Proposed new EWR site. *No data available.*	-21.916236	29.19836
Limpopo R. @ Mapungubwe	EWR3-LIM	LmEWR2r (2012) - Limpopo at Poachers Corner downstream of Shashe River confluence.	-22.184200	29.405200
Umzingwani R.	SEC2-UMZ	Umzingwani R. upstream of confluence with Limpopo River. *No data available.*	-22.135897	29.930200
Sand R.	SEC3-SAN	Sand R. upstream of confluence with Limpopo River. *No data available.*	-22.394852	30.099069
Bubye R.	SEC4-BUB	Bubye R. upstream of confluence with Limpopo River. *No data available.*	-22.310418	31.091345
Luvuvhu R.	EWR4-LUV	Luvuvhu River upstream of confluence with Limpopo R. Proposed new EWR site, located in lower Luvuvhu Floodplain, KNP	-22.429285	31.257614
Mwenedzi R. @ Gonarezhou	SEC5-MWN	Mwenedzi River in Gonarezhou NP. Proposed new site to collect additional critical habitat data to contribute to LmEWR3.	-22.002326	31.433299
Mwenedzi R. @ Malapati	EWR5-MWN	LmEWR3r (2012) - Mwenedzi at Malapati upstream of Limpopo River confluence.	-22.063900	31.423100
Limpopo R. @ Pafuri floodplain	SEC6-LIM	LmEWR4r (2012) - Downgraded site from EWR to secondary, located at Pafuri in floodplain area to provide additional data to LmEWR5r.	-22.69532	31.833644
Limpopo R. @ Combomune	EWR6-LIM	LmEWR5r (2012) - Limpopo at Combomune downstream of Mwenedzi and Luvuvhu Rivers.	-23.471700	32.443800
Shingwedzi R. @ Kanniedood	SEC7-SHG	LmEWR6r (2012) - Shingwedzi R. below Kanniedood Dam that has recently been removed. Site to add information to EWR7.	-23.144100	31.472800
Shingwedzi R. @ Border	EWR7-SHG	New site on the Shingwedzi River proposed to replace Shingwedzi d/s Kanniedood Dam site.	-23.221056	31.555109
Groot Letaba R.	EWR8-GTL	Groot Letaba R. upstream of confluence with Klien Letaba presently	-23.677528	31.098639

		EWR site for Letaba Basin (#4) located at Letaba Ranch.		
Letaba R.	EWR9-LET	Letaba R. upstream of confluence with Olifants River presently EWR site for Letaba Basin (#7) located at Bridge below Engelhard Dam, KNP.	-23.809833	31.590806
Olifants R. @ Marula	EWR10-OLF	Olifants River site at Marula Weir on western boundary of KNP. New EWR site for Limpopo E-flows study to address multiple stressors upstream of KNP and Mozambique.	-24.07851	31.249334
Olifants R. @ Balule	EWR11-OLF	Olifants River site at Balule Weir in KNP. New EWR site for Limpopo E-flows study to address multiple stressors upstream of KNP and Mozambique.	-24.054077	31.726423
Elephantes R.	ERW12-ELE	Elephantes River in Mozambique below Massingir Dam. New EWR site.	-23.875120	32.226237
Limpopo R. @ Chokwe	EWR13-LIM	LmEWR7r - Limpopo River at Chokwe below confluence with Elephantes River, upstream of lower Limpopo River floodplain and estuary.	-24.500200	33.010400

3.6 TASK 5: CONCEPTUAL MODELS:

Generate general conceptual models that, using available information, describe relationships between the sources of flow-change (e.g. upstream dams, abstractions etc.) and the endpoints. These are preferably quantifiable relationships but if data is lacking, then based on expert judgement. Once developed, these conceptual models will use the evidence gathered in the field surveys to develop a hypothesis on the relationships between multiple sources, stressors, habitats and impacts to endpoints selected for the study (example in Figure 3.3). This includes the holistic characterization of flow-ecosystem and flow-ecosystem service relationships in the context of a regional scale e-flows framework.

A specialist workshop will be held to present the ecological state, and to agree on the conceptual models, a draft shown below

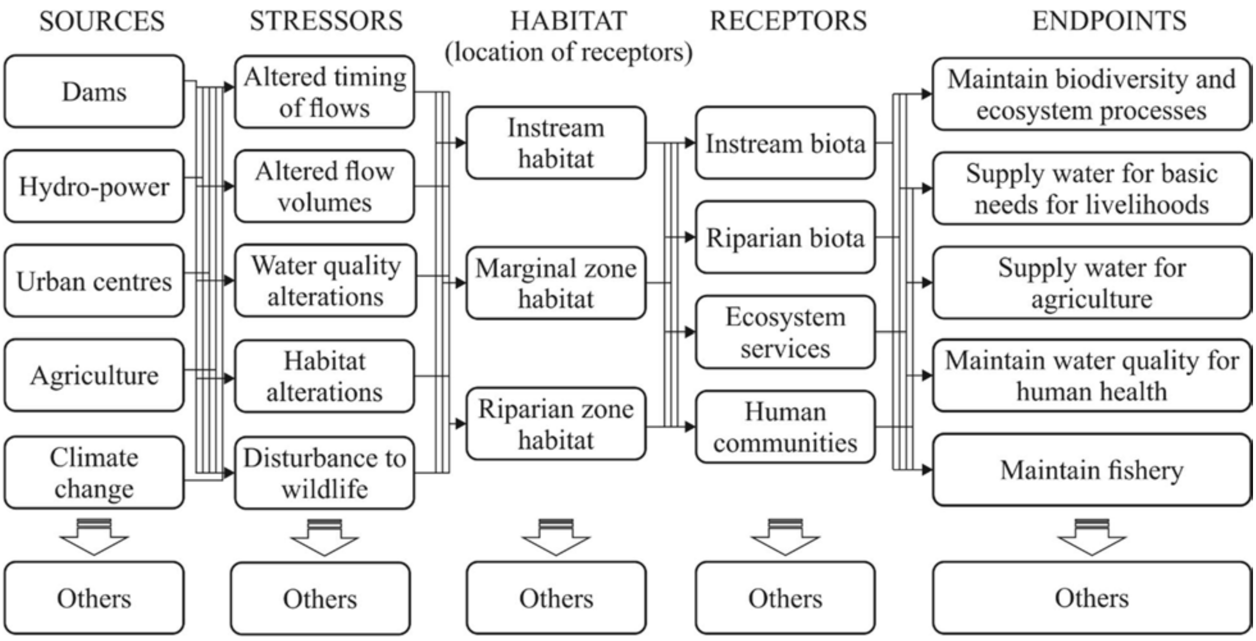

FIGURE 3.3: EXAMPLE OF A CONCEPTUAL MODEL FOR PROBFLO, WHICH DESCRIBES CAUSAL RISK RELATIONSHIPS BETWEEN SOURCES OF STRESSORS, BIOPHYSICAL IMPACTS OF STRESSORS, HABITATS, RECEPTORS AND THE IMPACTS TO ENDPOINTS. "OTHERS" REFER TO OTHER RELEVANT PARAMETERS IN THE BASIN. ENDPOINTS ARE DETERMINED BY SOCIAL AND ECOLOGICAL NEEDS.

Task 5b: New conceptual e-flows model for surface water / groundwater interactions:

This task will develop an explicit conceptual model for how to assess e-flows based on the source of water for the stream, whether surface water or groundwater. For an ephemeral part of the river, this takes into account the fact that the river is not flowing for part of the year, and flow-related services hence cannot be provided from these parts of the river during these periods and during the current overall flow setting. Groundwater may still sustain seasonal pools in the riverbed of great importance for the survival of certain species, and hence the surface water-groundwater interaction needs to be understood.

In a perennial part of the river, groundwater provides different flow components throughout the seasons, with a possibly different water quality profile than surface water, which certain species depend on. Especially in dry periods/seasons, groundwater may in these flow settings be the single largest contributor of flow to the river. This framework will guide and modify the traditional surface water e-flow assessment applied in the study with the aim of coming up with a more realistic assessment of e-flows applicable to ephemeral systems with seasonal lack of flow or only temporary standing water pools remaining in the system. It will also look at the role of groundwater in sustaining river flows in more perennial stretches of the river. It will help to develop guidelines on surface water as well as groundwater abstraction limits close to the river channel[6]. This approach will help guide water management in

[6] Sood, A., V. Smakhtin, N. Eriyagama, K.G. Villholth, N. Liyanage, Y. Wada, G. Ebrahim, and C. Dickens, 2017. Global Environmental Flow Information for the Sustainable Development Goals. Colombo, Sri

a more holistic manner and support a conjunctive water management strategy for the river system.

The approach that will be used is to identify one of the 12 e-flow sites where flow is ephemeral and groundwater and an alluvial sandbed is clearly important, as well as a site with perennial flow. Data on hydraulic heads, geological conditions, groundwater pumping, and isotope signals will be collected in order to understand the water balance and the interaction between groundwater and surface water. Groundwater will be incorporated into the conceptual model in Figure 3.3, where its relation to surface hydrology and modelling will be fully documented. The groundwater and surface water team will jointly develop the integrated framework to enhance the overall e-flow conceptual model, which will be relevant in other contexts.

3.7 TASK 6: CALCULATION OF RISK & DETERMINATION OF E-FLOWS:

From the general conceptual models established in Task 5, the smaller social and ecological endpoint models are converted into Bayesian Network models (example in Figure 3.4) for analyses. These include parent or input nodes and child or conditional nodes with links that represent causal relationships between nodes combined by Conditional Probability Tables (CPTs). Conditional Probability Tables describe conditional probabilities between the occurrence of states in the parent nodes and the resulting probabilities of states in the child nodes. These probabilities are supported by evidence, either historical or collected as part of the project.
The risks of flow (including from groundwater) and non-flow variable conditions to current and historical conditions observed in the study area are calculated. Next, the task is to evaluate socio-ecological trade-offs to endpoints to establish the e-flows with associated hydrological statistics. This information is used to evaluate the risk of alternative water resource use scenarios (due to developments and climate change) to the socio-ecological endpoints, following which a total endpoints risk associated with alternative water resources use scenarios is estimated.

A specialist workshop is held to review CPTs and establish e-flows.

3.8 TASK 7: UNCERTAINTY AND HYPOTHESIS GENERATION LEADING TO IMPLEMENTATION OF E-FLOWS:

Evaluate the uncertainty and sensitivity of the assessment by collecting evidence over time and then generate hypotheses to reduce uncertainty and direct field sampling that will inform monitoring and improve confidence associated with the outcomes of the study. This includes recommendations for the establishment of an adaptive management plan and a proposal for the way forward to implementation of e-flows.
A final specialist workshop is held to review e-flow results in relation to scenarios.

3.9 TASK 8: REPORTING AND COMMUNICATION:

Produce final reports and communicate the outcomes of the study to stakeholders.
Workshop giving feedback of findings to key stakeholders. A one- or two-day training workshop will be held with LIMCOM and nominated representatives including SADC and other important role-players, on the outcomes of the e-flow project and

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Lanka: International Water Management Institute (IWMI). 37p. (IWMI Research Report 168). DOI: 10.5337/2017.201.

recommendations for onward work in order to implement e-flows in the Limpopo Basin and scaling to other transboundary basins. This task will include an assessment of possible collaborative mechanisms to move beyond the e-flows assessment.

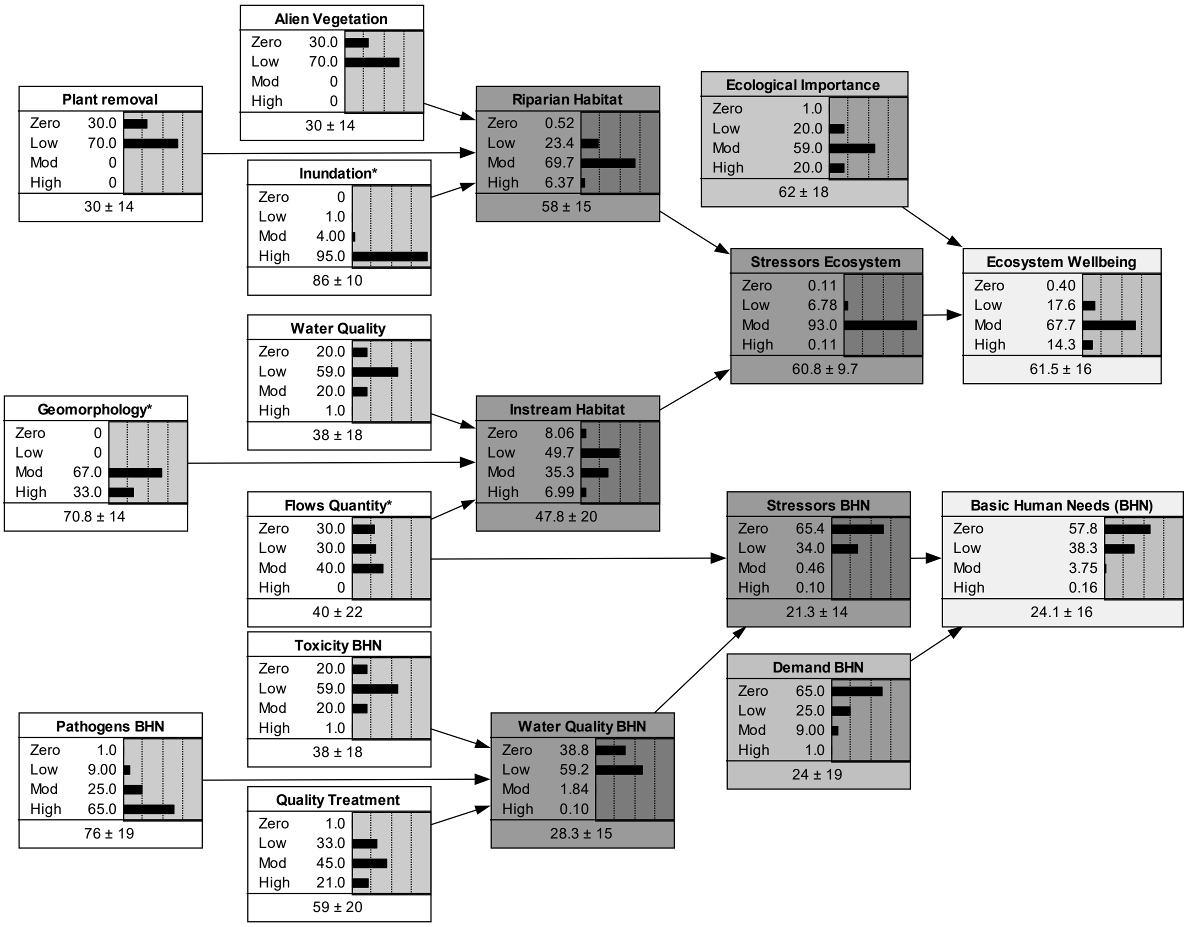

FIGURE 5.4: EXAMPLE OF A BAYESIAN NETWORK MODEL DEVELOPED FOR A PROBFLO CASE STUDY TO EVALUATE THE RISK OF WATER RESOURCE USE TO ECOSYSTEM WELLBEING AND BASIC HUMAN NEEDS ENDPOINTS

4 RESULTS TO BE PRODUCED:

The project will produce the following deliverables (Table 4.1)

TABLE 4.1: TITLES OF PROJECT DELIVERABLES

Deliverable no.	Milestone number	Deliverable title: E-flows for the Limpopo River Basin:
1	1	E-flows for the Limpopo River Basin – Inception Report
2	2,3	E-flows for the Limpopo River Basin – Basin Description (social and biophysical)
3	4	E-flows for the Limpopo River Basin – Literature and Data review
	5	Report on Vision, Objectives and Endpoints
4	6	E-flows for the Limpopo River Basin – Drivers of Ecosystem Change
5	6	E-flows for the Limpopo River Basin – Ecological Responses to Change
6		E-flows for the Limpopo River Basin – Database
7	5,7,8,9,10,11	E-flows for the Limpopo Basin – Synthesis Report

Within these reports will be contained the following key elements of the E-flow assessment:

1. A framework for assessing e-flows in ephemeral river systems that incorporates groundwater information.
2. The eight (8) Monograph e-flow sites upgraded with additional evidence and linked to ecosystem services. Four additional sites will be added totaling twelve sites being evaluated in the study.
3. A description of the vision and management objectives for water flows as contained within existing governance structures (national governments and transboundary agencies, especially LIMCOM) and agreed with key stakeholders. Coupled with this, a preliminary livelihoods and socio-economic description of the users of the flow-related ecosystem services and their e-flow requirements to retain resilience in the face of altered flows.
4. Detailed assessment of the alteration of flows in the basin (including historical, present and hypothetical future) and the impact that these will have on the geomorphology and sediment regime, hydraulic habitats within the river, the water quality, and the riparian vegetation.
5. Detailed assessment of the interactions between groundwater and surface water in representative ephemeral and perennial parts of the Limpopo River. The assessment will be incorporated into the E-flow conceptual model and will be based on a synthesis of information from two key sites linked to basin-wide data.
6. Detailed documentation of the flow-ecosystem interactions. This would in particular include the impact of flows on sediment movement and channel structure, the hydraulic habitat, the riparian vegetation, fish and invertebrates in the river.
7. The socio-ecological consequences of altered flows, the risk of developmental and climate change alterations in water flow to a number of ecological and

social endpoints that include the perspective of sustainable agriculture. This will include a risk assessment framework and additional monitoring spreadsheets to contribute to the adaptive management process designed to improve confidence in the assessment over time.

8. Based on the risk posed to these endpoints caused by different scenarios of change, **an e-flow (volume and timing of flow) will be determined that would maintain the resilience of the ecosystem and communities in their present form, will consider increasing resilience of the present days condition and also provide possible restoration options**. The final e-flows that are determined will come in three main forms, both of which will be important for management of water resources in the basin:
    a. A table of expected river discharges, per month, that will allow regulators to monitor and ensure there is sufficient water (according to the vision) in the river to continue to provide the services that it should. These flows can be built into management strategies, regulations and can be used to assist with issue of permits for water abstractions.
    b. The interaction and contribution of groundwater to maintaining e-flows during the wet season, and the role groundwater plays in supporting services throughout the year and in particular when river is dry. This will be documented with a focus on hotspots where such interaction is vital for river functioning.
    c. A presentation of the risks to all of the flow-related ecosystem services (endpoints) that will come about if the drivers of change (e.g. water abstraction, climate change) result in a further change to stream flow. These risks can be used in basin strategies, not only for water resource management, but also for other strategies that involve each of these endpoints, e.g. related to food security and agriculture, human settlements.
9. E-flows will be determined for a range of ecological states (limited to B, C and D ecological categories as described in Kleynhans and Louw, 2008[7]) and which formed the basis of the Monograph study and will consider associated socio-economic risks. The output will include a scenario evaluation template that can be used by stakeholders to evaluate the socio-ecological consequences of future development scenarios in the study.

[7] Kleynhans, C.J. and Louw, M. D. (2008). River EcoClassification: Manual for EcoStatus determination. Report No. TT 329/08. Water Research Commission, South Africa.

5 SPECIALIST APPROACHES:

5.1 HYDROLOGY

The hydrological information and results obtained from the Limpopo River Basin Monograph study, 2013 is a comprehensive set of rainfall, evaporation, catchment water use and stream flow time series for both pre-development and present-day conditions for the entire basin. The preparation and results from this study included:

- Delineation of sub-basins (mainly major tributaries of the Limpopo River).
- Sourcing of climatic data (rainfall, temperature and evaporation).
- Sourcing of data from the various gauging stations, water use for irrigation, urban, rural, including stock watering, forestry and dams;
- Screening and patching of missing, incomplete or suspect monthly rainfall data using the CLASSR and PATCHR tools and generation of catchment rainfall;
- Initial patching of monthly streamflow data through the use of PATCHS;
- Calibration of the Pitman Hydrological Model (WRSM2000) and final patching of the streamflow data. This process included the determination of transmission losses along the river stretches of tributaries and mainstem Limpopo River due to the deep sandy alluvial material of the beds and banks of the rivers; and
- Generation of long-term flow time series (1920-2010) for natural and present-day conditions.

The result from this study provides a broad database to serve as baseline for the hydrological information required for the current E-Flow determination of the Limpopo Basin.

Hydrological data for E-flow determination and ecological consequences evaluation

The pre-development flow time series as generated through the Limpopo River Basin Monograph study will be used as the reference flows at each of the selected E-Flow sites and at the outlets of those risk regions where no sites were selected. Specific hydrological statistics will be calculated for use by the ecologists. These statistics include the calculation of the monthly and annual mean, median, standard deviation, coefficient of variability, minimum, maximum, and various percentiles. Where daily data is available from a gauging weir close to the E-Flow sites or outlets of the risk regions, these statistics will also be calculated for daily data. Graphical representation of the flow time series (e.g. hydrographs, flow duration curves) will also be provided. Additionally, baseflow separation will be undertaken using the method as developed by Smakhtin, 2001. This will provide an indication as to the groundwater contribution to surface flows and its variability intra- and inter-annually.

Where information is available on stable isotopes and 'calibration' of baseflows, the baseflows will be adjusted to the groundwater information. Two indices of variability will be calculated to further describe the flows and provide additional information to the ecologists. These are:

(i) Flow Variability Index – summarizes 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). This index will provide an indication of perennial, seasonal or ephemeral rivers.

(ii) Baseflow Index – This is the proportion of total flow that occurs as baseflow and provides an indication of groundwater contribution to streamflow. It is calculated from the ratio of the mean annual baseflow to the mean annual total streamflow.

Similar statistics and graphs will be provided for the selected flow scenarios. These scenarios can include present day flow conditions, future management options and bulk water developments for water use, protection of the ecosystems or climate change.

Determination of E-Flows

The Desktop Reserve Model (DRM) within the SPATSIM framework (Hughes, 1999) will be used to calculate the E-Flows at the selected sites per risk region with the following information and data:

i. Reference flows: These are the pre-development flows at each of the selected sites as simulated during the Limpopo Monograph study.
ii. Daily flow data: Data available from gauging weirs in close vicinity of the selected sites will be used to confirm the low/ drought flows in the river as well as provide guidance for the specification of freshets and floods in terms of timing (which months), frequency (how many per month) and duration (number of days).
iii. Monthly flow distributions: Initial monthly flow distributions (pre-defined distributions within SPATSIM) will be selected and adjusted to fit the flow characteristics of the reference flows. These include, annual peak and low flow months, shape of low flow months, low and high flow assurance rules.
iv. Ecological information: Ecological information will be provided by the ecologists for selected quantity indicators that formed part of the Bayesian Network formulation. These indicators included inter alia flow requirements for fish, macroinvertebrates, riparian vegetation and movement of sediments through the system. Requirements are usually provided for various months, including highest and lowest flow months and those months when surveys were undertaken and specific flood requirements in terms of flood peaks and duration based on the hydrological information from the daily observed flows. These requirements will be checked against the reference flows to ensure that the requirements are not higher than the reference flows.

The DRM will then be run in an iterative process and changes made to the model parameters until a good fit is obtained with the ecological requirements supplied by the ecologists for the selected months. These parameters are then used to interpolate flows for those months where no ecological data was available.

References

1. Hughes, DA and 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.
2. 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.

3. 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.

5.2 HYDRAULICS

This holistic e-flow methodology incorporates a description and prediction of environmental river hydraulics as it influences the physical, chemical and ecological makeup of rivers (James, 2010). The modification of the flow regime changes sediment processes and associated habitat types and abundance thereof, which in the end affect the biotic composition (Tharme and King, 1998). The flow regime also affects the surface-groundwater interactions. By linking the hydraulic parameters to ecologically based information and instream habitat requirements, management decisions can be made on the flow volumes that are needed in the Limpopo River and its tributaries. Hydraulics acts as the translator between flows and ecological needs and preferences. The e-flow methods require a few general hydraulic parameters, such as water depth, velocity, wetted perimeter and surface water width in order to determine the required flows needed to maintain a river in a specific state (Rowlston, Jordanova and Birkhead, 2008). Fluctuations of these parameters are simulated over time in terms of a time series, which is important for understanding the effect of the duration and frequency of various flow magnitudes on biota and habitat (Rowlston, Jordanova and Birkhead, 2008). Hydraulic characteristics during low flows are particularly important as these are the conditions that biota experience for extended periods of time, e.g. drought, and they affect longitudinal connectivity (Rowlston, Jordanova and Birkhead, 2008). For this study, the topographic data, hydraulic data and hydraulic modelling output results for sites in the Limpopo basin.

The following objectives were set for the hydraulic assessment:

- site selection,
- survey relevant cross sections and energy slope,
- measure flow depth and velocity along each transect,
- induction of survey and hydraulic data for each site,
- model the hydraulics for each cross section,
- calculate the frequency distribution for various hydraulic biotypes for each transect,
- compile a report showing all the necessary hydraulic results
- workshop, and
- finalize the hydraulic report.

Topographic and hydraulic data will be based on available data and collected (at primary sites) from site surveys. In the field, data gathering will consist of transect selection and demarcation, survey of transects (perpendicular to flow); survey of water levels and measurement of depth and velocity along each transect as recommended by Rowlston, Jordanova and Birkhead (2008). Land based surveying will be undertaken with centimetre accuracy survey equipment (Topcon Total Station). Sites with deeper, fast flowing water (>1.2m deep and >1m.s) will be surveyed using a River Surveyor Acoustic Doppler Current Profiler (Sontek) along each transect. For very shallow depths an OTT MFpro electromagnetic current meter will be used to capture flow velocity and determine discharge at the date of sampling. The channel will be divided into 20 or more verticals to capture depth and flow velocity data in order to calculate discharge (Gordon *et al*., 2004). In the office, discharge, energy slope and transect data will be extracted from the field measurements. Roughness will be 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 and a continuous rating function, One-dimensional hydraulic modelling will be done using HEC RAS, a widely used free-ware hydraulic model (Hirschowitz, Birkhead and James, 2007). Steady state hydraulic modelling will be used as appropriate for e-flow projects where we assume steady flow and negligible changes in vegetation resistance (Birkhead, 2010). Output from the modelling and field measurements will be plotted with CurveExpert 1.4 to develop a power function that best described the discharge-stage relationship for each transect. HABFLO, a one-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). The model, its structure, corrections for flow velocity, etc. are discussed by Hirschowitz et al. (2007). The HABFLO assumptions given by Hirschowitz et al. (2007) are:

- Cross-sectional profiles and 1-D hydraulic parameters may be used to characterize the bed topography and hydraulic conditions, respectively, in morphological units.
- Frequency-distributions of depth-averaged velocity may be estimated with reasonable accuracy using statistical methods.
- Depth-averaged velocity, flow depth, and substrate type are mutually exclusive (independent) variables.

HABFLO flow-depth frequency distribution calculations for this assessment will be based on the work of Lamouroux et al. (1995). Details on how HABFLO calculates the frequency distribution are given by Hirschowitz et al. (2007).
This information will be provided to other specialist components in the study who can use the data to describe available habitat in the river given different discharge.

5.3 WATER QUALITY AND ECOTOXICOLOGY

Water quality has been identified as an important driver of ecosystem wellbeing, and in holistic e-flow assessments it needs to be integrated with flows to establish suitable flows to achieve ecosystem targets that represent sustainability in case studies (O'Brien et al., 2019). Water quality includes consideration of the chemical characteristics of the water and some physical system variables including temperature, pH, and oxygen levels. Categories of water quality that will be evaluated in the study include salts, nutrients and toxicants. In this study, a range of Lines of Evidence (LoEs) focusing on understanding historical, present and potentially future water quality characteristics were considered and integrated into the PROBFLO assessment to allow for the evaluation of water quality as a non-flow variable driving the ecosystem.

The eco-toxicological assessment as a component of the Limpopo e-flow study will make use of indicator fish that are proposed to have the widest distribution in the catchment including *Clarias gariepinus*, *Hydrocynus vittatus* and *Oreochromis mossambicus* as indicators of changes in water and sediment quality through a multi-metric approach that represents different levels of biological organization ranging from sub-cellular to whole organism responses. These biological responses will be related to the environmental drivers, i.e. water quantity (during high and low flow hydrological periods) and water (and sediment) quality (microplastics, metals and organics). The samples will be collected at the primary sites in the study area. Water and sediment samples will be collected in triplicates per site and 10 fish per species of each selected site.

In situ water quality variables will be assessed including: oxygen concentration and saturation, electrical conductivity, pH, and temperature. The water samples will be preserved and analyzed for macro-elements (Na, Ca, Mg, K, Cl, SO4), nutrients (PO4, NO2, NO3, NH4), metals (Al, Fe, Cr, Mn, Co, Ni, Cu, Zn, Cd, Pb and Hg) and organic [such as organochlorine pesticides (OCPs) DDT, chlordanes, hexachlorobenzene, polychlorinated biphenyls (PCBs), polybrominated diphenyl ethers (PBDEs) and per- and polyfluoroalkyl substances (PFASs)] pollutants. All analyses will be carried out as described by Gerber et al. (2015a). In addition, microplastics will be analyzed according to the methods described by Slootmaekers et al. (2019). Sediment quality is used to describe the physical and chemical properties of sediment that influence the potential for the water column to become contaminated. Sediment samples will be collected and preserved. In the laboratory, the physical properties (organic carbon content, particle size) and microplastic, metal and organic pollutants (same as those that were analyzed in water samples) will be analyzed according to the methods described by Gerber et al. (2015b).

Metal digestion and analysis in fish tissue (muscle) will be conducted using ICP-OES and ICP-MS techniques according to the methods of Gerber et al. (2016b). Organic contaminant extraction (solid phase matrix dispersion) and analyses (GC-MS) will be carried out using standardized techniques based on the methods described by Gerber et al. (2016a). Microplastics will be analyzed in the gastrointestinal tracts of the three fish species. Analytical efficiency will be tested using certified reference materials.

5.4 BIOLOGICAL ECOSYSTEM ATTRIBUTES

Scientists have used various biological components of rivers including: fish, macro-invertebrates and vegetation primarily, but also mammals, reptiles and amphibians and birds in e-flow determination studies (O'Brien et al., 2018). To achieve this, scientists establish and use numerous measures of the wellbeing and or ecosystem preferences and requirements of fish also termed Lines of Evidence (LoEs) to evaluate the current wellbeing (or Present Ecological State according to a range of ecological categories (Table 5.1)), environmental water requirements and or ecological consequences of altered flows and water quality to fish communities (Murchie et al., 2008 for example). In e-flow assessments, the integration of multiple biological LoEs, is considered to be the preferred approach, and international best practice, to evaluate the consequences of altered environmental variable conditions (incl. flows) and establish e-flows (Murchie et al., 2008). By implementing a range of multiple robust, validated LoEs on a range of levels of biological organization (Figure 5.1), with these modelling assessments, the uncertainty associated with the application of the modelling techniques is reduced. These other LoEs, such as the use of multivariate statistical procedures to evaluate community structure shifts, have specific data requirements including detailed information on existing biological community structures within the study area.

TABLE 5.2: ECOLOGICAL CLASSIFICATION SYSTEM (A-F) AND ASSOCIATED BIOTIC INTEGRITY AND DESCRIPTIONS FOR THE STUDY

CATEGORY	BIOTIC INTEGRITY	DESCRIPTION OF GENERALLY EXPECTED CONDITIONS
5.4.1.1 A	Excellent	Unmodified, or approximates natural conditions closely. The biotic assemblages compares to that expected under natural, unperturbed conditions.
B	Good	Largely natural with few modifications. A change in community characteristics may have taken place but species richness and presence of intolerant species indicate little modifications. Most aspects of the biotic assemblage as expected under natural unperturbed conditions.
C	Fair	Moderately modified. A lower than expected species richness and presence of most intolerant species. Most of the characteristics of the biotic assemblages have been moderately modified from its naturally expected condition. Some impairment of health may be evident at the lower end of this class.
D	Poor	Largely modified. A clearly lower than expected species richness and absence or much lowered presence of intolerant and moderately intolerant species. Most characteristics of the biotic assemblages have been largely modified from its naturally expected condition. Impairment of health may become evident at the lower end of this class.
E	Very Poor	Seriously modified. A strikingly lower than expected species richness and general absence of intolerant and moderately tolerant species. Most of the characteristics of the biotic assemblages have been seriously modified from its naturally expected condition. Impairment of health may become very evident.
F	Critical	Critically modified. Extremely lowered species richness and an absence of intolerant and moderately tolerant species. Only intolerant species may be present with complete loss of species at the lower end of the class. Most of the characteristics of the biotic assemblages have been critically modified from its naturally expected conditions. Impairment of health generally very evident.

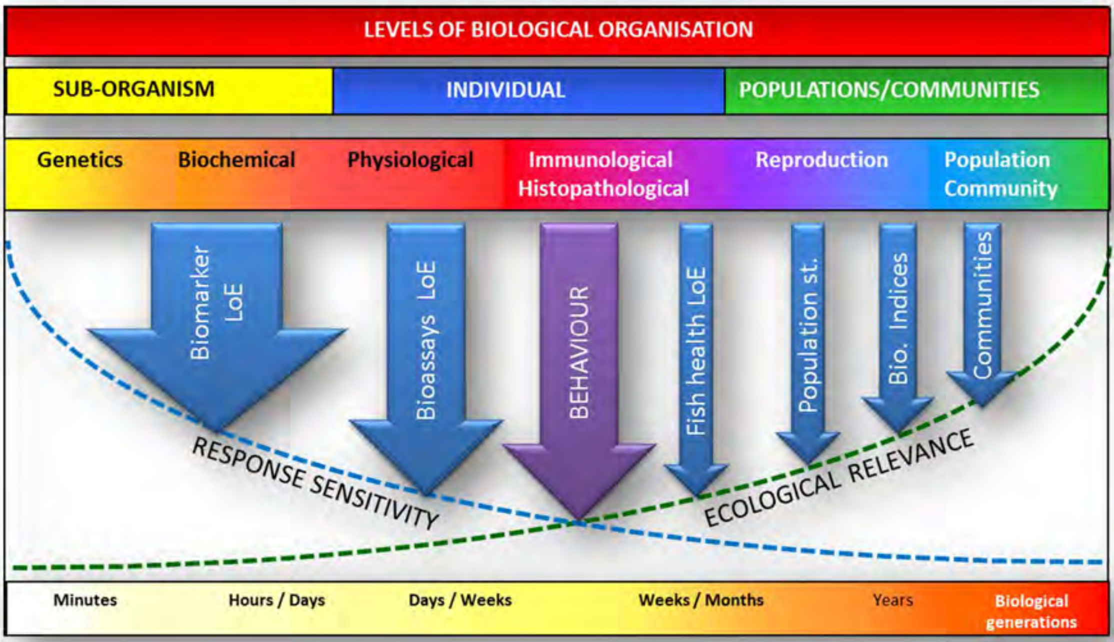

FIGURE 5.1: RELATIONSHIP BETWEEN MULTIPLE LINES OF EVIDENCE, LEVELS OF BIOLOGICAL ORGANISATION AND THE RESPONSE SENSITIVITY AND ECOLOGICAL RELEVANCE.

5.5 FISH

In this e-flow study, fish have been considered as an ecological component of the Limpopo River basin that can contribute to the establishment of volume, timing, duration and frequency of flow variables. Fish are not only good indicators of ecological health, they are charismatic animals that people easily relate to and they are an important source of food for many human communities throughout the world (Skelton 2000 for example). As indicators of ecological health; (1) fish are useful in that they are long-lived and are therefore good indicators of long-term exposure to impacts, (2) they occupy a wide range of aquatic habitat usually due to their mobility allowing for the consideration of multiple, diverse environments, (3) communities are comprised of a range of species from different trophic levels integrating and allowing for the consideration of a range of environmental changes and (4) when established as sensitive umbrella species, the conservation of some species can allow for the protection of large diversity of other species and associated ecosystems processes.

Fish are already being extensively used throughout the world as indicators of ecological health, including flow alterations in river ecosystems (Karr 1981, Kleynhans1999, Kleynhans 2008, Pont et al. 2006). In particular the known biological attributes of fish have been routinely used to develop many fish community metric measure approaches commonly termed fish indices of ecological health. In addition, fish have been shown to be important indicators in the evaluation of flow requirements for river ecosystems and have been documented to provide protection for many other aquatic organisms. Thus, fish are considered to be very important in the establishment of e-flows for river ecosystems throughout Africa and the rest of the world (O'Brien et al., 2018).

Numerous advantages and disadvantages are associated with the application of many of the available Lines of Evidence (LoEs) to evaluate the current wellbeing (or Present Ecological State), environmental water requirements and or ecological consequences of altered flows to fish communities (Murchie et al., 2008). As such, the integration of multiple LoEs, is considered to be the preferred approach, and international best practice, to evaluate the consequences of altered environmental variable conditions (incl. flows) to fish (Murchie et al., 2008). By implementing a range of multiple robust, validated LoEs on a range of levels of biological organization (Figure 5.1), the uncertainty associated with the application of the modelling techniques is reduced. Some LoEs, such as the use of multivariate statistical procedures to evaluate community structure shifts, have specific data requirements including detailed information on existing fish community structures within the study area. In this study, a range of LoEs will be implemented as follows:

- Community metric measure index using the Fish Response Assessment Index developed and extensively used in southern Africa by Kleynhans (2007). This LoE has been implemented to evaluate the state of fish communities and possible attributes of the communities that may be impacted and/or are sensitive to flow alterations.
- Multivariate statistical evaluation of fish community structures and drivers of community structure changes (using a Redundancy Analyses ordination technique) using the Canoco version 4.5 software (Ter Braak, 1994). This approach allows for the direct interpretation of the community structures of fish in terms of the taxa obtained during detailed surveys (O'Brien et al., 2009). These techniques allow for the assessment of complex responses or changes in community structures obtained in the study and then when combined with Monte Carlo permutation testing, the statistical significance of hypothesized differences in the community structures can be tested (Ter Braak and Smilauer, 2004; Van den Brink et al., 2003). This approach allows for constrained analyses of the community structures to be undertaken, which involves overlaying captured variance of explanatory environmental variables such as habitat and water quality variables onto fish sample and species ordinations. This approach allows for the habitat drivers of shifts in fish community structures of riverine ecosystem in the study to be statistically evaluated (O'Brien and Husted, 2010).
- Additional indicator information pertaining to the behavioral response of indicator species to altered volumes, duration, timing, and water quality of flows is available from the leverage projects considered in the study. This data will be incorporated into the study as an additional LoE.

5.6 MACROINVERTEBRATES

The approach adopted for macroinvertebrates will be similar to fish. Benthic macroinvertebrates consist of a diverse group of long-lived, sedentary invertebrate species that react strongly and often, predictably to human influences on aquatic ecosystems. For this reason, benthic communities are increasingly studied and commonly used as indicators of ecological disturbance (Lewis et al., 2001) because of their sensitivity to environmental changes and ease of sampling. The community structures and associated response to multiple stressors is used as an LoE in e-flow assessments globally (O'Brien et al., 2018). In addition, some indicator species have been identified and used as an LoE to recommend the volume, timing, duration and water quality of flows to maintain these species in the catchment.

5.7 RIPARIAN VEGETATION

Riparian vegetation will also be included in this study to establish flow requirements for the ecosystems of the sites/rivers considered in the study.

The biophysical survey for riparian vegetation at each site will consist of the following components:

1) Site and riparian zone delineation
2) Determination of the present ecological status (PES)
3) Determination of the ecological importance (EI)
4) Determination of the ecological sensitivity (ES)
5) Determination of riparian vegetation in a historical context, from remote sensing
6) Determination of e-flows (including from groundwater) for riparian vegetation at the site (to be used as a benchmark for scenario evaluation if required)
7) Define and parameterize endpoints for inclusion in risk analyses using PROBFLO
8) Conduction of a baseline survey for riparian vegetation at the site and propose monitoring protocol for future surveys so that continuity with the baseline is ensured

Riparian and Wetland Delineation
Satellite imagery (Google Earth ©) will be used to do a desktop assessment of all possible wetland and riparian features. These will be noted and each possible feature visited for field verification. All wetland and riparian features that may be within the influence zone of flow alterations in the study sites of proposed study will be delineated in accordance with guidelines set out by DWS (DWAF, 2008), using topography, evidence of water movement through the landscape, evidence of water pooling in the landscape and changes in vegetation species composition and structure associated with such features. GPS coordinates will be taken at the edge of riparian features and wetlands to support delineation. National wetland maps will be assessed to see if any recognized wetlands occur within or near the site (NFEPA, Nel *et al.*, 2011). Wetland and riparian zone indicator species will mainly be used to aid delineation into riparian zones.

Determination of the Present Ecological Status
The PES of all affected riparian zones will be assessed using the Riparian Vegetation Response Assessment Index (VEGRAI) level 4 (Kleynhans *et al.*, 2007). The riparian vegetation response assessment index (VEGRAI) is a tool that was designed to rapidly evaluate the ecological status of riparian vegetation at any riparian site (Kleynhans *et al.*, 2007). It requires an understanding of the reference (natural) condition, against which change of vegetation structure, composition and distribution are measured. The deviation from the natural condition, in which no anthropogenic impacts occur, is expressed as a percentage score commonly referred to as the present ecological state (PES) and can be categorized into meaningful management units (A-F) (Table 5.2). The PES score itself may be used as a monitoring metric to assess whether overall

ecological health changes over time but is specifically intended to derive a current measure of ecological condition in the riparian zone.

Ecological Importance and Sensitivity (EI & ES)

Kleynhans & Louw (2008) defined ecological importance of a river as its importance to maintain biological diversity and ecological functioning on a local and wider scale. The ecological sensitivity (or fragility) on the other hand refers to a river's ability to resist disturbance and its capability to recover from disturbances once they have occurred. The EI and ES determinations will be based on the latest available information and data of species and habitats assessed in the field. The table below indicates the metrics that will be assessed on a rating of 1-5 in order to determine an outcome.

TABLE 5.3: INSTREAM AND RIPARIAN METRICS THAT WILL BE USED FOR ASSESSMENT OF E & ES

INSTREAM BIOTA									RIPARIAN/WETLAND							
BIOTA					HABITAT				BIOTA				HABITAT			
RARE & ENDANGERED	UNIQUE	INTOLERANT OF NO FLOW	INTOLERANT PHYSICO-CHEMICAL CHANGES	SPECIES/ TAXON RICHNESS	DIVERSITY OF TYPES AND FEATURES	REFUGIA AND CRITICAL	SENSITIVITY TO FLOW CHANGES	MIGRATION ROUTE	RARE AND ENDANGERED	UNIQUE	INTOLERANT	SPECIES/ TAXON RICHNESS	DIVERSITY OF TYPES AND FEATURES	REFUGIA AND CRITICAL	SENSITIVITY TO FLOW CHANGES	MIGRATION CORRIDOR

Determination of Environmental Flows

The determination of environmental flow requirements will comprise three main processes:

1) Defining endpoints or indicators
2) Parameterizing the hydrological / hydraulic niche of endpoints / indicators from measurement in the field
3) Integration of "rule-set" into 1D or 2D modelling for scenario outputs or risk analyses

Endpoints

The ecosystem endpoints relate to the most vital vegetation habitats with the aim to maintain habitats and ecosystem processes for critical indicator macrophytes and riparian/wetland vegetation. Vital habitat/indicator combinations should be chosen to represent ecosystem endpoints and are determined on-site and are specific for each site.

Social endpoints can also be recognized and are based on those components of the vegetation that are vital to sustaining livelihoods and as such the aim is to maintain indigenous vegetation components in order to sustain community livelihoods including natural vegetation production and subsistence agriculture. Endpoints (which are also indicators) feature in flow determination, scenario assessment and provision of ecosystem services.

Defining the hydraulic / hydrological niche of endpoints / indicators

The ultimate drivers of all ecosystem and social endpoints are the flow regime and rainfall. Vital components of the flow regime include perenniality (wet and dry season baseflows), timing (seasonality) of floods, magnitude and duration of flood events and by implication the distribution of depth/area parameters associated with floods. Various biotic indicators show niche preference for combinations of the drivers and can be modelled as such for integration into a 1D or 2D hydraulic model. Each vegetation type (endpoint) has clear niche preferences in terms of flooding depth, duration and timing, as well as timing and severity of flows during the dry season. Each set of such preferences can be defined as endpoint-specific "rule-sets" that will respond within the modelled environment and the outcome of which can be measured. The flow regime that describes the current situation represents the environmental flow requirements, against which response to scenarios may be measured. Both the endpoints and the "rule-sets" require definition to describe an acceptable ecological quality, deemed to be the environmental flow requirement. Measurement is site-based and usually entails surveying vegetation onto a hydraulically calibrated profile at each site.

5.8 GROUNDWATER

The groundwater (GW) field survey will be implemented in the second half of 2020 and field work done in early 2021, or as soon as the Covid-19 lockdown is cancelled. To possibly kickstart the field implementation ahead of the cancellation, a field permit will be sought from relevant authorities, to allow early reconnaissance, a hydrocensus, and monitoring in the groundwater sites. This will be followed by regular monitoring over the dry and wet seasons in 2020 and 2021 (approximately 5 field visits). The field sites selected for the in-depth GW studies are the Limpopo R. @ Mapungubwe (EWR3-LIM) and the Groot Letaba R. (EWR8-GLR) (Table 5.1 and Figure 3.1). A workshop will be implemented in the EWR3-LIM site as soon as possible to seek existing GW data and hydrogeological information from e.g. the Vanetia Mine, who has done significant monitoring in the area due to their dependence on GW for their mining activities. Farmers from the area will also be invited or visited/interviewed during this activity to inquire on data and information on use of GW for irrigation in the vicinity of the river. A monitoring plan for the site will be set up and initiated subsequent to the workshop.

It is likely that data on GW levels already exist to infer on surface water-groundwater interactions, but these will be checked, interpreted and further expanded as possible in existing monitoring boreholes, and possibly by installing new piezometers in transect(s) across the river channel. Since this is an ephemeral part of the river, existing seasonal pools in the riverbed will be identified for dry season investigations in partnership with the surface water (SW) team. Riparian vegetation, which is likely a groundwater-dependent ecosystem, will be mapped around the site, using remote sensing and in a seasonal/historical perspective to get a sense of the alterations and variability over time, e.g. to understand when the river started becoming ephemeral and the variation over time. Likewise, irrigation area mapping will be performed around the site, to infer abstraction amounts from the GW. Modelling will be performed to estimate the impact of present and historic GW pumping on river flow and river depletion, and scenarios representing future vision around e-flows will be tested. Water samples for stable isotope (^{18}O, ^{2}H) and tracer (likely Si) analysis will be collected in GW and SW (flowing stream and pools) and precipitation at various times of the year, to infer on the source of the water for the stream, and to calibrate the baseflow assessment, performed though numerical baseflow separation. Data for river flow will be obtained from the SW team.

The second site in the Groot Letaba (EWR8-GLR) will similarly be investigated, representing a perennial part of the river. However, since previous work has already been done by SANParks and others in this site, the level of fieldwork will be reduced to those aspects that were not covered sufficiently in these studies when it comes to understanding SW-GW interactions, baseflows, etc. Renewed isotope studies may be carried out for this site. Early on, an intern will be contracted to work on the review of previous work in the two sites, to collate data and identify data gaps.

For the full basin assessment of e-flows, the information from the two sites (ephemeral and perennial) will be extrapolated across the basin according to degree of perenniality and baseflow. This is a novel approach, and further exploration of this methodology will be required. This method requires that a measure of perenniality and baseflow is available for all the sub-basins/catchments of the basin. In addition, the e-flow assessment will depend on the desired Ecological Class (Table 5.21) of the river in the sub-basin.

The conceptual framework for the GW component of the project is illustrated below.

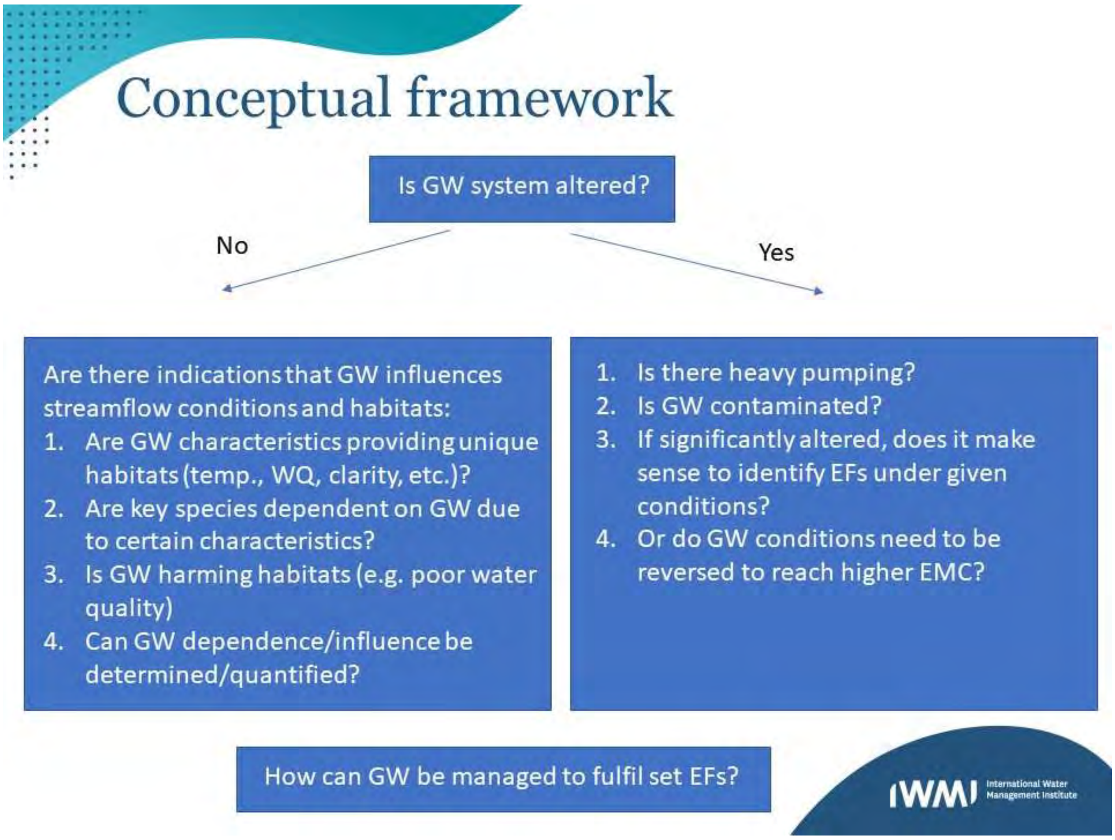

FIGURE 5.2: CONCEPTUAL FRAMEWORK FOR THE GROUNDWATER COMPONENT OF E-FLOWS

The steps to be taken to determine the role of groundwater in E-flows are as follows:

A. Determine typology of river reaches for GW assessment for E-flows

1. Ephemeral, perennial or in-between (definition will be defined)
    a. Predominant SW-GW flow direction and recharge processes
    b. If perennial, is it spring-fed?
    c. Are there other SW features, like wetlands, lakes, etc. that govern SW-GW integrations?
2. Natural vs. disturbed (land use, damming, abstraction from SW/GW)
3. Geology/morphology/structural features:
    a. Tributary or main stem, stream order, elevation
    b. Dikes, faults, etc.
    c. Confining layers, perched aquifers
    d. Riverbed characteristics
4. Natural GW chemistry

B. Determine field site(s), selected based on the above criteria

1. One perennial, one ephemeral
2. Overlap with EF sites from Monograph Study
3. As natural as possible, not downstream of dam, or far from dam
4. Adequate exiting monitoring BHs with good data
5. Previous studies around EFs or SW-GW interactions or BFs
6. Data/knowledge on GW abstraction

C. Determine baseflows and surface water-groundwater interactions

1. Determine baseflow in the two in-depth GW sites and in other sub-basin units
2. Determine loosing/gaining river characteristics from hydraulic head gradients in transects in in-depth GW sites
3. Determine stable isotope fingerprints of river, GW and rainwater, in in-depth GW sites to determine major source of water in river.
4. Map riparian vegetation along the river in in-depth GW sites
5. Model river and GW interaction at min one in-depth GW site

D. Extrapolate findings in in-depth GW sites

1. Requirements for GW in terms of securing baseflow and link to seasonal pools is inferred from in-depth GW sites for desired Ecological Class
2. Depending on the Ecological Class of other stretches of the river, a requirement for GW in these areas is inferred from the information of the in-depth GW sites, using baseflow and degree of perenniality of the streams as scaling parameters.
3. Using the model assessments, it is inferred how much GW pumping is recommended along the stream, in order to maintain the e-flows.

6 BENEFICIARIES OF THE STUDY:

Impact on local communities: This e-flows study is designed to integrate the needs of local communities at several levels e.g., it documents the linkages between river flow and domestic water supply, irrigation, stock watering, reeds for construction, fish for food, medicinal plants, etc., from the headwaters to the coast. It describes the risks faced by communities to loss of these ecosystem services as potentially caused by altered river flow and recommends e-flows that are designed to minimize the risk to that provision, with coupling to the requirements for leaving water in the underlying aquifer as well, to enhance e-flows. It will also link to basin and country policy, strategies, etc. Thus, if the e-flow recommendations are fully implemented by riparian countries, then the local communities can be relatively risk-free in receiving these services (noting that other non-flow impacts may detract from this e.g. overfishing cannot be rectified by flow management). The e-flows and associated risks provide evidence for the trade-offs that need to be made between different allocations of water. These beneficiaries and uses of the river ecosystem will be determined during high-level stakeholder consultation and will be disaggregated into gender where this information has been published.

Gender, equality and social inclusion: Local stakeholders will be included in clarifying the vision and documenting the objectives for river management but only through consultation with representatives and in particular LIMCOM. The e-flows will be described to deliver services that are essential for the daily lives of people living in association with the river and will be equally considered for all sectors of society. Additional capacity building of female students/scientists will be specifically included in the study especially through the collaborative research of the BRICS and WIOMSA studies.

Member states and LIMCOM:
LIMCOM and member state governments will be involved from the beginning of the project (if possible synchronized with Resilient Waters operations) to clarify the vision, objectives and with setting endpoints for the e-flow study. The e-flow data and results (described above) will be of benefit to all member states and LIMCOM and will provide the foundation for future water allocations.

Regional managers of the biodiversity, ecosystem processes and resources of the east coast of Africa:
The collaborative research with the WIOMSA and BRICS studies will result in a direct contribution to stakeholders of the biodiversity, ecosystem processes and resources of the east coast of Africa. This includes SADC nations and other Western Indian Ocean stakeholders. Additional research and scientific community will benefit from this research. The approach selected outcomes and relevance to the management of regional riverine resources, and their biodiversity and ecosystem processes will be presented to stakeholders of the collaborative research projects.

6.1 STRATEGIES FOR ENSURING SUSTAINABILITY:

By working with Resilient Waters, riparian countries, and in particular with LIMCOM as key stakeholders, and involving participants in definition of the vision and objectives for the water resources and related ecosystem services in the basin, this will help to achieve "buy-in" to the e-flows outputs and long-term ownership. LIMCOM and similar key stakeholders will be given opportunity to join field work of both the groundwater and surface water teams, although logistics of such participation will need to be organized by LIMCOM. LIMCOM will remain the key beneficiary of the project and ownership by them is important for sustainability.

It is anticipated that the e-flow data produced will be used by the above organizations to assist with water resource management in the basin. The DWS in South Africa have already indicated a willingness to participate, to share their data and to adopt the e-flow results into their formal database. Ideally, LIMCOM will use the e-flows in their own strategies and ideally as a reference for coordination with member states. Thus, the e-flows data should have a direct impact on water resource decision making.

The two complementary studies in the Limpopo Basin have been established by the University of Mpumalanga that will contribute to this USAID/Resilient Waters funded project including a JAF - BRICS Multilateral Joint Science and Technology Research Collaboration study and a Western Indian Ocean Marine Science Association (WIOMSA) study (Objectives of the studies are attached). The total estimated amount of financial resources allocated by these projects to the Limpopo e-flows study through specialist time, student training, additional evidence and operational support totals R650 000. This will make a noticeable contribution to the confidence of this assessment and training of students and implementation of the outcomes.

The final reports that are produced by the project will be detailed and will contain sufficient information to be an exemplary case study of e-flow determination in the region. These will be supported by data and tables of e-flows that will enable long-term implementation of e-flows in the Limpopo. The project will also end with training of representatives of LIMCOM and other stakeholders that will help to embed the results of the project in future water resource management activities.

7 ANNEXURE A: REPORT ON THE DRY SEASON FIELD SURVEY

BACKGROUND

In 2019 between September and November (Table A1) a series of surveys to evaluate a range of bio-physical attributes of the lower Olifants River and Elephantes River was undertaken by members of the project team. Note that this pre-dated the Resilient Waters contract but the timeframe was forced by the leveraging partners. This included dedicated assessments of the following components:

- Hydraulic assessment
- Water quality and ecotoxicology
- Fish
- Riparian vegetation

A brief report of the data collected during the survey is presented here.

HYDRAULICS

Hydraulic cross sections and associate analyses were generated at the sites on the Olifants River and in Massingir during the dry flow survey in 2019. This data has been used to generate 1d cross sections and associated relationships between flow (discharge) and river depth and associated velocity depth instream habitats. This data will be used to evaluate instream habitat availability associated with modeled hydrology and be able to establish flow requirements associated with habitat requirements. Here an example of the cross section data collected and hydraulic model outputs are presented in Figures A1, A2 and A3.

TABLE A1: SURVEY PLAN FOR THE 2019 DRY SEASON SURVEY TO THE LOWER OLIFANTS AND ELEPHANTES RIVERS

	08-Sep	09-Sep	10-Sep	11-Sep	12-Sep	13-Sep	14-Sep	15-Sep	16-Sep	17-Sep	18-Sep	19-Sep
Accomodation	Letaba			Palaborwa				Massngir				Home
PLAN	Arrive	Balule Day 1	Balule Day 2	Finish Balule & drive to Palaborwa	Palaborwa day 1	Palaborwa day 1	Palaborwa day 3 and pack up	Drive to Massingir	Elephantes day 1	Elephantes day 2	Elephantes day 3	Drive home
Ecotoxicology	Arrive	Assist with fykes, angling and ecotox data collection		Finish up data collection and travel to palaborwa	Assist with fykes, angling and ecotox data collection			Drive to Massingir	Assist with fykes, angling and ecotox data collection			Drive home
Water quality	RP, GG & BS Arrive & deploy WW mobile WQ probe	Collect samples & in situ data		Finish up data collection and travel to palaborwa	Collect samples & in situ data			Drive to Massingir	Collect samples & in situ data			Drive home
Geomorphology	Arrive	Habitat assessment & data collection		Finish up data collection and travel to palaborwa	Habitat assessment & data collection			Drive to Massingir	Habitat assessment & data collection			Drive home
Hydraulic cross sections	Arrive	Select cross sections	Survey cross sections	Finish up data collection and travel to palaborwa	Select cross sections	Survey cross sections		Drive to Massingir	Select cross sections	Survey cross sections		Drive home
Stb. Isotope data collection	Arrive	Collect data with team		Finish up data collection and travel to palaborwa	Collect data with team			Drive to Massingir	Collect data with team			Drive home
Fish survey	RP, GG & GO Arrive & deploy WW mobile WQ probe	Fykes, gill nets, electro, angling and cast nets = link with habitat survey		Collect fykes and depart for Mamba - deploy nets	Fykes, gill nets, electro, angling and cast nets = link with habitat survey		Collect fykes and pack up for trip to Moz	Drive to Massingir	Fykes, gill nets, electro, angling and cast nets = link with habitat survey		Collect fykes and pack up for trip to SA	Drive home
Invertebrate surveys	RP, GG & BS Arrive & deploy WW mobile WQ probe	Collect data - drift nets, suber and Kick net		Collect drift nets and depart for Mamba - deploy nets	Collect data - drift nets, suber and Kick net		Collect drift and pack up for trip to Moz	Drive to Massingir	Collect data - drift nets, suber and Kick net		Collect drift and pack up for trip to SA	Drive home
Vegetation surveys	Arrive	Assessment and data collection		Finish up data collection and travel to palaborwa	Assessment and data collection			Drive to Massingir	Assessment and data collection			Drive home
FISHTRAC	NA	Tag suitable fish for FISHTRAC			Tag suitable fish for FISHTRAC		Set up FISHTRAC NETWORK IN MAMBA AREA					Drive home

FIGURE A1: SATELLITE IMAGE OF THE ELEPHANTES RIVER SITE (EWR12) SITE IN THE STUDY WITH THE CROSS SECTION USED FOR THE HYDRAULIC EVALUATION OF THIS SITE.

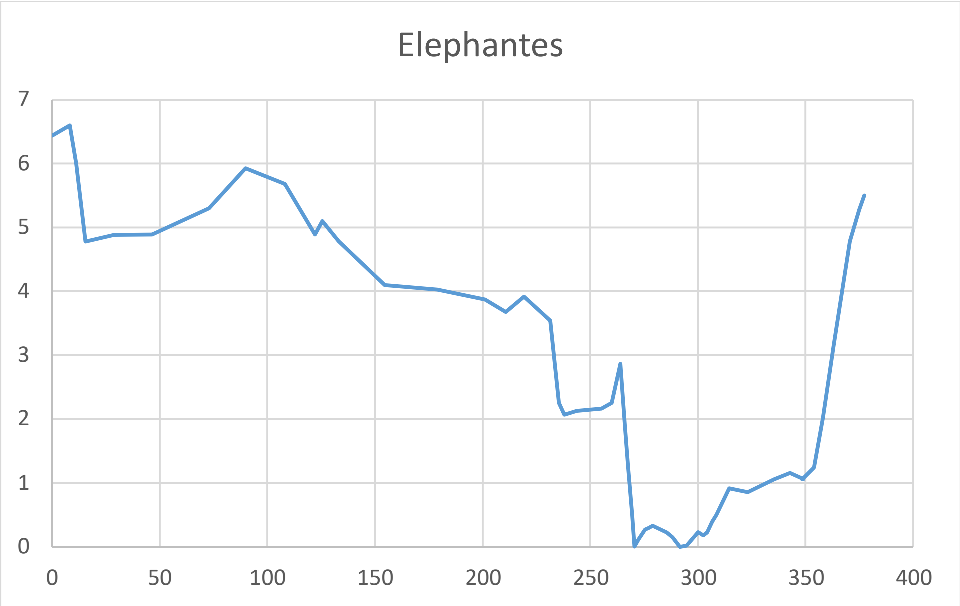

FIGURE A2: MODELLED CROSS SECTION OF THE ELEPHANTES RIVER SITE (EWR12) SITE USED FOR THE HYDRAULIC EVALUATION.

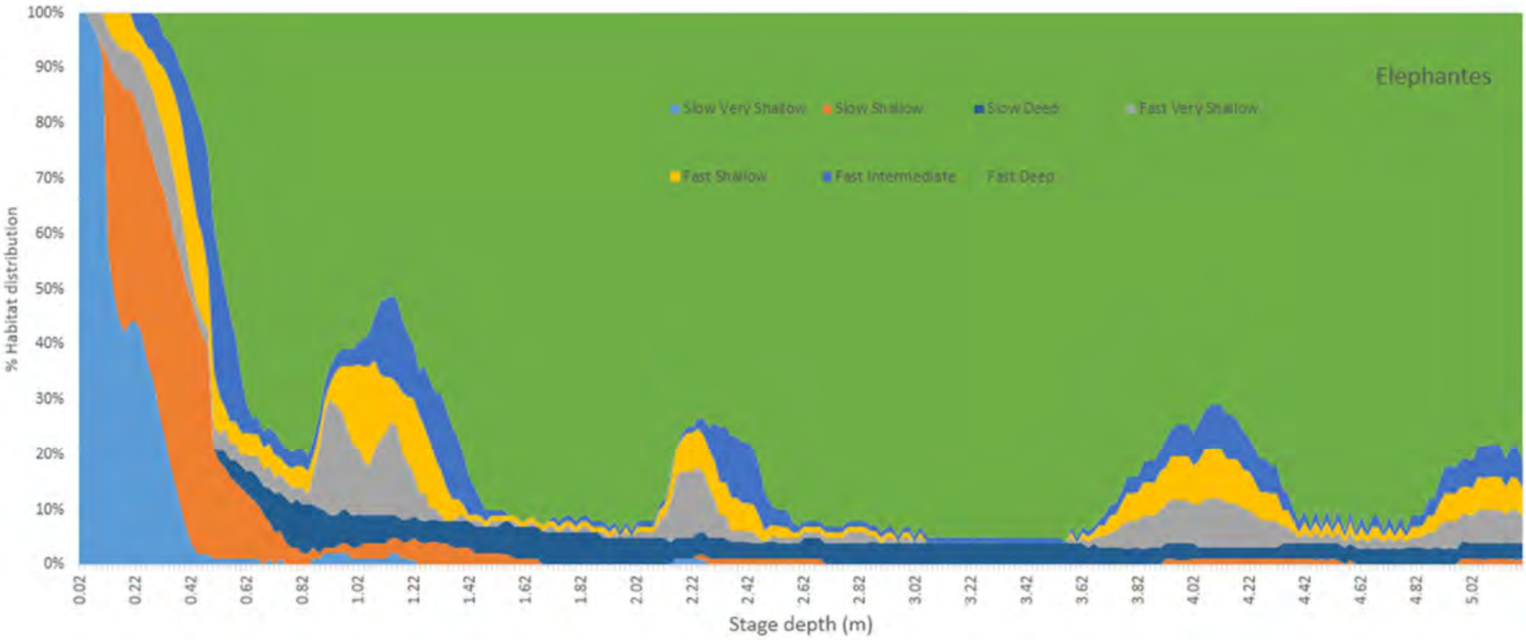

FIGURE A3: SIMPLIFIED RELATIONSHIP BETWEEN FLOWS AND INSTREAM HABITAT AVAILABILLITY FOR THE ELEPHANTES RIVER SITE (EWR12) SITE USED FOR THE HYDRAULIC EVALUATION.

WATER QUALITY AND ECOTOXICOLOGY

The ecotoxicological assessment of Massingir Dam will make use of three fish species (*Clarias gariepinus, Hydrocynus vittatus* and *Oreochromis mossambicus*) as indicators of changes in water and sediment quality through a multi-metric approach that represents different levels of biological organization ranging from sub-cellular to whole organism responses. These biological responses will be related to the environmental drivers, i.e. water quantity (during high and low flow hydrological periods) and water (and sediment) quality (microplastics, metals and organics). The samples will be collected in five selected sites, two sites representing the inflow water from South Africa (Lower Olifants River), two representing the inflow and out flow of Massingir Dam, and the last one below the Dam where the Olifants River flows into the Limpopo River. Water and sediment samples will be collected in triplicates per site and 10 fish per species of each selected site.

Environmental drivers

In situ water quality variables will be assessed including: oxygen concentration and saturation, conductivity, pH, and temperature. The water samples will be preserved and analyzed for macro-elements (Na, Ca, Mg, K, Cl, SO_4), nutrients (PO_4, NO_2. NO_3, NH_4), metals (Al, Fe, Cr, Mn, Co, Ni, Cu, Zn, Cd, Pb and Hg) and organic [such as organochlorine pesticides (OCPs) DDT, chlordanes, hexachlorobenzene, polychlorinated biphenyls (PCBs), polybrominated diphenyl ethers (PBDEs) and per- and polyfluoroalkyl substances (PFASs)] pollutants. All analyses will be carried out as described by Gerber et al. (2015a). In addition microplastics will be analyzed according to the methods described by Slootmaekers et al. (2019).

Sediment quality is used to describe the physical and chemical properties of sediment that influence the potential for the water column to become contaminated. Sediment samples will be collected and preserved. In the laboratory the physical properties (organic carbon content, particle size) and microplastic, metal and organic pollutants (same as those that were analyzed in water samples) will be analyzed according to the methods described by Gerber et al. (2015b) and.

Biological responders

Metal digestion and analysis in fish tissue (muscle) will be conducted using ICP-OES and ICP-MS techniques according to the methods of Gerber et al. (2016b). Organic contaminant extraction (solid phase matrix dispersion) and analyses (GC-MS) will be carried out using standardized techniques based on the methods described by Gerber et al. (2016a). Microplastics will be analyzed in the gastrointestinal tracts of the three fish species. Analytical efficiency will be tested using certified reference materials.

Low flow survey 2019

Survey was undertaken to three sites in the Olifants River, inflow and outflow of Massingir Dam and one site above the confluence with the Limpopo River. All abiotic (water and sediment) and biotic (fish muscle and GIT) samples have been prepared for analyses (i.e. digestion, extraction, clean-up, etc.). The following analyses were completed prior to the social distancing and lockdown that was implemented at NWU since 10 March 2020:

Water quality from Olifants River sites: in situ parameters, anions, nutrients.

Sediment quality from Olifants Rivers sites: particle size distribution, moisture content, organic carbon content

TABLE A2: PRELIMINARY WATER QUALITY RESULTS FROM THE OLIFANTS RIVER: VALUE REPRESENTS MAN OF THREE SAMPLES PER SITE

Parameter	Mamba weir	Balule	Gorge
pH	8.8	8.42	8.45
Conductivity (µS/cm)	561	674	319
Temperature (°C)	23.4	21	21.2
Dissolved oxygen (mg/l)	4.05	4.65	5.65
Ammonia (NH_4 mg/l N)	0.09	0.08	0.12
Nitrite (NO_2 mg/ N)	0.08	0.05	0.04
Nitrate (NO_3 mg/l N)	1.9	1.5	1.6
Inorganic phosphate PO_4 mg/l P)	0.12	0.1	0.11
Sulphate (SO_4 mg/l)	66	141	75
Chloride (mg/l)	41.7	52	45.3
Turbidity (FAU)	13	9.3	13.7
Chemical oxygen demand (mg/l)	4.75	7.1	6.9
Total hardness (mg/l)	102	100	100

TABLE A3: PRELIMINARY SEDIMENT QUALTIY RESULTS FROM THE OLIFANTS RIVER: VALULE REPRESENTS MEAN OF THREE SAMPLES PER SITE

Parameter	Mamba weir	Balule	Gorge
Particle size contribution (%)			
Very coarse sand (>VCS)	0.6	0.11	0.16

Very coarse sand (VCS)	4.7	0.6	1.1
Coarse sand (CS)	29	3.3	52
Medium sand (MS)	45.6	68.4	39
Fine to very fine sand (FS & VFS)	18.2	26.8	6.6
Mud (MUD)	1.4	0.7	0.5
Organic carbon (%)	1.5	0.9	1
Moisture content (%)	23.4	27	23.4

TABLE A4: GEOMETRIC GRADATION OF SEDIMENT PARTICLE SIZE (UM)AND DESCRIPTION OF EACH SIZE CLASS BASED ON THE WENTWORTH SCALE

Particle Size (µm)	Description
4000>	> Very coarse sand (>VCS)
4000-2000	Very coarse sand (VCS)
2000-500	Coarse sand (CS)
500-212	Medium sand (MS)
212-53	Fine sand (FS) - Very fine sand (VFS)
>53	Mud (MUD)

FISH

A fish assessment was undertaken to sites in the lower Olifants River and Elephantes River. Some additional assessments of fish in the Massingir Dam were also considered. Expected species of the study area (only lower Olifants and Elephantes Rivers and tributaries) is available in the Table A5. The objectives of the fisheries assessment for the dry flow period includes the following:

- Evaluate the Present Ecological State (PES) of the fish communities at each site, including an evaluation of the flow dependent habitat preferences of fish and the potential response of indicator fish communities to altered flow and non-flow drivers of change in the study area,
- Evaluate the trajectory of change in the wellbeing of the fish communities at each site,
- Determine the Ecological Importance and Sensitivity (EIS) of the fish component of the river ecosystem at each site,
- Statistically evaluate the population and community structures of fish collected during a low survey.
- Statistically evaluate the flow-dependent habitat preferences of fish from the study area,
- Characterize preferences of species for flow dependent habitat characteristics.

TABLE A5: FISH AND THEIR CONSERVATION STATUS, EXPECTED TO BE FOUJND IN THE LOWER OLIFANTS AND ELEPHANTES RIVERS, SOUTHERN AFRICA (FROM SCOTT ET AL, 2006)

FAMILY	SPECIES	CATEGORY	CRITERIA
Anguillidae			
	Anguilla bengalensis labiata	Least Concern	
	Anguilla mossambica	Least Concern	
Aplocheilidae			
	Nothobranchius orthonotus	Least Concern	
Poeciliidae			
	Aplocheilichthys katangae	Least Concern	
Characidae			
	Brycinus imberi	Least Concern	
	Hydrocynus vittatus	Least Concern	
	Micralestes acutidens	Least Concern	
Cyprinidae			
	Barbus afrohamiltoni	Least Concern	
	Barbus annectens	Least Concern	
	Barbus anoplus	Data Deficient	
	Barbus lineomaculatus	Least Concern	
	Barbus paludinosus	Least Concern	
	Barbus radiatus	Least Concern	
	Barbus rapax	Least Concern	
	Barbus sp. 'neefi cf. South Africa'	Data Deficient	
	Barbus sp. 'viviparus cf. Mozambique'	Least Concern	
	Barbus spp. 'eutaenia complex'	Least Concern	
	Barbus toppini	Least Concern	
	Barbus trimaculatus	Least Concern	
	Barbus unitaeniatus	Least Concern	
	Barbus viviparus	Least Concern	
	Labeo congoro	Least Concern	
	Labeo cylindricus	Least Concern	
	Labeo molybdinus	Least Concern	
	Labeo rosae	Least Concern	
	Labeo ruddi	Least Concern	
	Labeobarbus marequensis	Least Concern	
	Labeobarbus polylepis	Least Concern	
	Mesobola brevianalis	Least Concern	
	Opsaridium peringueyi	Least Concern	
Kneriidae			
	Kneria sp. 'South Africa'	Critically Endangered	B2ab(i,ii,iii,iv,v)
Protopteridae			
	Protopterus annectens	Least Concern	
Mormyridae			
	Marcusenius pongolensis	Data Deficient	

Mormyridae		
Petrocephalus wesselsi	Least Concern	
Cichlidae		
Chetia flaviventris	Least Concern	
Oreochromis mossambicus	Near Threatened	A3e
Pseudocrenilabrus philander	Least Concern	
Serranochromis meridianus	Endangered	B2ab(iii,v)
Tilapia rendalli	Least Concern	
Tilapia sparrmanii	Least Concern	
Gobiidae		
Awaous aeneofuscus	Least Concern	
Glossogobius callidus	Least Concern	
Glossogobius giuris	Least Concern	
Amphiliidae		
Amphilius natalensis	Least Concern	
Amphilius uranoscopus	Least Concern	
Clariidae		
Clarias gariepinus	Least Concern	
Mochokidae		
Chiloglanis paratus	Least Concern	
Chiloglanis pretoriae	Least Concern	
Chiloglanis swierstrai	Least Concern	
Synodontis zambezensis	Least Concern	
Schilbeidae		
Schilbe intermedius	Least Concern	

Of the 51 species expected to occur in the study area 27 were collected during the dry flow survey. The data collected also includes habitat, water depth, velocity and cover feature associations that will be statistically evaluated to establish preference information for the river.

TABLE A6: FISH SAMPLING EFFORT AND COLLECTIONS FROM 2019 DRY SEASON IN THE LOWER OLIFANTS AND ELEPHANTES RIVERS

	Bafro	Bim	Bimb	Buni	Cgar	Cpar	Cren	Cswi	Ecyl	Eeut	Emol	Etri	Eviv	Gcal	Ggui	Hvit	Lcon	Lcyl	Lmar	Lmol	Lros	Macu	Mbre	Mcva	Omos	PPhi	Tren	Grand Total
Balule bridge	**1**		**1**	**1**	**5**	**5**	**1**	**2**				**7**	**4**	**1**			**1**	**8**	**12**	**8**	**1**	**2**		**1**	**10**	**1**	**2**	**76**
Cast net	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1	2	1	-	-	-	-	1	-	-	5
E-fisher (Samus)	-	-	-	-	2	1	-	-	-	-	-	1	-	-	-	-	-	2	2	2	-	-	-	1	1	-	1	13
Fyke small	-	-	-	-	2	-	-	-	-	-	-	3	-	-	-	-	-	1	1	-	-	1	-	-	3	-	-	11
Galaxid fyke	1	-	-	1	1	1	-	-	-	-	-	3	3	1	-	-	-	1	3	2	-	1	-	-	4	1	1	25
Seines	-	-	-	-	-	1	-	-	-	-	-	-	1	-	-	-	-	1	1	1	-	-	-	-	-	-	-	5
(blank)	-	-	1	-	-	2	1	2	-	-	-	-	-	-	-	-	1	2	3	2	1	-	-	-	1	-	-	17
Confluence	**-**	**-**	**-**	**-**	**2**	**3**	**-**	**-**	**-**	**-**	**-**	**-**	**-**	**1**	**3**	**1**	**1**	**3**	**1**	**3**	**1**	**-**	**-**	**-**	**1**	**-**	**-**	**22**
Angling	-	-	-	-	1	-	-	-	-	-	-	-	-	-	-	1	-	-	-	-	-	-	-	-	-	-	-	2
E-fisher (Samus)	-	-	-	-	-	-	-	-	-	-	-	-	-	1	-	-	-	-	-	-	-	-	-	-	1	-	-	2
(blank)	-	-	-	-	1	3	-	-	-	-	-	-	-	-	3	-	1	3	1	3	1	-	-	-	-	-	-	18
Mamba Klaseri	**-**	**1**	**-**	**-**	**4**	**6**	**-**	**1**	**2**	**1**	**1**	**8**	**14**	**-**	**-**	**-**	**-**	**8**	**15**	**5**	**1**	**-**	**-**	**-**	**8**	**-**	**-**	**75**
Cast-Net	-	1	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1	1	-	1	-	-	-	1	-	-	5
E-fisher (Samus)	-	-	-	-	2	6	-	1	2	1	1	8	12	-	-	-	-	6	11	4	-	-	-	-	6	-	-	60
Running seine	-	-	-	-	2	-	-	-	-	-	-	-	2	-	-	-	-	1	3	1	-	-	-	-	1	-	-	10
Mamba Weir	**-**	**-**	**-**	**-**	**2**	**-**	**-**	**-**	**-**	**-**	**-**	**2**	**1**	**-**	**-**	**-**	**-**	**-**	**1**	**-**	**-**	**-**	**1**	**-**	**-**	**-**	**-**	**8**
E-fisher (Samus)	-	-	-	-	2	-	-	-	-	-	-	1	-	-	-	-	-	-	1	-	-	-	-	-	-	-	-	4
Grand Total	**1**	**1**	**1**	**1**	**13**	**14**	**1**	**3**	**2**	**1**	**1**	**17**	**19**	**2**	**3**	**1**	**2**	**19**	**29**	**16**	**3**	**2**	**1**	**1**	**19**	**1**	**2**	**485**

MACROINVERTEBRATES

SASS data was collected in the Olifants River in the Kruger National Park (KNP) by KNP staff from September 2010 to September 2019. Currently only access to data from 2010 to 2017 was provided. In the Luvuhu River at Outpost (KNP) SASS5 and Odonata data was collected carried out by Gerhard Diedericks in September 2018. An Odonata-Fish survey was carried out in the intermittent Singwedzi River by various people in January 2020, following surface flow after a prolonged period of no surface flows.

TABLE A7: INVERTGEBRATE DATA AVAILABLE FOR OLIFANTS RIVER IN THE KRUGER NATIONAL PARTK

Index	River	Data Period	Collector
SASS5	Olifants	Sep 2010 - 2017	Hendrik Sithole
SASS5-Odonata	Luvuvhu	Sep 2018	Gerhard Diedericks
Odonata	Shigwedzi	Jan 2020	Gerhard Diedericks

Methods

Flow sensitivity ratings for taxa (NB – not species) used in the Macro-Invertebrate Response Assessment Index (MIRAI) (Thirion, 2008) was applied to the Olifants-Kruger National Park and Luvuvhu-Outpost SASS data. This was to determine broad flow dependence of the stream community sampled. With Odonata, habitat preference values (Dijkstra 2016) were applied to adults, larvae and exuviae encountered.

Olifants River – Kruger National Park

SASS data for the Olifants River suggests the dominance of taxa associated with slow flowing to stagnant waters during all surveys (September 2010 to 2017). Taxa rated as sensitive were present but not dominant. The data further suggests correlation with an increase in the presence of alien taxa (Gastropoda: Thiaridae: Tarebia grandifera) and the dominance of flow tolerant taxa in the stream community ().

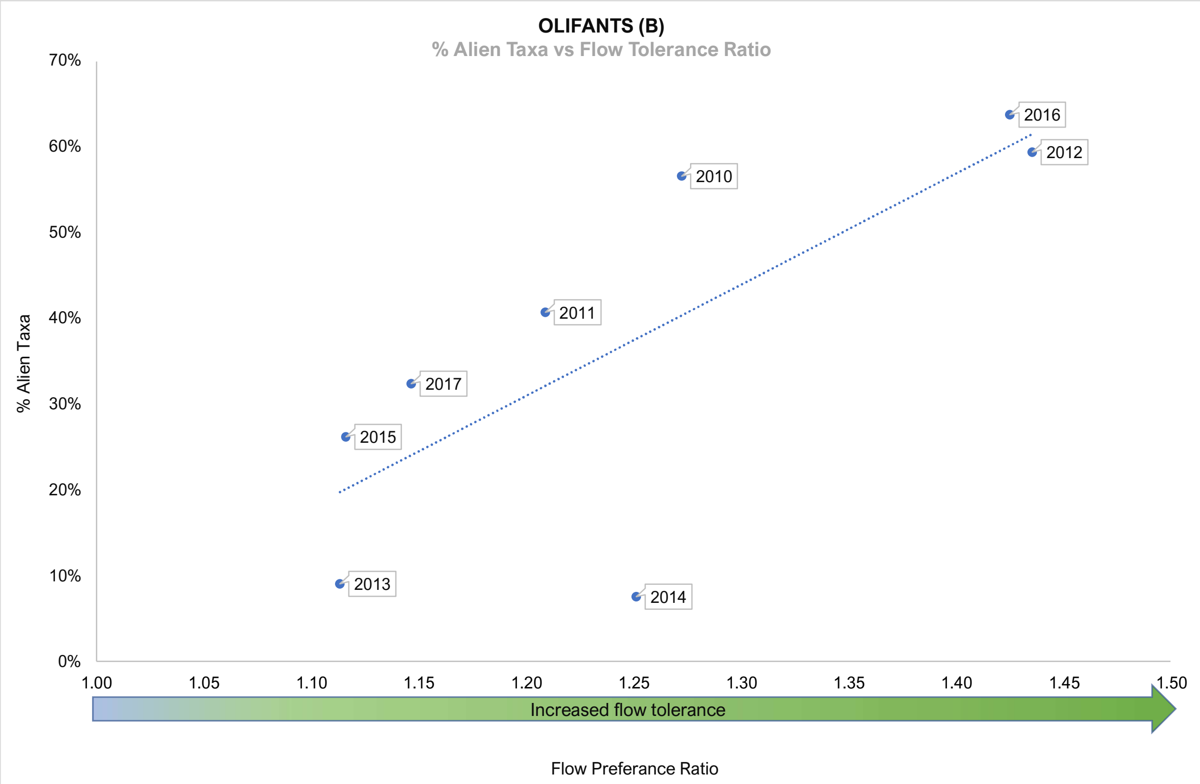

FIGURE A4: FLOW TOLERANCE RATIONS FOR EACH SEPTEMBER SAMPLING YEAR IN THE OLIFANTS RIVER, KRUGER NATIONAL PARK, COMPARED AGAINST THE PERCENTABE ALIEN TAXA (TEREBIA GRANDIFERA)

Luvuvhu River (Outpost) – Kruger National Park

SASS data for the Luvuvhu River at Outpost in September 2018 indicates the dominance of taxa with a preference moderate to fast flows, but taxa with a preference for slow flows to stagnant waters are also represented. In comparison to the Olifants River sites, sensitive taxa dominated in the Luvuvhu. Direct comparisons between the Olifants and Luvuhu September 2018 data is not yet possible, with data not available.

Shingwedzi River – Kruger National Park

An Odonata survey in the Shingwhedzi River in January 2020 (Diedericks, 2020) focused on larvae, exuviae and imagos. Other aquatic taxa encountered while sampling wadeable aquatic habitats were also recorded. The Shingwedzi River is intermittent but was flowing at the time of this survey.

Odonata species with a high preference for permanent-lotic waters were dominant (Figure A5). The presence of the exuviae of Ictinogomphus ferox, Brachythemis leucosticta, and Tholymis tillarga at some sites indicates the presence of permanent surface water. Species at other sites are migratory or species associated with temporal waters, indicate freshly inundated pioneer and migratory species.

The presence of freshly emerged Paragomphus genei with several exuviae at some sites further supports the permanent availability of water, even though its subsurface. Larvae of P. genei close to emergence (well-developed wing pads) were recorded at various sampling locations. High abundances of larvae were recorded where sandy substrates in moderate to fast flows. Shells of the mollusc Unio caffer were abundant at some sites, while live unidentified molluscs were encountered buried in moist sand-gravel substrates away from the main channel. The presence of the well-developed P.

genei larvae and live molluscs suggest subsurface flows maintain some aquatic invertebrates in the "dry" sand beds of the intermittent Shingwedzi River. It is highly unlikely that the larvae of P. genei will develop from egg to a larva ready to emerge within six days (19 to 25 January) of the first reported surface water flows.

Way forward

For this project, the collection of aquatic macro-invertebrate samples needs to be in a variety of well-defined biotopes. Flows measurements and in situ water variables such as temperature and conductivity should be collected at each biotope. Identification of aquatic macro-invertebrates should as far as possible be carried out to genus or species level. This is to determine genus-species environmental preferences to support evidence-based decisions.

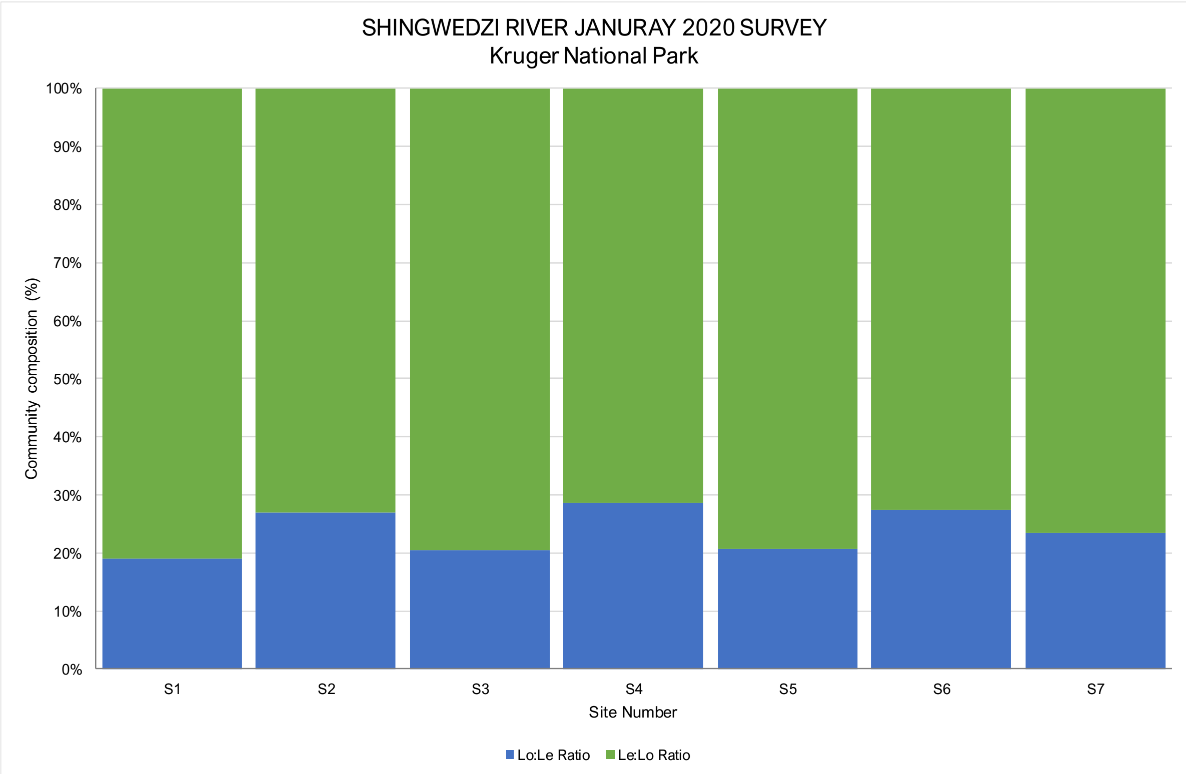

FIGURE A5: COMMUNITY COMPOSITION PER SITE, INDICATING PERCENTAGE OF ODONOTA SPECIES WITH A PREFERENCE FOR LOTIC WATERS (BLUE) COMPARED TO LENTIC (GREEN)

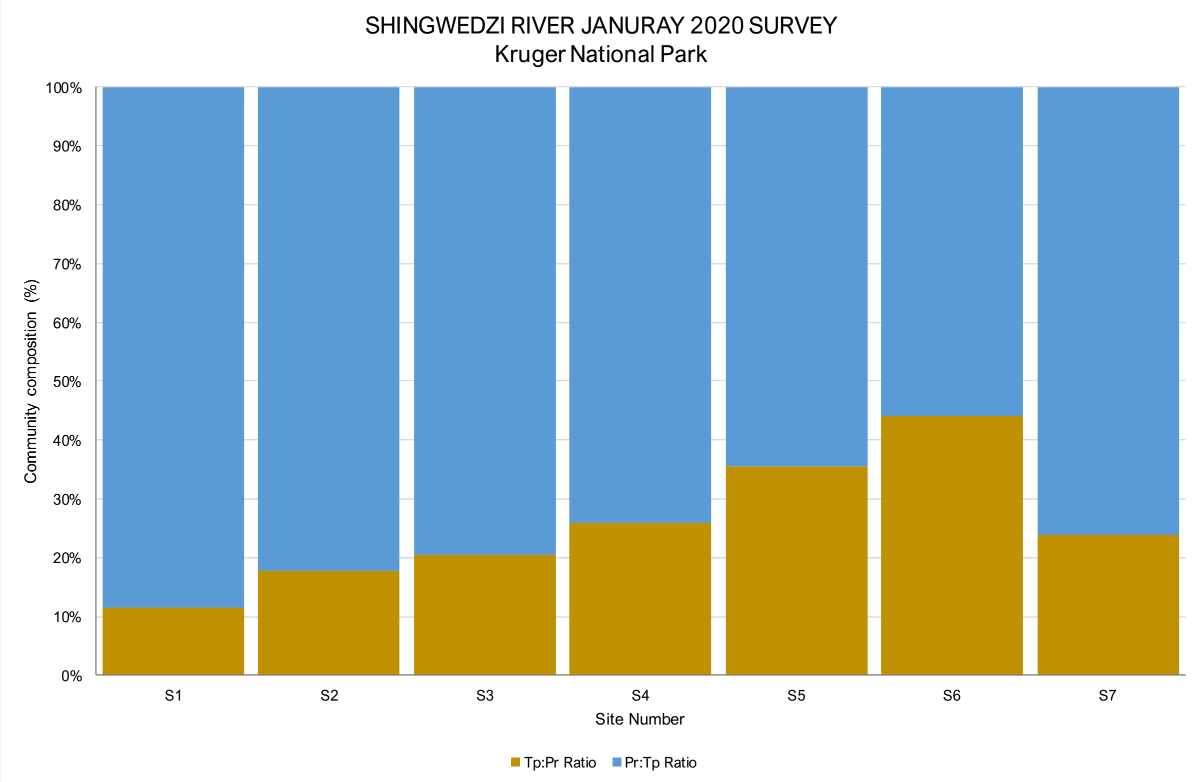

FIGURE A6: COMMUNITY COMPOSITION PER SITE, INDICATING PERCENTAGE OF SPECIES WITH A PREFERENCE FOR PERMANENT WATERS (BLUE) COMPARED TO TEMPORARY (BROWN)

RIPARIAN VEGETATION

Two surveys took place in 2019, extending from 10th to 13th September 2019 (Kruger National Park, Olifants River) and 8th to 14th of December 2019 (Massingir Dam, Mozambique). During these two surveys, the team conducted inspections of the proposed sites and was able to identify three sites for the study that would yield valuable data. The three sites include the following:

i. **Balule Site:** The site is situated approximately 600m downstream of Balule Weir and upstream of the bridge depicted in the Figure A7 (Google Earth ©).

   The site consisted of multiple channels with a combination of alluvial deposits and bedrock exposed outcroppings. The riparian vegetation was dominated by *Phragmites, Schoenoplectus* and a well-defined grass-layer. The well-defined tree-line consisted of large populations of *Philenoptera* and *Vachellia.*

   One benchmarked transect was conducted along the study site as well as numerous off-line vegetation points in order to supplement the data. A total of 212 data points was collected for this site.

FIGURE A7: BALULE SITE, OLIFANTS RIVER, KRUGER NATIONAL PARK (GOOGLE EARTH ©).

ii. **Mamba Site:** The site is situated approximately 3km downstream of Mamba Weir and about 500m upstream of Klaserie River Lodge (see Figure A8 below).

FIGURE A8: MAMBA SITE, OLIFANTS RIVER, KRUGER NATIONAL PARK (GOOGLE EARTH ©).

The entire site was dominated by alluvial deposits and exposed soil, however the section along the transect had numerous bedrock outcroppings that provided optimal habitat for *Brunadia salicina*, *Gomphocarpus fruticosus* and *Gomphostigma virgatum*. The above-mentioned species, along with *Phragmites* and *Schoenoplectus* dominated the in-stream, marginal and lower riparian zones. A well-developed population of *Croton gratissimus* and *Nuxia* *oppositifolia* dominated the upper zones as well as the tree-line which was well defined.

One benchmarked transect was conducted within the study site, consisting of 153 data points.

iii. **Elephantes Site:** The site is located approximately 8km downstream of Massingir Dam on the Elephantes River in Mozambique (see Figure A9 below).

FIGURE A9: BALULE SITE, OLIFANTS RIVER, KRUGER NATIONAL PARK (GOOGLE EARTH ©).

The site was dominated by alluvial deposits and in-stream cobbles and exposed cobble-bars on northern banks. The site was comparatively sparsely vegetated, however distinctive *Ficus sycomorus* cohorts indicated defined flood benches. A relatively well-defined in-stream aquatic vegetation population was evident, with species including *Potamogeton crispus, Ceratophyllum demersum, Spirogyra* sp. and *Azolla* sp. Dominant marginal vegetation included *Ficus sycomorus, Pluchea dioscoridis*, *Combretum microphyllum* and some *Vachillia xanthophloea.*

One benchmarked transect was conducted at the site with 69 data points along the transect and as well as additional vegetation points. Visibility along the transect due to undulations in the landscape proved challenging at this site, despite the team having spent several hours in search of additional alternatives for the site. The placement of indicator vegetation along the geomorphic profile is shown in Figure A9. The levels of these indicators will be used to determine the discharge required for each indicator using the hydraulic rating curve and lookup tables. This will enable the determination of environmental flows for each indicator.

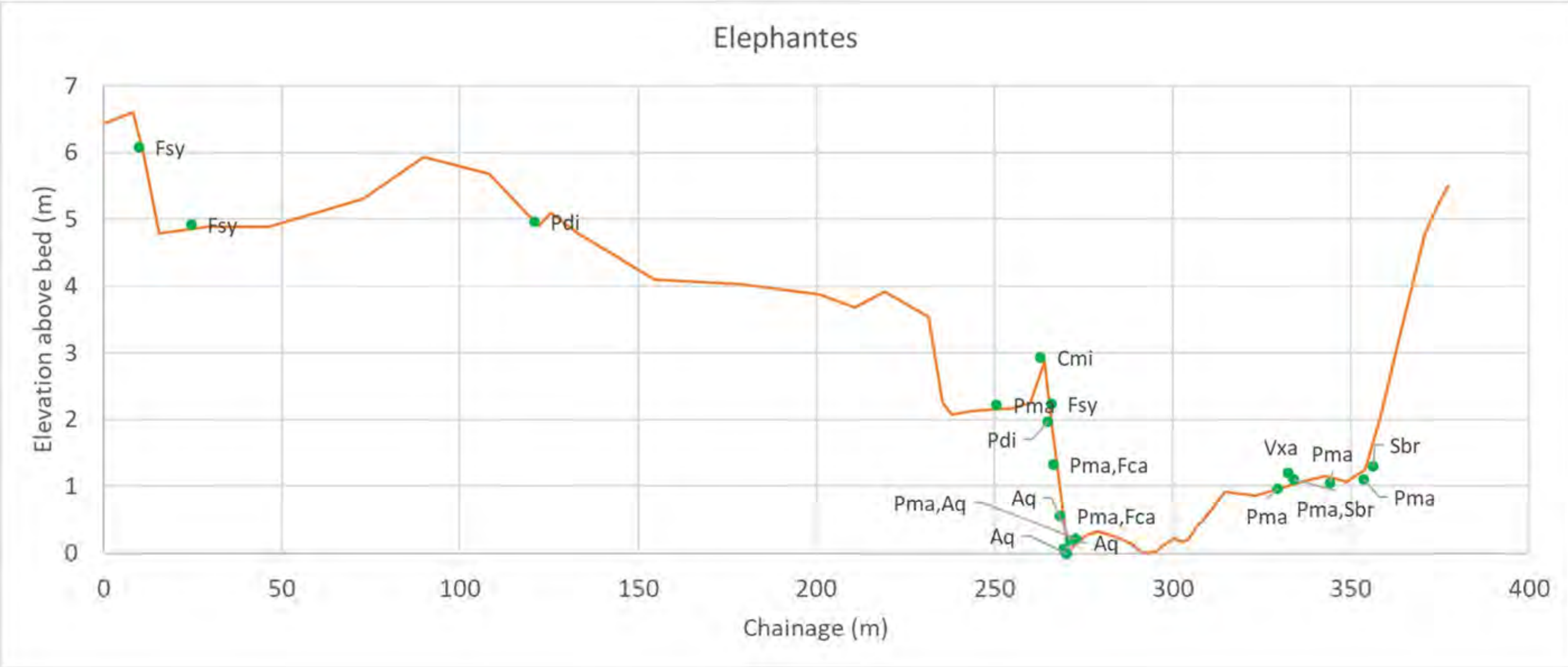

FIGURE A9: GEOMORPHIC PROFILE OF THE ELEPHANTES SITE, SHOWING INDICATOR VEGETATION PLACEMENT - WHERE: AQ = AQUATIC VEG INCL POTAMOGETON CRISPUS, CERATOPHYLLUM DEMERSUM, SPIROGYRA SP. , AZOLLA SP.; CMI = COMBRETUM MICROPHYLLUM; FCA = FICUS CAPREIFOLIA; FSY = FICUS SYCOMORUS; PDI = PLUCHEA DIOSCORIDIS; PMA = PHRAGMITES MAURITIANUS; SBR = SCHOENOPLECTUS BRACHYCERAS; VXA = VACHILLIA XANTHOPHLOEA).

REFERENCES

1. DWS (DWAF) (2008). Updated Manual for the Identification and Delineation of Wetlands and Riparian Areas, prepared by M. Rountree, A. L. Batchelor, J. MacKenzie and D. Hoare. Department of Water Affairs and Forestry. Sub-Directorate: Stream Flow Reduction Activities.
2. Gerber, R., Smit, N. J., van Vuren, J. H., & Wepener, V. (2016a). Metal concentrations *in Hydrocynus vittatus* (Castelnau 1861) populations from a premier conservation area: relationships with environmental concentrations. *Ecotoxicology and Environmental Safety*, 129, 91-102.
3. Gerber, R., Smit, N. J., Van Vuren, J. H., Nakayama, S. M., Yohannes, Y. B., Ikenaka, Y., & Wepener, V. (2016b). Bioaccumulation and human health risk assessment of DDT and other organochlorine pesticides in an apex aquatic predator from a premier conservation area. Science of *the Total Environment, 550, 522-533.*
4. Kleynhans CJ, Mackenzie J, Louw MD. (2007). Module F: Riparian Vegetation Response Assessment Index in River EcoClassification: Manual for EcoStatus Determination (version 2). Joint Water Research Commission and Department of Water Affairs and Forestry report.
5. Macfarlane, DM, Kotze, DC, Ellery, WN, Walters, D, Koopman, V, Goodman, P and Goge, C. (2009). WET-Health: A technique for rapidly assessing wetland health. WRC Report TT 340/09 WRC, Pretoria.
6. Hughes, DA and 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.
7. 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.
8. 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.
9. Slootmaekers, B., Carteny, C.C., Belpaire, C., Saverwyns, S., Fremout, F., Blust, R., & Bervoets, L. (2019). Microplastic contamination in gudgeons (Gobio gobio) from Flemish rivers (Belgium). *Environmental Pollution*, 244, 675e684

8 ANNEXURE B – PLAN FOR THE WET SEASON FIELD SURVEY

The wet season survey is planned for late summer 2021 according to the following approximate schedule.

TABLE A8: WET SEASON FIELD SURVEY PLANS (FEB/MARCH 2021)

;	Gordon O'Brien	Robin Pietersen	Gerhard Diederiks	James MacKenzie	Enrico Roest	Bennie vd Waal	Angelica Kaizer	Stacey Gerber	Victor Wepener	Nico Smit	Wynand Malherbe	Hanro Pearson	**Data/sample considerations**
Site characteristics													Data collected prepared in the field - survey report
Hydraulic cross section (>2 per site)													Data collected in the field, transferred off total stations etc. I
Discharge													Data collected prepared in the field - survey report
Habitat characteristic assessment													Data collected prepared in the field - survey report
Regional habitat/land use assessment (desktop)													Data collected prepared in the field - survey report
Water & sediment quality assessment													Samples collected, frozen/preserved for later analyses
Ecotoxicology samples													Samples collected, frozen/preserved for later analyses
Vegetation community assessment													Data collected prepared in the field - survey report
Vegetation indicator life cycle assessment													Data collected prepared in the field - survey report
Fish community assessment													Data collected prepared in the field - survey report
Fish indicator life cycle assessment													Voucher samples incl. DNA, samples preserved
Invertebrate community assessment													Data collected prepared in the field - survey report
Invertebrate indicator life cycle assessment													Voucher samples incl. DNA, samples preserved
Stable isotope collection & preservation													Samples collected, frozen/preserved for later analyses
Consideration of other biota/indicators													Data collected prepared in the field - survey report
Site driver discussion													Data collected prepared in the field - survey report

E5: GANTT CHART

The Gantt Chart below summarises project actilvities and shows dates for delivery of Milestone reports and Project deliverables.

Milestones & Reports	Project Deliverable	Apr-20	May-20	Jun-20	Jul-20	Aug-20	Sep-20	Oct-20	Nov-20	Dec-20	Jan-21	Feb-21	Mar-21	Apr-21	May-21	Jun-21	Jul-21	Aug-21	Sep-21
1. Inception report	1. E-flows for the Limpopo River Basin – Inception Report		15-May																
2. Report on basin ecosystems; biophysical characteristics; Risk regions mapped	2. E-flows for the Limpopo River Basin – Basin Description (social and biophysical)				31-Jul														
Progress report					31-Jul														
Project steering committee meeting						11-Aug													
3. Preliminary flow related livelihoods and ecosystem service report livelihoods and ecosystem service report							15-Sep												
4. Specialist eflow data and literature review	3. E-flows for the Limpopo River Basin – Literature and Data review						15-Sep												
Workshop 1 - stakeholder workshop on the Vision and Endpoints							18-Sep												
5. Report on vision, objectives and endpoints.							28-Sep												
Workshop at Tuli Karoo site								15-Oct											
Progress report								30-Oct											
Project steering committee meeting									10-Nov										
Groundwater survey											20-Jan	to	15-Mar						
Wet season field survey											20-Jan	to	15-Mar						
6. Wet Season Field Survey Report													30-Mar						
Project steering committee meeting														15-Apr					
	4. E-flows for the Limpopo River Basin – Drivers of Ecosystem Change														15-May				
	5. E-flows for the Limpopo River Basin – Ecological Responses to Change														15-May				
Workshop ll - specialist workshop on e-flow conceptual model															19-21/05/2020				
7. Workshop ll report																30-Jun			
8. Conceptual models																30-Jun			
Progress report																	06-Jul		
Project steering committee meeting																	13-Jul		
Workshop lll - specialist workshop on e-flows																	19-23/07/2020		
9. Bayesian Networks and Conditional Probability Tables (CPTs)																	30-Jul		
Progress report																		10-Aug	
Project steering committee meeting																		17-Aug	
10. Draft E-flows synthesis Report																		31-Aug	
Workshop lV - stakeholder training and workshop																			14-15/09/2020
	6. E-flows for the Limpopo River Basin – Database																		30-Sep
11. E-flows synthesis Report	7. E-flows for the Limpopo Basin – Synthesis Report																		30-Sep
Project close-out report																			30-Oct

Legend

- milestone
- deliverable
- steering committee meeting
- workshop
- fieldwork

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