SERVICES FOR AN INTEGRATED EFLOWS ASSESSMENT TO FACILITATE THE DEVELOPMENT AND AGREEMENT OF "OBJECTIVE FLOWS" AT KEY SITES IN THE PUNGWE BASIN

INCEPTION REPORT

AUGUST 2022

FINAL

INCEPTION REPORT - DRAFT
EFlows Assessment of the Pungwe River Basin

26th August 2022

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On behalf of Global Water Partnership Southern Africa (GWPSA)

Project Title:	SERVICES FOR AN INTEGRATED FLOWS ASSESSMENT TO FACILITATE THE DEVELOPMENT AND AGREEMENT OF "OBJECTIVE FLOWS" AT KEY SITES IN THE PUNGWE BASIN
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EXECUTIVE SUMMARY

Project number	GWPSA/0120/010/March 2022
Assignment	SERVICES FOR AN INTEGRATED FLOWS ASSESSMENT TO FACILITATE THE DEVELOPMENT AND AGREEMENT OF "OBJECTIVE FLOWS" AT KEY SITES IN THE PUNGWE BASIN
Countries	Zimbabwe and Mozambique
Objectives	The objective of the assignment is to support the Mozambique and Zimbabwe governments to facilitate the consultation process of determining 'objective' EFlows at strategic points in the transboundary Pungwe Basin that will, among other considerations, inform specifications on EFlows in the Pungwe Basin Agreement. Downstream flows agreed between the two countries will depend on EFlows allocations based on environmental targets as specified by Basin stakeholders, and abstraction allocations.
EFlows Methodology	The EFlows Assessment for the Pungwe will use the Downstream Response to Imposed Flows Transformation (DRIFT) method for seven sites in the Basin. DRIFT is a process and Decision Support System (DSS) for managing and interrogating knowledge on the links between river flows (water, sediment and biota), ecosystem functioning and social uses. DRIFT allows for: Time-series based evaluation of changes to hydrology, hydraulic or sediment characteristics. Incorporation and evaluation of measured or modelled time-series data. Use of models, data, knowledge and experience to model ecosystem functioning. Calibration or evaluation of time-series predictions against ecological data, where available. Inclusion of social and management criteria. The results from the DRIFT assessment, augmented with results from other studies as required, will be extrapolated to a further 15 sites in the Basin using the EFlows Basin Configuration Excel Model.
Technical Team	Project Leader: Prof. Cate Brown Knowledge Management: Dr Alison Joubert, Hassan Bukhari and Herminio Mulungo/José Sawanguane Hydrology: Gerald Howard River Team Team Lead and Water Quality: Dr Patsy Scherman Ecohydraulics: Dr Drew Birkhead Geomorphology: Prof. Kate Rowntree Riverine vegetation: Dr Karl Reinecke and Tongai Castigo Macroinvertebrates: Dr Justine Ewart-Smith, Prof. Tamuka Nhiwatiwa (plus water quality) and Ricardo Guta Fish: Dr Stephen Lamberth and Dr Lighton Marufu Estuarine and Marine Team Team Lead and Physical Habitat: Dr Lara van Niekerk Hydrodynamics: Roy van Ballegooyen Water quality: Dr Susan Taljaard and Prof. Antonio Hoguane Macrophytes: Prof. Celia Macamo and Prof. Janine Adams Invertebrates: Fiona MacKay Fish: Steven Weerts and Dr Bernardino Sérgio Malawene Fisheries: Dr Bernardino Sérgio Malawene and Dr Stephen Lamberth Social Team Team Lead: Dr Jane Turpie Resource economics: Gwyn Letley and Luke Wilson Sociology: Prof. Lindah Mhlanga
Stakeholder Engagement Strategy	The EFlows project is part of a much bigger process with various Stakeholder fora; and the role of the EFlows Assessment team is to provide information and inputs that enhance the outcomes of that process. Thus, the Stakeholder engagement for this project will build on an earlier stakeholder mapping exercise by IUCN and GWPSA. GWPSA will mobilise these stakeholders on various platforms as needed during the delivery of this assignment: virtually, in workshops and meetings, but also for the main field data collection trips to the

	river and estuary. As part of the broader project implementation framework for stakeholder engagement, the issue of gendered participation is cross-cutting and the GWPSA gender expert will liaise with the EFlows team's socio-economic experts on the adequate handling of this aspect of the work.
Phases and Tasks	The phases and tasks are for the assignment are: Phase 0: Inception Phase 1: Delineation and status Task 1.1: Delineation and confirmation of EFlows zones Task 1.2: Preliminary selection of indicators for EFlows zones Task 1.3: Desktop status and trends assessment for EFlows zones Task 1.4: Preparation of baseline hydrology Task 1.5: Write-up Phase 1 Reports Phase 2: Field work and model set up Task 2.1: Topographic and bathymetry surveys Task 2.2: Collection of ecologically-relevant data at EFlows Zones Task 2.3: Sectoral use of water Task 2.4: Ecosystem services assessment Task 2.5: Hydraulics and hydrodynamic modelling for EFlows zones Task 2.6: Set-up and calibrate EFlows model for rivers Task 2.7: Set-up and calibrate EFlows model for estuary Task 2.8: Write-up Phase 2 Reports Phase 3: Assessment and EFMP Task 3.1: Analyse the scenarios Task 3.2: Marine EFlows assessment Task 3.3: Development of Holding EFlows for key remaining parts of the Basin Task 3.4:Develop an EFlows basin configuration model/balance model Task 3.5: Write-up Phase 3 Reports Integrated tasks Task I.1: Project management Task I.2: Stakeholder engagement Task I.3: Capacity building
Capacity Building	The Pungwe EFlows assessment includes provision for capacity building at several levels such as: Formal information sharing workshop Technical workshops for the project team Opportunities for interactions between team, GWPSA Project Management Unit and country representatives Close links with and liaison between river, estuarine and marine scientists from South Africa, Mozambique and Zimbabwe
Project start date	April 2022
Project period	18 months

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ACRONYMS

ARA-Centro	Regional Water Administration of Central Mozambique
ASGM	Artisanal and Small-scale Gold Mining
BES	Baseline Ecological Status
CPUE	Catch Per Unit Effort
DRIFT	Downstream Response to Imposed Flow Transformations
DSS	Decision Support System
EFlows	Environmental Flows
EFZones	Focus zones for EFlows assessment
EIA	Environmental Impact Assessment
FEWS	Famine Early Warning System
GEF	Global Environment Fund
GNP	Gorongosa National Park
GSOD	Global Summary of the Day
GWPSA	Global Water Partnership Southern Africa
GWPSA NPC	Global Water Partnership Southern Africa Not for Profit Company
HABFLOW	Habitat Flow simulation model
HBV	Hydrologiska Byråns Vattenbalansavdelning
HECRAS	Hydrologic Engineering Center's River Analysis System
HPP	Hydropower Plant
IWRMS	Integrated Water Resources Management Strategy
MAE	Mean Annual Evaporation
MAP	Mean Annual Precipitation
MAR	Mean Annual Runoff
masl	metres above sea level
SADC	Southern African Development Community
SADC-GMI	Southern African Development Community - Groundwater Management Institute
SAIAB	South African Institute for Aquatic Biodiversity)
SIDA	Swedish International Development Co-operation Agency
SWAT	Soil and Water Assessment Tool
TRMM	Tropical Rainfall Measuring Mission
WRSM	Water Resources Simulation Model
ZIMVAC	Zimbabwe Vulnerability Assessment Report
ZINWA	Zimbabwe National Water Authority

1 INTRODUCTION

The Pungwe Basin in Zimbabwe and Mozambique covers a total area of 31 022 km^2, of which 1 465 km^2 (4.7%) lies in Zimbabwe (generating 24.2% of the Mean Annual Runoff; MAR = ~62.1 Mm^3), and 29 555 km^2 (95.3%) is in Mozambique (generating 75.8% of the MAR; MAR = ~194.1 Mm^3; Figure 1.1). The main Pungwe River is ~414 km long. It originates in the eastern highlands of Zimbabwe, from the western slopes of the Inyangani Mountains at an altitude of 2 500 m above mean sea level (amsl) and flows in a general easterly direction through Mozambique into the Indian Ocean (Governments of the Republics of Mozambique and Zimbabwe 2006). The low-lying and gentle slopes that characterise most of the basin give rise to a wide meandering river with large floodplains and extensive wetlands.

The principal tributaries of the Pungwe River in Zimbabwe are the Honde River on the right bank and the Nyazengu, Chiteme, Nyamhingura, Nyawamba, Nyamukombe, and Rwera rivers on the left bank. The main tributaries in Mozambique are the Nhazonia, Txatora, Vunduzi and Urema rivers rising from the north to join the main river on its left bank, and the Honde, Metuchira and Muda from the south (Governments of the Republics of Mozambique and Zimbabwe 2006).

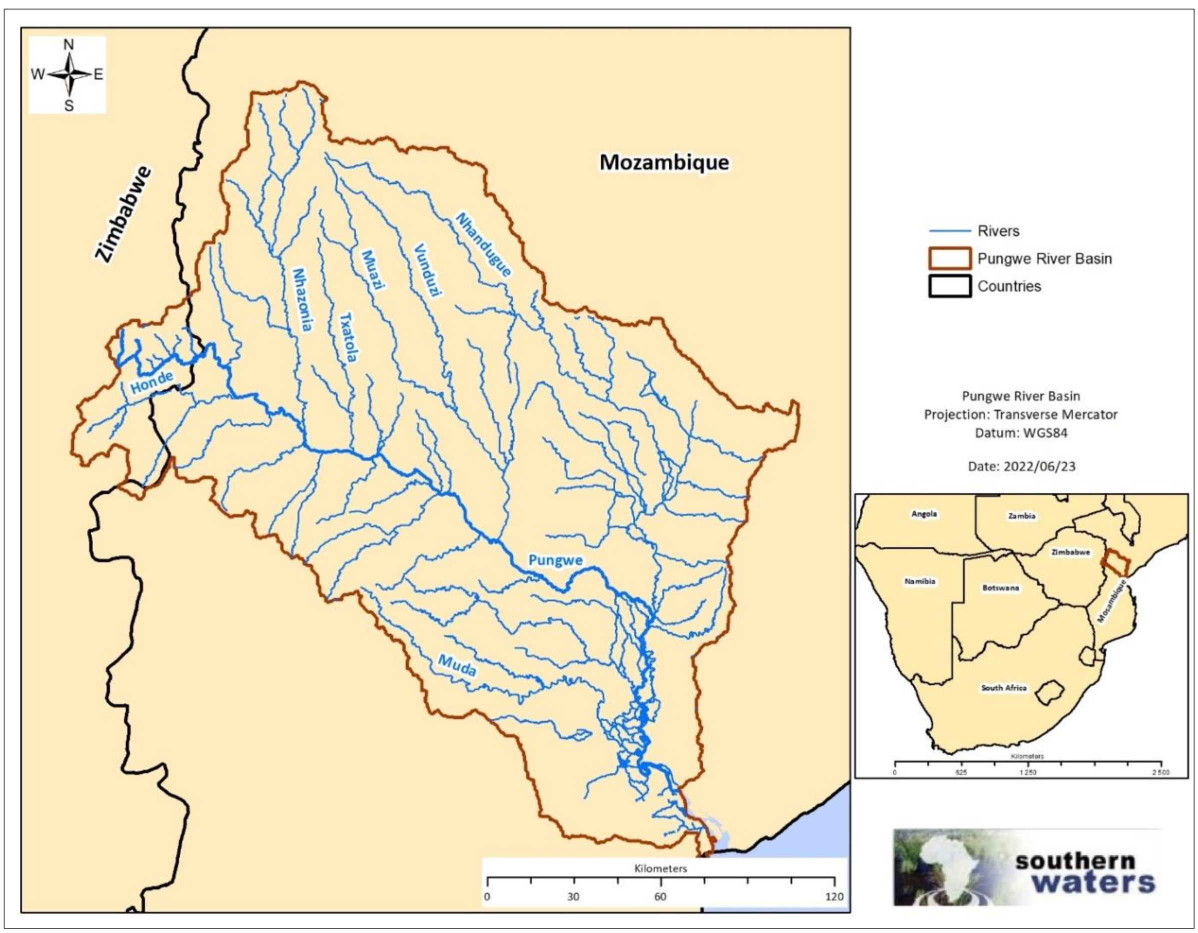

Figure 1.1 Map of the Pungwe Catchment

The Pungwe River Basin in Zimbabwe has a large dam on the Nyawamba River, with a capacity of 17 million m^3, and a small 40 000-m^3 impoundment on the Nyamasupa River. Nyawamba Dam is owned and operated by the Eastern Highlands Tea Estate. There are no large dams in the Pungwe River Basin in Mozambique, but there are 19 small dams used for crop irrigation, including Muda dam with a capacity of ~56 Mm^3. Major water supply schemes located on the Pungwe River include the Pungwe Mutare Water Supply Project and the Mafambise Sugar Estate/Beira Water Supply System. Other water supply schemes comprise small, piped water supply schemes on tributaries of the Pungwe River in Zimbabwe, and several small irrigation schemes in both countries (Governments of the Republics of Mozambique and Zimbabwe 2006).

Freshwater flows from the Pungwe River support the estuarine and marine ecosystems near Beira (e.g., Brito and Pena 2007). Changes in these flows as a result of storage of water, abstraction of water from the Pungwe River (e.g., Droogers and Terink 2014; Terink and Droogers 2014) or climate change (Anderson *et al.* 2010) could thus have significant consequences for these systems and the activities they support. For example, estimates of low flow freshwater volumes from the river required to prevent salinity intrusion at the water intake for the City of Beira range between 8.8 (Swatek and van der Zaag 2009, Zanting *et al.* 1994) and 12 m^3/s (Graas and Savenije 2008).

Demand to harness Pungwe River waters for inter-basin water transfer, municipal water supply, salinity control, hydropower, flood mitigation, large, irrigated agriculture (sugar) schemes, and other uses is increasing.

1.1 BACKGROUND AND PROJECT CONTEXT

The Global Environmental Facility (GEF)-funded project "Management of competing water uses and associated ecosystems in Pungwe, Buzi and Save basins" is being implemented by the International Union for Conservation of Nature (IUCN) and executed by Global Water Partnership (GWPSA) together with the Government of Mozambique (GoM) and Government of Zimbabwe (GoZ). It targets the conservation and sustainable use of the transboundary water resources, including the risk mitigation components within the Buzi, Pungwe and Save river basins shared bilaterally by Mozambique and Zimbabwe. The three basins are located along the Beira corridor, an important economic corridor that links Beira harbour to the hinterland, with associated impacts on the environment (pollution from mining activities, intensive agriculture, deforestation, saline water intrusion etc.). Populations in the basins have become highly vulnerable to climate hazards (i.e., floods, droughts, cyclones) whose occurrence is likely to increase with climate change aggravation.

The increasing water uses are raising the issue of equitable water allocation and the accompanying dimension of Environmental Flows (EFlows) that has particular importance in a transboundary context. For example, a number of dams are planned in the Pungwe Basin on the Mozambique side, including Gorongosa Dam, which was recently commissioned. Both upstream and downstream there are current and planned developments with an impact on the flows. These resource aspects are of highest importance for the communities that derive their livelihood from ecosystem services; in a context of endemic poverty and low resilience to climate change impacts. The project seeks to promote holistic approaches to the water-food-energy nexus, with specific interest in connected ecosystems. It has a double focus of developing capacities for managing water resources and designing participatory and community–based strategies.

The project's main objective is to strengthen the management of transboundary water resources and connected ecosystems for sustained ecological benefits and improved resilience for the riparian communities.

This contributes to GEF's Strategic Objective 1, which seeks to conserve, sustainably use, and manage biodiversity, ecosystems and natural resources globally, taking into account the anticipated impacts of climate change. The need for developing transboundary cooperation for water resources management has been materializing for years through several initiatives, including the signing of the Pungwe and Buzi transboundary agreements (the Save agreement is under preparation), and the wish to establish a bilateral tri-basin river basin organisation.

The project will contribute to supporting transboundary cooperation for water resources management through the development of joint initiatives (joint hydrological monitoring campaigns), common tools development (TDA/SAP, adoption of guidelines for EFlows implementation), bilateral capacity building or through experience sharing (on community-based early warning systems for instance). There are three main components to the project:

1. Component 1 will contribute to strengthening water-related risk management through the reinforcement of monitoring systems, the development of real-time operational tools, and the empowerment of communities in their flood mitigation autonomy.
2. Component 2 will focus on enhancing ecosystem services through quantitative water management, including operationalisation of environmental flows (assessment and legal framework establishment), and through water quality improvement.
3. Component 3 will focus on national inter-ministry committees and technical advisory teams that will contribute to the development of a regional Transboundary Diagnostic Analysis and subsequently to the preparation of a Strategic Action Plan.

1.2 ENVIRONMENTAL FLOWS

Environmental Flows (EFlows) are the water quantity, quality, pattern of water and sediment flow, and more, that support a desired level of ecological functioning in river and estuarine systems, and the human livelihoods and wellbeing dependent on that level of functioning (Figure 1.2).

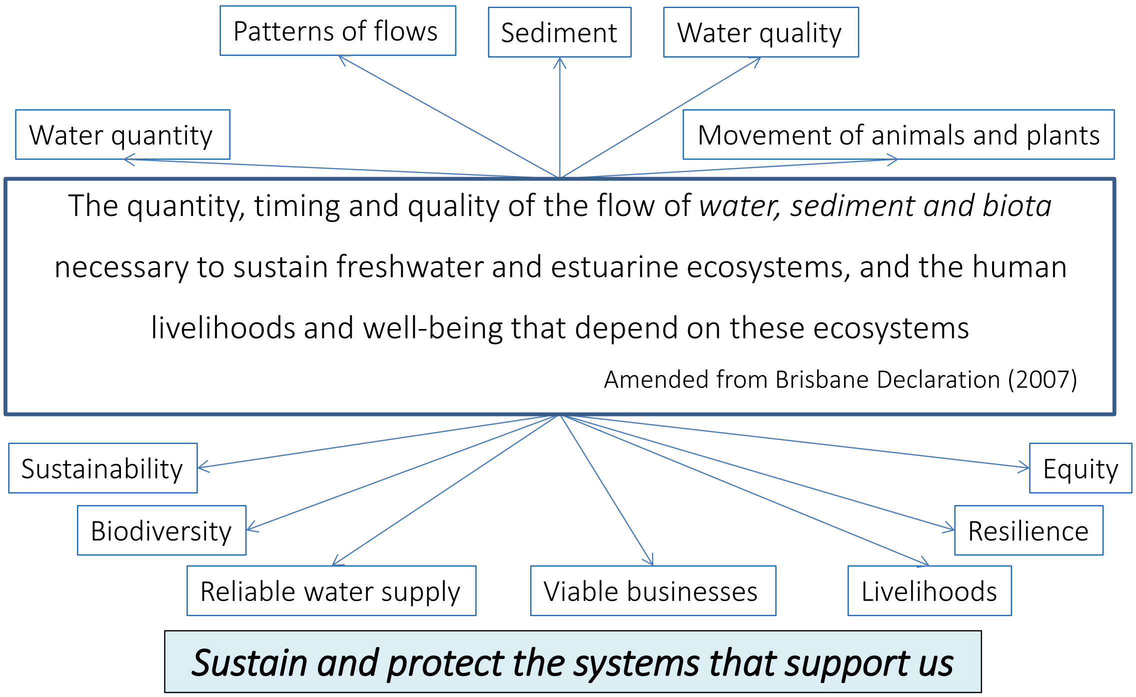

Figure 1.2 EFlows are the required water quantity, quality, pattern of flows (above box) that support human livelihoods and wellbeing (below box) (Brown *et al.* 2019)

The setting of EFlows for rivers in a sub-catchment is essentially a two-part process:

- Through the technical EFlows Assessment process, scientists provide expert technical advice on how river ecosystems will change under various patterns and volumes of water and sediment flow, and water quality, linked with development scenarios (top of Figure 1.2).
- Stakeholders then use this information to decide what different reaches of a river are used for, how these various uses will be balanced and what level of protection the river and associated ecosystems will be afforded (lower part of Figure 1.2).

1.3 THIS ASSIGNMENT

This assignment is the INTEGRATED EFLOWS ASSESSMENT TO FACILITATE THE DEVELOPMENT AND AGREEMENT OF "OBJECTIVE FLOWS" AT KEY SITES IN THE PUNGWE BASIN. It is referred to more colloquially as **EFlows Assessment of the Pungwe River Basin**.

The objective of the assignment is to support the Mozambique and Zimbabwe governments to facilitate the consultation process of determining 'objective' EFlows at strategic points in the transboundary Pungwe Basin that will, among other considerations, inform specifications on EFlows in the Pungwe Basin Agreement. Downstream flows agreed between the two countries will depend on EFlows allocations based on environmental targets as specified by Basin stakeholders, and abstraction allocations.

Within this overarching objective, the itemised sub-objectives are:

1. Identification and characterisation of key surface-water ecosystems connected to rivers (aquatic, wetlands) and of their water needs
2. Identification of key water management nodes from a resource allocation and use perspective
3. EFlows model development and determination of EFlows in a range of typical aquatic habitats and "hotspot" ecosystems
4. Characterisation of current and potential water demand and uses and their impact on river flows
5. Determination of EFlows and the corresponding ecological status they can support at strategic points in the basins, based on the environmental targets agreed upon by basin stakeholders
6. Recommendations to both countries of EFlows values at strategic points and rules/tools for computing these values elsewhere
7. Recommendations on the incorporation of EFlows considerations in the establishment of guidelines and legal texts for the transboundary framework (basin agreements) and national frameworks (water allocation).

1.3.1 Inception Phase

The Inception Phase comprised the following tasks and deliverables:

Task #	Name of task	Linked to deliverable
0.1	Literature review	Inception Report
0.2	Data and model review	
0.3	Selection of EFlows zones	
0.4	Recce field visit	
0.5	Updated Workplan	
0.6	Inception Report and Inception Meeting	

1.4 THIS REPORT

This report is the Inception Report for the EFlows Assessment of the Pungwe River Basin. It provides the outputs for the Inception Phase, including background information on the various aspects of the assessment, and comprises

- Section 2, which covers the methodological approach to and the specialist team appointed for the study
- Section 4: The Recce Field Trip Report (Task 0.4)
- Section 3: EFlows sites (Task 0.3)
- Section 5: Scoping of existing data and knowledge for the various aspects of the study
- Section 6: Preliminary list of indicators for use in the DRIFT Model
- Section 7: Stakeholder engagement strategy
- Section 8: Updated phase and task descriptions
- Section 9: Schedule (Task 0.5)
- Section 10: Financial management and Section 11: Risk management.

2 APPROACH AND TEAM

2.1 EFLOWS METHODOLOGIES

The ToR calls for three different kinds of EFlows methodologies:

1. An EFlows methodology for the rivers and estuary
2. A EFlows Basin Configuration Model
3. A marine EFlows methodology.

For the first, based on our experience, the anticipated complexity of the EFlows Assessment is best handled through a scenario-based ecosystem-modelling EFlows approach (Overton *et al.* 2014). These approaches were previously categorised together with holistic EFlows methods (Overton *et al.* 2014). Thus, we propose to use the DRIFT Methodology.

For the second we have based the approach on the recommendations of King (2012) and the work done in the Kafue and Luangwa basins in Zambia.

For the third, the approach to be adopted is based on that of van Ballegooyen *et al.* (2007).

2.1.1 The DRIFT approach

The EFlows Assessment for the Pungwe River and Estuary will use the Downstream Response to Imposed Flows Transformation (DRIFT) method (King *et al.* 2003; Brown *et al.* 2013). DRIFT is a process and Decision Support System (DSS) for managing and interrogating knowledge on the links between river flows (water, sediment and biota), ecosystem functioning and social uses. It was developed to aid management and future planning of water-resource developments, rehabilitation of rivers or any other management activity that could affect the flow of water or sediment through inland water ecosystems. DRIFT allows for:

1. Time-series based evaluation of changes to hydrology, hydraulic or sediment characteristics
2. Incorporation and evaluation of measured or modelled time-series data at any time-step
3. Use of a combination of models, data, knowledge and experience to model ecosystem functioning
4. Calibration or evaluation of time-series predictions against ecological data, where available
5. Inclusion of social and management criteria.

DRIFT has been the subject of numerous scientific papers (e.g., Brown *et al.* 2010; Brown *et al.* 2013; Brown *et al.* 2018; Seaman *et al.* 2014; Joubert *et al.* 2022) and has been widely applied in Africa, and Asia. It is supported by tutorials, a User Manual and training programmes (www.drift-eflows.com).

Using DRIFT promotes transparency as all assumptions and linkages are recorded within the DRIFT DSS and can be viewed and changed as required based on new knowledge and evidence.

> The EFlows Assessment for the Pungwe River and Estuary will use the Downstream Response to Imposed Flows Transformation (DRIFT) method.

Within DRIFT, each specialist uses discipline-specific methods to derive the links and develop the relationships between river flow and river condition. The central rationale of DRIFT is that different aspects of the flow regime of a river elicit different responses from the riverine ecosystem. Thus, removal of part or all of a particular element of the flow regime (of water or sediment) will affect the riverine ecosystem differently than will removal of some other element. DRIFT will also be used to evaluate the impacts on people and resource economies of a changing river ecosystem.

The intention is to use DRIFT to organise EFlows related data for the Pungwe Basin, information in the international scientific literature and expert opinion to provide a clear, comprehensive and integrated picture for the main aquatic ecosystems on the Pungwe River and Estuary, in terms of:

- The baseline (2022) condition in terms of the river ecosystem and its dependent social structures
- Reasons for this condition
- Possible future conditions, relative to the baseline condition, as described through the evaluation of the thematic area configurations for each representative EFlows zone/site/area.

Once established, the DRIFT database can be used to assess an array of water-resource scenarios to guide management and development of the Pungwe Basin. One of the goals of this assignment is to ensure that regional specialists receive training in using the DSS so that the ability to evaluate scenarios and use the DSS for adaptive management is retained in the region, and so that similar EFlows studies can be conducted for the Busi and Save Basins. This goal is reflected in the make-up of the specialist team for this assignment (Section 2.2)

The DRIFT EFlows Model is divided into three stages (Figure 2.1):

1. Set-up
2. Knowledge Capture
3. Analysis.

The first two stages deal with the population of the DRIFT database and the calibration of the flow-ecosystem relationships (indicators and response curves; Section 2.1.1.2 and 2.1.1.3) that will be used to predict the ecosystem response to changes in flows. The third stage is used to generate results once the first two stages have been completed, and to export to data detailing the predictions for the configurations under consideration generated for post-processing and reporting.

The basic data requirement for DRIFT is daily (or, on occasion, sub-daily) hydrological flow sequences for a continuous time period – preferably 30 years or more. The first time-series produced is a continuous record of baseline flows for each site over a given period. Thereafter, simulated time series are produced for the naturalised condition and for all chosen configurations, over the same period. For each time series, the water-resource conditions chosen are imposed over the full period.

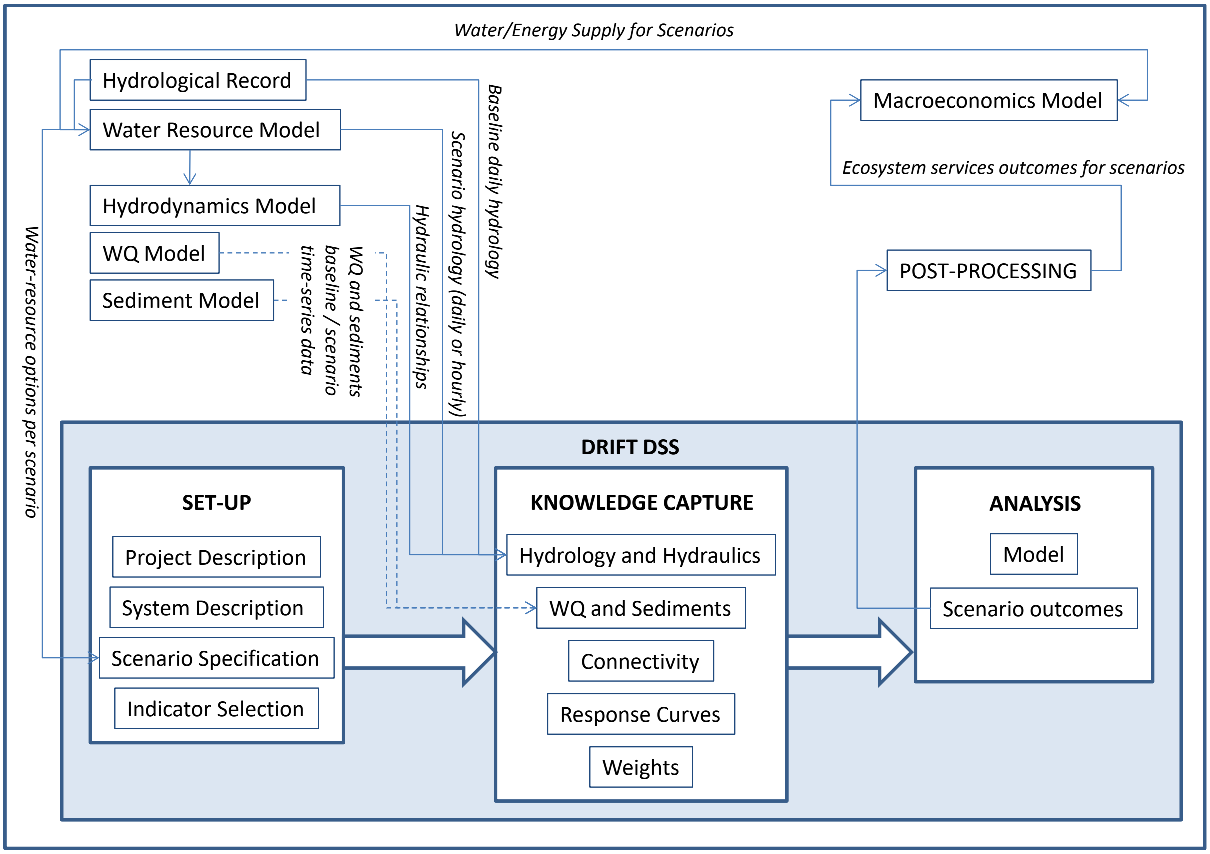

Figure 2.1 Arrangement of modules in DRIFT and inputs/outputs from/to external models

> The basic data requirement for DRIFT is daily hydrological flow sequences for a continuous time period – preferably 30 years or more.

For the Pungwe River, the hydrological data used as input to the DRIFT Model will be derived from the Water Resources Simulation Model (WRSM) suite of software, which includes the Pitman Model. The Pitman Model will be calibrated on the observed records. Daily flows will be generated either by disaggregating the calibrated monthly hydrology using the daily observed records or using the Pitman Daily Model to generate the appropriate input to DRIFT.

The baseline and expected future flow regimes associated with water resources developments need to be modelled / generated and the outputs required from the model are daily[1] hydrological data since monthly data do not provide the resolution required.

[1] If HPPs are planned in the system, for those that generate power at peak times each day, sub-daily data are needed. The DRIFT-Pungwe will not be set up for these in this project, but they can be added at a later stage if needed.

As flow time-series are not easy to interpret ecologically, they are transformed into a set of hydrological indicators and summary statistics chosen by the EFlows team and Stakeholders (see Section 6).

In DRIFT, the hydrological time series are used to generate year-by-year information for each flow indicator: a 40-year hydrological record, for instance, will have 40 values for “dry season onset”. The flow indicators thus reflect the natural variations of the intra-annual and inter-annual hydrological cycle. They are summarised by mean, median, standard deviation and range.

In summary, daily time series form the hydrological input to the DRIFT tool, and DRIFT uses these to calculate the values for the flow indicators and summary statistics (Figure 2.1). DRIFT can incorporate data via external models on hydraulics and hydrodynamics set up for the Pungwe River EFlows zones and the estuary.

2.1.1.1 Disciplines

The ecological and social aspects of the Pungwe River Basin ecosystems are represented by eight disciplines in DRIFT-Pungwe, *viz*.:

- Hydrology
- Hydraulics/hydrodynamics
- Water Quality
- Geomorphology/Physical habitat
- Macrophytes
- Invertebrates
- Fish
- Social use.

2.1.1.2 Indicators and links

Discipline-specific indicators and the links between driving and responding indicators will derived by the EFlows specialist team. The time-series from which the hydrological and hydraulic/hydrodynamic driving indicators are derived are generated outside of the DRIFT-Pungwe. Others are ecosystem or social indicators whose predicted changes are provided through response curves in DRIFT-Pungwe.

The initial list of ecosystem and social indicators in DRIFT-Pungwe are listed in Section 6. The links with the external indicators and with each other will presented and discussed in subsequent project reports

2.1.1.3 Response Curves

Response Curves depict the relationships between indicators. The aim is not to include every conceivable link but rather to restrict the links to those that are most meaningful and can be used to predict the bulk of the likely responses to a change in the flow, water quality, sediment or other changes in the river’s flows.

The Response Curves will be constructed by the relevant discipline specialists in a workshop, where they are able to interact with the rest of the EFlows team; and with members of GWPSA and other Stakeholders (see Section 7). The final curves and explanations for their shape will be contained in a project-specific DRIFT DSS, and in the specialists'' reports.

The time-series approach means that the Response Curves are used to predict the likely seasonal change in an ecosystem indicator in response to the flow/sediment conditions experienced in that, or possibly preceding, seasons, and thus build up a seasonal time-series of responses.

2.1.2 The EFlows Basin Configuration Model

In 2011, WWF commissioned a document entitled *Establishing the process of developing and implementing environmental flows (EFlows) for the Zambezi River Basin* (King 2012), which suggested that, in the short term, rapid 'holding' EFlows assessments should be done for river reaches that are largely unregulated, and for which no previous EFlows assessments have been done, to provide EFlows information for coarse planning purposes.

To assist with decisions on EFlows for different parts of the Basins, an EFlows Basin Configuration Model will be set up for the Pungwe. This is an Excel-based tool designed for a first, low-resolution assessment of the implications of water resource developments on a basin's river ecosystem. It can be used to illustrate how development in one part of the basin could impact the river system, and thus water resources, in other parts. Developments such as an irrigation area or dam can be inserted in a location of interest in the basin, and an estimate made of their impact on the flow regime and ecological condition of the nearest downstream site and others further downstream likely to be affected. The tool helps develop an understanding of where in the basin future water resources could be located and where they should perhaps be avoided if they would conflict with other aspirations for the basin.

The EFlows Basin Configuration Model will use the results for 4 river sites and the estuary generated in the EFlows assessment, augmented where needed with outcomes of EFlows assessments that have been done for similar rivers to the study rivers. This is based on a 10-step process:

1. Delineate the rivers into homogeneous Integrated Units of Analysis (see Section 8.2.1).
2. Generate monthly hydrology for each node.
3. For IUAs represented by the EFlows sites in this study, use the resulted generated in the study.

For other nodes:

4. Calculate the Hydrological Index (HI) for the representative node for each IUA.
5. Identify areas in South Africa with similar HI values as those for the Pungwe Basin representative nodes.[2]
6. Use the South African Desktop Model to generate dry-season low flow EFlows requirements to maintain these similar rivers in an A/B, B, C or D ecological condition as appropriate. Express these requirements as a percentage of each month's naturalised flow.

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[2] Values from South Africa are suggested for use because that is the closest region where a comprehensive analysis of HI values has been done.

7. Augment the outputs from Step 4 with results for dry-season flows from EFlows assessments done for the Pungwe (this study), similar rivers within eastern and southern African but outside of South Africa (i.e. ones not included in the Desktop Model) where available and applicable.
8. Cross-check the results for dry-season flows against present day dry-season flows in the study rivers.
9. Assess the wet-season EFlows based on considerations in the Pungwe River.
10. Summarise the total EFlows requirements to maintain the river/estuary at each representative node in an A/B, B, C or D ecological condition as relevant.

2.1.3 Marine EFlows methodology

The ecological needs of freshwater dependent coastal and marine environments should be considered in the allocation of freshwater resources to ensure healthy functioning marine ecosystems that support productive and sustainable fisheries. Van Ballegooyen *et al.* (2007) developed an assessment framework for the marine ecosystems that take cognisance of their freshwater requirements. A scenario-based version of the proposed framework (Table 2.1) implemented in van Niekerk and Lamberth (2013) is recommended for this project to evaluate a range of freshwater flow scenarios at a screening level to ascertain if the transitional waters of the nearshore marine environment will be sensitive to proposed changes in the Pungwe catchment.

Table 2.1 Recommended steps for determining the EFlows requirements of transitional waters (modified from Van Ballegooyen *et al.* (2007)

EFlows Step	Description of tasks
Step 1	1.1 Define legislative obligations (in terms of biodiversity protection, sustainable fisheries, coastal protection - beach development) 1.2 Identify ecosystem extent (delineation) 1.3 Identify key ecosystem functions and services 1.4 Identify ecosystem resource use
Step 2	2.1 Identify biodiversity and resource use targets (e.g. fish nurseries, fisheries production, Marine Protected Areas, sediment requirement of beaches)
Step 3	3.1 Determine ecosystem sensitivity to freshwater flow 3.2 Identify relevant abiotic components (e.g. habitat) and assess responses to flow modification 3.3 Describe the implications of present flow regime on selected biological components (i.e. keystone/indicator species life-cycle and habitat requirements in terms of freshwater flow)
Step 4	4.1 Assess hydrological scenarios Predicted the responses, if any, to predicted change in abiotic drivers Describe the implications of flow alteration on selected biological components 4.2 Evaluation of socio-economic importance of marine aquatic ecosystems and resource uses 4.3 Provide implications for different EFlows for marine environment
Step 5	6.1 Once as decision has been made on EFlows, set resource targets (e.g. freshwater flow, river water quality and sediment delivery) for nearshore marine environment.

2.2 SPECIALIST TEAM

The EFlows consultant team members and their respective roles are listed in Table 2.2. All team members have been formally engaged and all non-Southern Waters personnel have signed sub-contracts.

Table 2.2 Team designations for the assignment

No.	Position	Name	Organisation
1	Project Leader	Prof.Cate Brown	Southern Waters
2	River EFlows Lead/Water quality	Dr Patsy Scherman	Southern Waters
3	Estuaries EFlows Lead	Dr Lara van Niekerk	CSIR
4	Lead: socio-economics	Dr Jane Turpie	Anchor Environmental
4	Hydrologist	Gerald Howard	Private
6	Ecohydraulics (freshwater)	Dr Andrew Birkhead	Streamflow Solutions
7	Geomorphologist/ sedimentologist	Prof. Kate Rowntree	Private
8	River botanist (freshwater)	Dr Karl Reinecke	Southern Waters
9		Tongai Castilo	Private
10	Fish ecologist (freshwater)	Dr Lightone Marufu	Univ. of Zimbabwe
11		Dr Stephen Lamberth	Private
12	River macroinvertebrate ecologist/algologist	Dr Justine Ewart-Smith	PhD (River ecology)
13		Prof. Tamuka Nhiwatiwa (and water quality)	Univ. of Zimbabwe
14		Ricardo Guta	UCT Masters Student
15	Estuarine hydrodynamics	Roy van Ballegooyen	WSP
16	Estuarine water quality specialist	Prof. Antonio Hoguane	Eduardo Mondlane University
17		Dr Susan Taljaard	CSIR
18	Macrophyte botanist	Prof. Celia Macamo	Eduardo Mondlane University
19		Prof. Janine Adams	NMMU
20	Invertebrate ecologist	Fiona MacKay	ORI
21	Fish ecologist	Steven Weerts	CSIR
22	Estuarine and marine fisheries specialist	Dr Bernardino Sérgio Malawene	Mozambique Marine and Fisheries Research Institute
23		Dr Stephen Lamberth	Private
24	Resource economics	Gwyn Letley	Anchor Environmental
25		Luke Wilson	Anchor Environmental
26		Prof. Lindah Mhlanga	Univ. of Zimbabwe
27	Knowledge managers	Dr Alison Joubert	Southern Waters
28		Hassan Bukhari	Southern Waters/Stellenbosch University PhD Student
29		Herminio Mulungo (assisted by José Sawanguane)	Afrikaia

3 EFLOWS ZONES

The DRIFT EFlows assessment will focus on EFlows six zones within the study area:

EFZone 1: The Pungwe River in Zimbabwe

EFZone 2: The Pungwe River in Mozambique, from downstream the Honde confluence to upstream the Vunduzi confluence

EFZone 3: The Pungwe River in Mozambique, from the Vunduzi confluence to the Nhandugue confluence

EFZone 4: The Nhandugue tributary upstream of Lake Urema

EFZone 5: Estuary

EFZone 6: Near-shore marine environment.

The locations of the river EFlows sites, EF1-4 (Figure 3.1), representing the four river EFlows zones were assessed on the Recce Field Trip (Section 4.6), and their positions adjusted accordingly, however, the location of the sites is still preliminary and the zone boundaries have not yet been set.

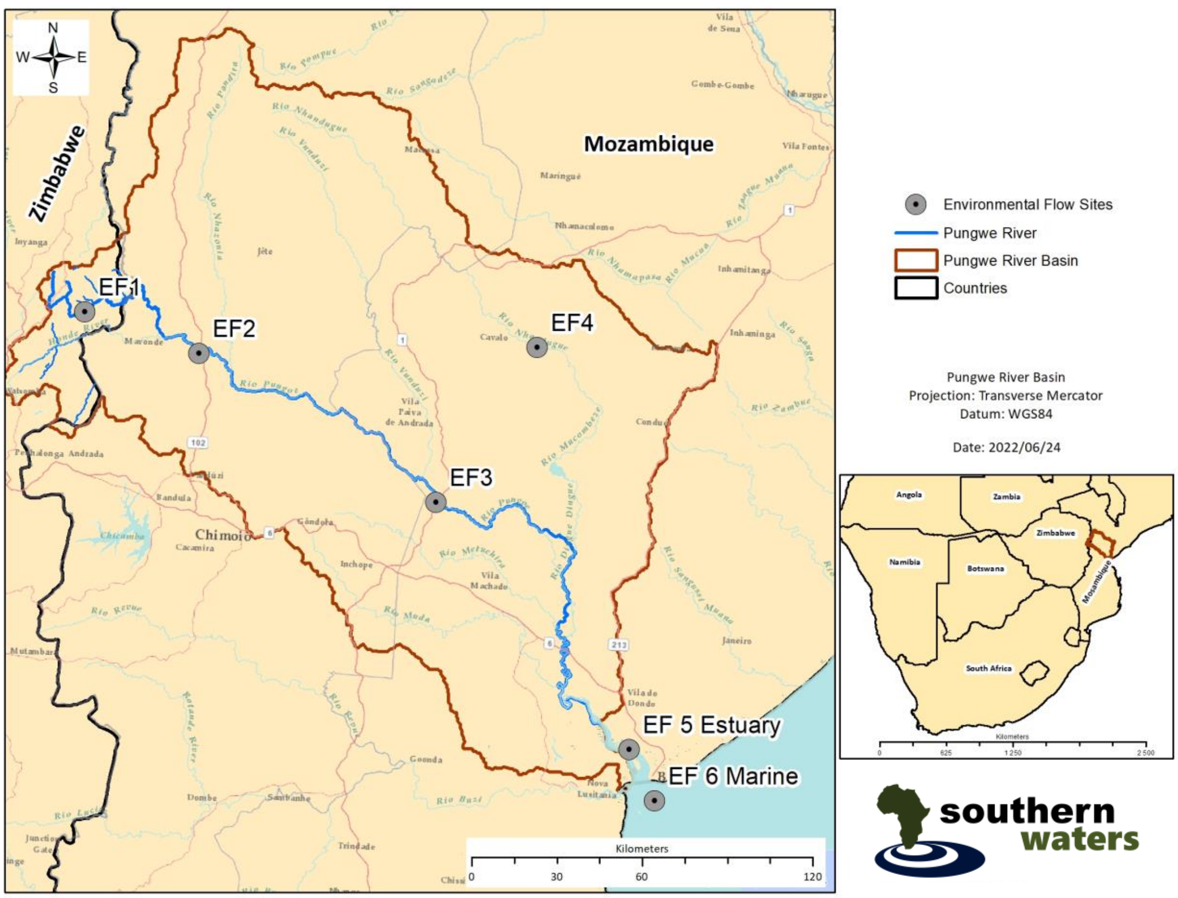

Figure 3.1 The preliminary river EFlows sites and the estuarine and marine Zones proposed for EFlows assessment for the Pungwe Basin

The location of the EFlows sites and the EFZone boundaries will be agreed and set during the Phases 1 and 2 on the basis of, *inter alia*, the delineation of the river and input from Stakeholders.

4 RECCE SITE VISIT

The Recce Site Visit described here is one of the Inception Phase activities. The aims of were to:

- gain a first-hand understanding of the character of the rivers and human activities in the study area, and the implications for site selection
- make first-hand observations and talk to key informants to fill knowledge gaps
- visit the location of relevant flow monitoring stations and to assess whether or not these could be incorporated into the EFlows sampling programme
- identify possible locations for sampling for later discussion and final selection of the EFlows sites, based on *inter alia:*
    - position in the basin
    - access
    - safety considerations
    - staging areas for parking, equipment and sample sorting
- compute travel times and estimate time needed for data collection at each site to inform the detailed design of field work
- check options for accommodation and other logistical considerations.

This section summarises the aspects of the Recce Field Trip, which took place from 13th to 18th June 2022.

4.1 RECONNAISSANCE TEAM

The EFlows team members present on the Reconnaissance Field Trip were:

- Dr Patsy Scherman
- Dr Karl Reinecke
- Prof Tamuka Nhiwatiwa
- Prof Lindah Mhlanga
- Dr Lightone Marufu
- Ms Gwyneth Letley
- Mr Jose Sawanguane.

Representatives of the Client and Stakeholders on the trip were:

- Mr Hilarion Pereira: Head of the International Rivers and also the focal point for BUPUSA (Buzi, Pungwe and Save), Mozambique
- Mr Agnelo Jorge, Civil Engineer/Technician at ARA Centro, Mozambique, and works with the Catchment Manager/Director of the Pungwe Basin Unit, Mr Melembe
- Mr Gerald Mundondwa - Chief Hydrologist Ministry of Water Resources Zimbabwe and Focal Point for BUPUSA, Zimbabwe
- Ms Tendai Muyambo: Catchment Manager for Save Basin (which also includes Pungwe), Zimbabwe
- Mr Elisha Madamombe: GWPSA, Regional Coordinator for GEF BUPUSA
- Mr Jose Malanco: Integrated Water Resources Management (IWRM) Advisor, GEF BUPUSA,

Mozambique

- Mr Alfred Misi, IWRM Advisor GEF BUPUSA, Zimbabwe.

4.2 ACCOMMODATION

The reconnaissance team travelled together and stayed at the same accommodation venue most nights, based at:

- Beira Terrace Hotel, Beira, Monday 13 June;
- Hotel Kapulana, Gorongonza, Tuesday 14 to Wednesday 15 June;
- Hotel Amarina and Hotel Inter Chimoio, Chimoio, Thursday 16 June, and;
- Gordons Select B&B, Mutare, Friday 17 June: specialist team.
- Musangano Lodge, Friday 17 June: Client team.

A typical day comprised eight hours from 08:00 am - 16:00 pm.

4.3 WEATHER

The weather was partly cloudy with no wind and rain, which allowed the required work to be completed on each day, with no interruptions.

4.4 INTINERARY

The Reconnaissance Field Trip itinerary is summarised in Table 4.1.

Table 4.1 Reconnaissance Field Trip itinerary

Day and date	Time of day	Activity
Mon 13 June	AM	SW team travel to Beira, from Mozambique and South Africa
		Client team travel to Beira
	PM	Client and SW team meet and greet, discuss trip itinerary. The team is joined by Dr Loreen Katiyo (Transboundary Water Governance & Environment Specialist, GWPSA) and Mr Antonio Melembe (Director: Pungwe Basin Unit, Mozambique) for the team discussion.
		SW socio-economic team (Letley, Mhlanga and Sawanguane – translator) visit Mercado Praia Nova (New Beach Market) and fish landing site at Pungwe River estuary

Day and date	Time of day	Activity
Tue 14 June	AM	Travel Beira to gauge E67 Pungwe River, Mafambisse bridge on the EN6
		Socio-economic key informant interviews conducted
		Travel to gauge 651 Pungwe River, EFlows Zone 3, Mozambique
	PM	Ecological site assessment completed
		Socio-economic key informant interviews conducted
		Travel to Kapulana Hotel
		Meet with botanists from Gorongonza National Park (GNP): Mr Tongai Castigo (recently left GNP) and Ms Francisca Salma Andicene (currently based at the EO Wilson Lab, GNP).
Wed 15 June	AM	Travel to Nhandugue River, EFlows Zone 4, Mozambique
	PM	Assess two sites. Ecological site assessment completed
		Socio-economic key informant interviews conducted
		Travel back to Kapulana Hotel
Thu 16 June	AM	Travel to Pungwe River, EFlows Zone 2, Mozambique
	PM	Ecological site assessment completed
		Socio-economic key informant interviews conducted
		Travel to Chimoio
Fri 17 June	AM	Travel to gauge F24 Pungwe Murara, Pungwe River, EFlows Zone 1, Zimbabwe
	PM	Ecological site assessment completed
		Socio-economic key informant conducted
		Also visit gauge F22, Pungwe Katiyo, at Mozambique/Zimbabwe border. Travel to Mutare
Sat 18 June	AM	SW team travel to Harare, Cape Town and Maputo
	AM-PM	Client team travel back to respective locations, Maputo Beira Harare

4.5 TRAVEL TIMES

Travel times between destinations are shown on Table 4.2.

Table 4.2 Time taken to travel the routes taken

Route taken	Time (hours)
Beira to Gauge E67, Pungwe River	00:45
Gauge E67 to gauge E651, Pungwe River, EFlows Zone 3	02:10
Gauge E651,Pungwe River, EFlows Zone 3 to Gorongoza Town	01:30
Gorongoza Town to Casa Banana Village, Nhandugue River, EFlows Zone 4	01:50
Gorongonza Town to Pangwasul, Pungwe River, EFlows Zone 2 via Chimoio	05:00
Chitundo, Pungwe River, EFlows Zone 2 to Chimoio	01:30
Chimoio to Mutare	03:00[3]
Mutare to Mukupe Village, (Honde Valley), EFlows Zone 1	02:00
Mutare to Harare	03:30

4.6 RIVER EFLOW SITES

Four EFlows zones and sites were assessed (Table 4.3) and are described in turn.

Table 4.3 Location and co-ordinates of the four EFlows sites.

EFlows site	Location	Co-ordinates
1	Mukupe Village, Honde Valley Road, Pungwe River, gauge F24	-18 ° 26' 00'', 32° 53' 49''
2	Pungwasul Village, N7 road bridge crossing, Pungwe River, gauge E65	-18 ° 33' 10'', 33° 16' 49''
3	N1 bridge crossing Pungwe River, Matenga-Pungwe Village, gauge E651	-18 ° 59' 43'', 34° 05' 05''
4	Casa Banana Village, Nhandugue River	-18° 29' 33'', 34 ° 23' 59''

[3] Includes two hours for the border post

4.6.1 EFlows 1

LOCATION: Mukupe Village, Honde Valley Road, Pungwe River, at gauge F24 (Figure 4.1).

COORDINATES: -18° 26’ 00’’, 32° 53’ 49’’

DIRECTIONS: Drive North out of Mutare on the A15 road, turn right onto the Honde Valley road, gauge F24 is located at Mukupe village.

ACCESS: Both banks can be easily accessed from the road, the river is relatively narrow and wadeable.

SAFETY: The villagers said there were no resident crocodiles or hippopotami at this site, the small size of the river and shallow depth of water would suggest this is true. There is safe parking off the road at the gauge.

HABITAT: The macro-channel of river is ~ 20 m wide and comprised a riffle-pool-riffle-pool sequence over a longitudinal distance of ~ 100 m. The channel is not braided. The riffles provide options as hydraulic controls along which the cross-section may be surveyed.

The water was clear and the channel bed comprised a mixture of alluvial sand, gravels and cobbles.

The active channel comprised a good variety of in-channel habitats for aquatic invertebrates and fish. There were fast and slow flowing areas at different depths in the main channel with a variety of different sediments.

The channel edges were well vegetated with grasses and ferns. The left bank was well vegetated with large trees while the right bank was either cultivated or comprised grazing grasses.

EFFORT: Surveying the cross-section will be possible because the line of sight from one bank to the other is clear. The channel is narrow and the trees are large and their canopies are high so will not pose obstructions. It will be possible to measure discharge using the velocity-area method and an electronic flow meter.

Sampling the riparian vegetation will be relatively straightforward as the riparian zone is not densely vegetated.

Sampling invertebrates in a variety of habitats will be possible because there are reportedly no crocodiles at this site.

Sampling fish with the electroschocker and with fyke nets will be possible because there are reportedly no crocodiles at this site.

Figure 4.1 EFlows 1

4.6.2 EFlows 2

LOCATION: Downstream of the N7 road bridge crossing Pungwe River, Pungwasul Village, gauge E65 (Figure 4.2).

COORDINATES: -18° 33' 10'', 33° 16' 49''

DIRECTIONS: Drive West out from Chimoio on the EN6, turn right onto the N7 toward Chitundo, gauge E65 is located at the road bridge crossing the river at Pungwasul Village.

ACCESS: Both banks of the river can be accessed from the edges of the bridge.

SAFETY: There are two resident crocodiles near the bridge as well as a pod of hippopotami that move up and down the river at this site. Two sons of the farmer on the left bank are willing to assist as animal spotters for the project team on the next trip, as they are familiar with the movement of the animals and the paths on both banks of the river.

There is a safe parking area under a tree on the left bank of the river near the bridge.

HABITAT: The macro-channel of river is ~ 50 m wide and comprised a run-riffle sequence over a longitudinal distance of ~ 100 m downstream of the bridge. There is one riffle, the hydraulic control.

The water was too turbid to be able to see the channel bed. The turbidity was high because of mechanised gold mining on the Nyamukwarara River upstream, a tributary of the Pungwe River in Mozambique.

The active channel had a variety of in-channel habitats for aquatic invertebrates and fish which included rocky, sandy and muddy areas. Fast and slow-flowing areas at varying depths were observed along the main channel. Backwater pools with a variety of different sediments were also observed. Some sections of the shoreline/channel edges had rocks and some had sand or muddy sections which also indicated the variety of substrate types along the channel. The channel edges and banks were densely vegetated with *Phragmites* reeds, making it unclear where the solid bank is located on the right bank. There were some trees higher up on the channel banks and there is extensive subsistence cultivated fields on both banks.

EFFORT: Surveying the cross-section is going to take considerable effort. The channel is wide and deep and the banks are densely vegetated. It will be necessary to clear a line of sight through the reeds on both banks to survey in the channel banks with the total station. It will be necessary to use an acoustic Doppler to survey in the channel bed and to measure discharge.

Sampling the riparian vegetation is going to take considerable effort because of the density of the vegetation. The diversity of plant species on the banks was low.

Sampling invertebrates on the channel edges and in the riffle downstream will be possible, taking all possible precautions against the presence of crocodiles and hippopotami.

Sampling fish with the electroshocker and with fyke nets will be possible, taking all possible precautions against the presence of crocodiles and hippopotami.

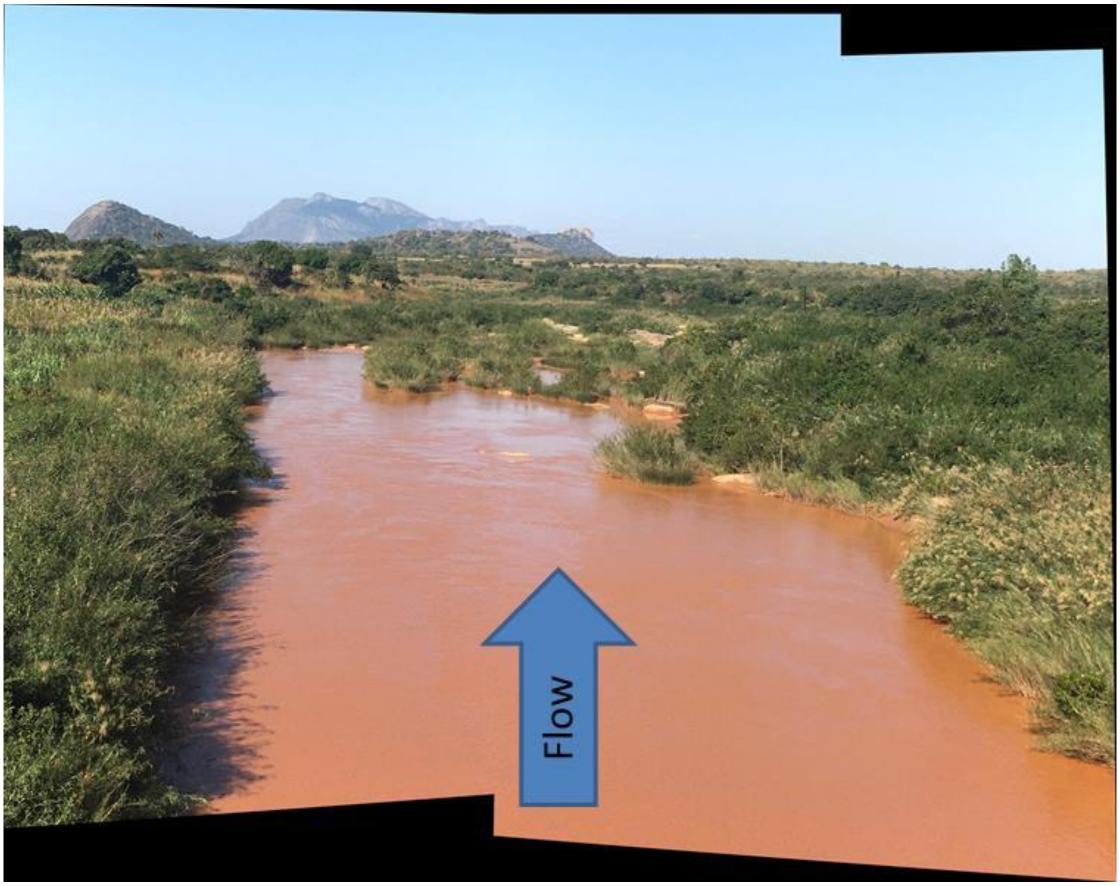

Figure 4.2 EFlows 2

4.6.3 EFlows 3

LOCATION: Upstream of the N1 road bridge crossing Pungwe River, Matenga-Pungwe village, gauge E651 (Figure 4.3).

COORDINATES: -18 º 59' 43'', 34º 05' 05''

DIRECTIONS: Drive out from Beira on the N6, turn right onto the N1, travel for ~40 km to the road bridge.

ACCESS: Both banks of the river can be accessed from the edges of the bridge.

SAFETY: There is a police camp upstream on the left bank that is there to guard the bridge against attack from Renamo. The Client representatives spoke with the police officers about the project and informed them about the project. **The police officers at this camp must be informed prior to the next data collection trip in August.** There is a safe parking area under a tree at the bridge were the officers on duty are stationed. There are apparently no crocodiles or hippopotami upstream of the bridge because of the faster flowing water and bedrock. Crocodiles are found downstream in the slower flowing runs and pools downstream of the bridge.

HABITAT: The macro-channel of river is ~ 100 m wide and comprised a riffle-pool-riffle-pool-riffle-pool-riffle-run sequence over a longitudinal distance of ~ 500 m upstream of the bridge. The riffles provide options as hydraulic controls along which the cross-section may be surveyed.

The water was too turbid to be able to see the channel bed.

The active channel comprised a good variety of in-channel habitats for aquatic invertebrates and fish. There were fast and slow flowing areas at different depths in the main channel and there were still backwater pools with a variety of different sediments. Some channel edges were vegetated and others were either rocky, of different sediments, bedrock or of alluvial (sandy) sediments.

The reed/grass zone in the channel was well vegetated with a diverse mix of different reeds, sedges, grasses and recruiting trees and shrubs. The tree/shrub zone on the channel banks was densely vegetated with a diverse mix of different trees, shrubs and understorey species.

EFFORT: Surveying the cross-section is going to take a considerable effort. The channel is wide and well vegetated. The tree/shrub zone is particularly dense. It will be necessary to clear a line of sight through the reeds and the trees/shrubs on both banks to survey in the channel banks with the total station. It will be necessary to use an acoustic Doppler to survey in the channel bed and to measure discharge.

Sampling the riparian vegetation is going to take considerable effort because the reed/grass and tree/shrub zones are densely vegetated and rich in plant species.

Sampling invertebrates in a variety of habitats will be possible, taking all possible precautions against the presence of crocodiles.

Sampling fish with the electroschocker and with fyke nets will be possible, taking all possible precautions against the presence of crocodiles.

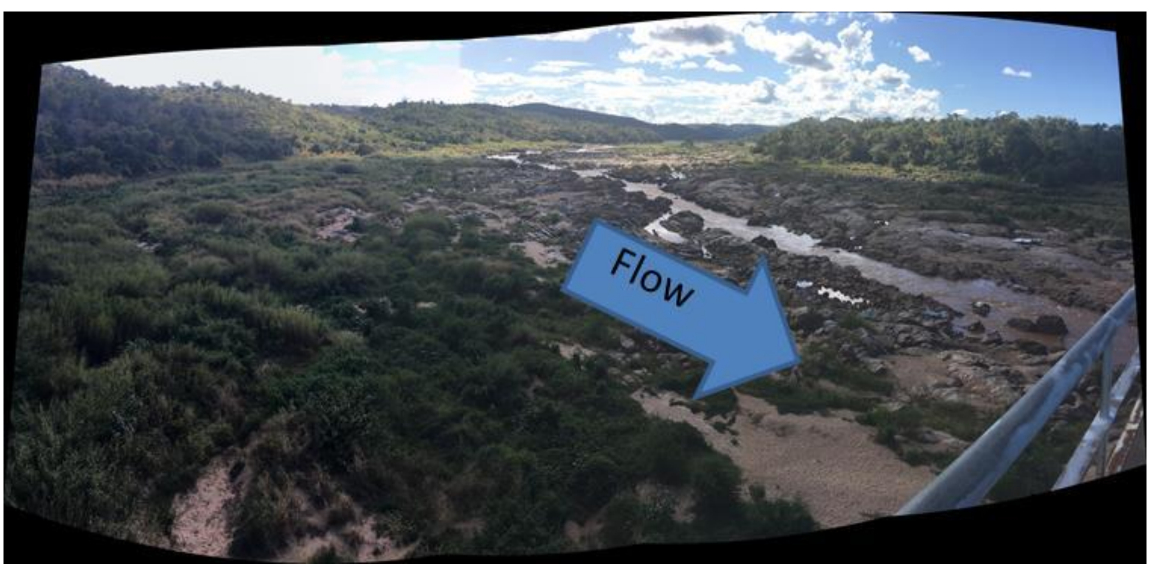

Figure 4.3 EFlows 3

4.6.4 EFlows 4

LOCATION: Casa Banana, Nhandugue River

COORDINATES: -18 º 29’ 33’’, 34º 23’ 59’’

DIRECTIONS: Drive South out from Gorongosa and take the dirt road from Gorongosa to Vunduzi, cross the Nhandugue River and turn right onto another dirt road that follows the Nhandugue River East to the village of Casa Banana.

ACCESS: Both banks of the river can be accessed via a path taken from the village to the river, a short flat 10-minute walk.

SAFETY: We were stopped by police once on the dirt road to Vunduzi. Safety is a concern as this is Renamo territory. **An ARA-Centro representative, accompanying letter and forewarning, would be required for this site.**

There is safe parking under trees at the village. There are apparently no crocodiles or hippopotami in the river here. The channel is wide, flat and the water shallow during low flow.

HABITAT: The macro-channel of the river is ~ 150 m wide and comprised a shallow run over a longitudinal distance of ~ 100 m. Flow at the time of the site visit was restricted to the main channel. There was no visible hydraulic control.

The water was clear and the channel bed comprised alluvial sand and small gravel.

The diversity of in channel habitats for invertebrates and fish was low. Flow was steady through a run over fine sediments.

There were *Phragmites* reeds on the channel edges and adjacent wide floodplain. There were trees and shrubs on the edges of the macro-channel some distance from the active channel.

EFFORT: Surveying the cross-section with a total station is going to take a considerable effort because of the great width of the floodplain and the height of the reeds. It is also going to be difficult to establish permanent bench marks as the channel bed and banks are sandy. It may be necessary to consider cutting a cross-section from an aerial image for this site.

Sampling the riparian vegetation is going to be relatively straight forward because of the low diversity of plants present.

Sampling invertebrates will be possible.

Sampling fish with the electro-shocker will be possible.

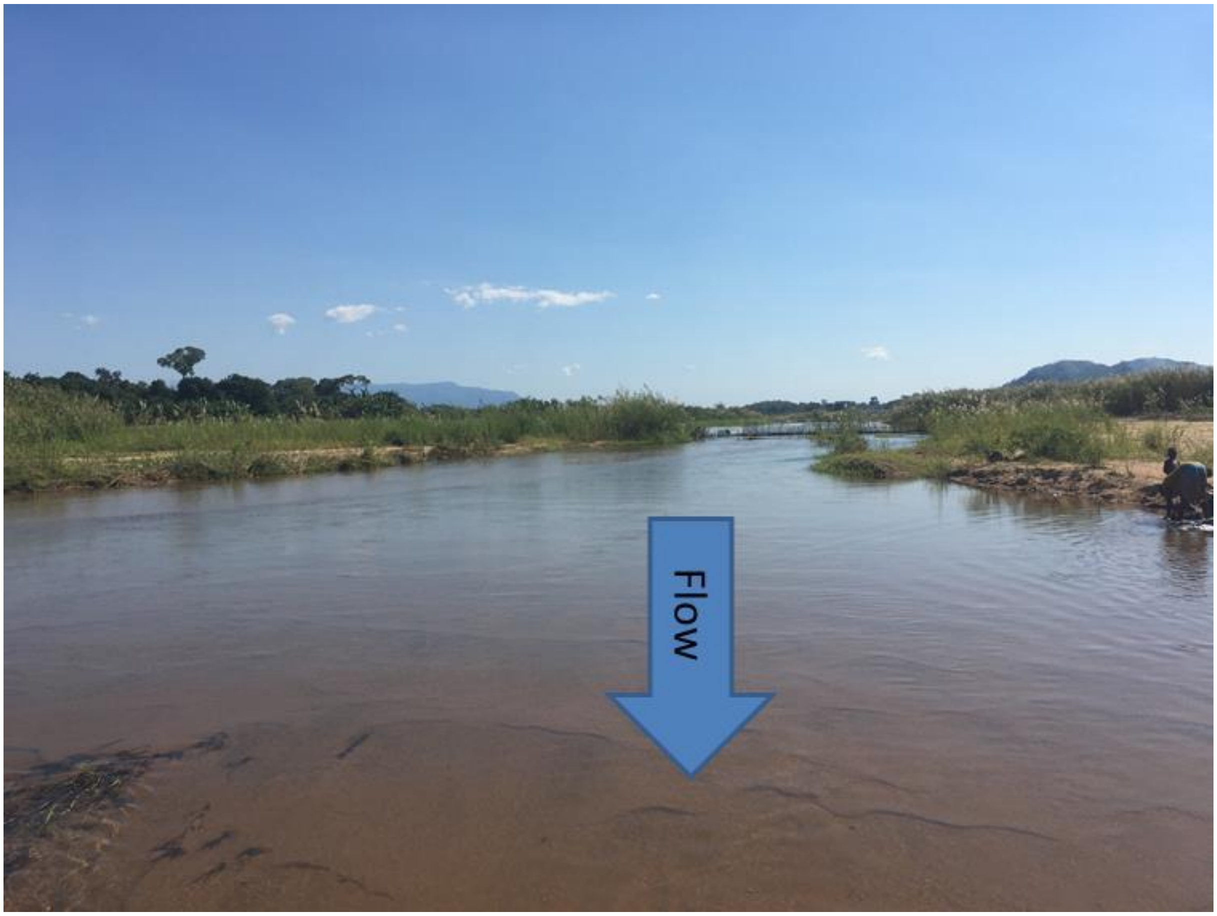

Figure 4.4 EFlows 4

4.7 SOCIO-ECONOMIC CONTEXT

Within each of the EFlows zones the socio-economic team undertook key informant interviews to get a better understanding of population characteristics and livelihoods, as well as commercial activities that are linked to water use. The information collected from this trip will be used to describe the socio-economic context in detail and to determine current value of the river system and the implication of changes in flow on local people and the economy. Here, a simple description of the interviews and the socio-economic context is provided for each site.

4.7.1 EFlows zone 1 and surrounds

In this zone agriculture is the main land use. Small-scale cultivation of bananas and sugarcane dominates with some commercial cultivation taking place in some areas. There is also commercial plantation forestry in this zone. The notable commercial crops are maize, sugarcane, avocados and macadamia nuts, all of which appeared to be irrigated. Small-scale farmers grow bananas, sugarcane and other vegetables such as yams, tomatoes and beans. The produce is transported in large bags to the main market in Harare where it is sold. Both men and women are involved in farming activities. There is a significant amount of cultivation adjacent to the river in the floodplain. The local communities living along the river do fish, but this is mainly during the high flow season when fish are more abundant and easier to catch. The fish caught during this time are sold whereas the few fish that are caught during the low flow season are usually kept for household consumption only. Both men and women are involved in fishing activities during the high flow season when they actively enter the water to "herd" the fish using nets and baskets. During the low flow season, it is mostly men that fish using rod and line. While reeds are not abundant along this stretch of river, there are still some dense pockets which the men harvest to make sleeping mats and baskets, both of which are sold. The river is also used for washing of clothes and bathing. The road through this zone is not a main highway and as such is not heavy with traffic or large trucks.

Women and children from the village of Mukupe, which is adjacent to the EFlows site, were interviewed while in this zone. The women were aged between 25 and 40 years and were washing clothes in the river when interviewed. They provided detailed descriptions and information pertaining to their farming activities, crops grown, quantities sold, input costs, transport costs, and prices of produce, as well as information on fishing and harvesting of reeds, types of fish commonly caught, prices, and amounts caught. The interview was of a high standard.

4.7.2 EFlows zone 2 and surrounds

The population in this zone is predominantly rural to peri-urban, relying heavily on agriculture as a main livelihood activity. There are some commercial maize and sugar fields in this zone which appeared to be pivot irrigated. There are a number of main highways that pass through this zone making it one of the more accessible areas in the basin. The accessibility has opened up opportunities for other activities, such as charcoal production and gold panning, both of which are environmentally damaging. Charcoal is produced on a larger scale in this zone and sold along the main through roads for transport to the larger towns and main cities. The gold is also sold at the markets in the larger settlements. Only men are involved in charcoal and gold panning activities. The people living in the village situated adjacent to the river are poor with few economic opportunities. The main livelihood activity is agriculture with a focus on staple crops such as maize and sorghum. Some vegetables are grown in the gardens that lie within the river floodplain. Both men and women are involved in agricultural activities, tending to fields and gardens. However, mostly men attend to the gardens in the floodplain due to the presence of crocodiles and hippos. The fields are cultivated mostly by hand with very little in the way of inputs. The gardens next to the river are irrigated using handheld buckets. However, these are very small and are mainly for household consumption. Some produce is sold at the local market or to the trucks and other vehicles that pass through or stop at the adjacent toll gate on the main road. Fishing used to be more important than it is today and is undertaken by men mostly during the high flow season when fish are easier to catch. The villagers reported the presence of large crocodiles which has restricted fishing activities. Reeds are harvested here by the men and used for making sleeping mats and baskets which are sold on the side of the road.

An elderly man (aged 60 years), a group of young men (18-35 years) and two women (30 and 70 years) were interviewed at this site. They provided detailed information about agricultural activities, fishing, gold panning, and harvesting of natural resources, as well as detailed accounts of how the river (in this zone) has changed over time.

4.7.3 EFlows zone 3 and surrounds

The people living in this part of the basin are rural and small-scale agriculture is the dominant livelihood activity with sesame, banana and sugar being the most abundant crops grown as well as the staples of maize and sorghum. In the village of Matenga-Pungwe livelihood activities are limited and people lead very simple lives. While agricultural activities are undertaken by both men, women and young girls, the gardens in the floodplain are attended to mostly by the women and girls. However, it appears that the decision making with regards to farming activities still lies with the men of the household. Fishing is an activity undertaken only by men during the high flow season and most of the fish is for household consumption or used to barter for other goods. Women wash clothes and bathe in the river. There was evidence of gold panning on the river by groups of men and some young boys. More young boys are getting involved in gold panning as it reportedly more profitable than fishing and agriculture.

At this site three young women (aged 18-25 years), a middle-aged man (40 years) and a young boy (12 years) were interviewed. They provided a detailed description of their livelihood activities (agriculture, fishing, gold panning). The interview with the young women was disjointed and difficult to follow due to language barriers.

4.7.4 EFlows zone 4 and surrounds

This zone is the most remote and rural of all the zones. Access to this part of the study area is difficult and as such it is somewhat removed and people here live a simple, subsistence lifestyle dominated by agriculture. Sesame, banana, maize and sorghum are important as well as other vegetables such as sweet potatoes and leafy greens which are grown in the gardens adjacent to the river (in the floodplain). As with the other sites visited, agricultural activities are undertaken by both men and women, as well as young girls. At this site it was reported that young girls leave school early to assist with harvesting and planting of crops, a decision made by the men of the household. Much of this zone and the villages found here fall within the conservation buffer area of Gorongosa National Park and as such are required to obey certain laws with regards to land use and the harvesting of natural resources. For example, only certain types of fishing are allowed (with rod and line) and fishing with fences is prohibited. Fishing is only undertaken by men. Also, charcoal production is prohibited and so is the opening (slash and burn) of new fields for cultivation. Villagers are allowed to use existing fields only. One of the main villages is known as Casa Banana and is one of the largest villages visited on this trip. Goats and chickens are kept by the households here.

At the two sites visited within this zone, a young man (28 years) and a group of men (fishermen and farmers aged between 20 and 60 years) were interviewed.

4.7.5 Estuary (including nearshore marine environment) and surrounds

Fishing is an important livelihood activity in the coastal city of Beira. The New Beach Market a popular place and the beach behind the market is the location of the fish landing site where fishermen return to Beira after the day at sea. These fishermen go out every single day for between 9 and 12 hours, leaving in the early hours of the morning and returning early afternoon. The fish are offloaded onto the beach from the boats and either taken to the market to be sold or sold directly from the beach. The smaller fish that are caught are usually dried and then sold. A large variety of fish are sold (different species, different sizes). Fishermen explained that fishing has become very difficult with lots of effort only yielding small returns. There are fewer fish than before and definitely not as many large fish to be caught. Most of the fishermen operate from the larger semi-industrial boats that are wooden with a motor and have a small crew.

At this site a number of fishermen and vendors (both male and female) were interviewed. The fishermen provided information about artisanal and semi-industrial fishing in Beira, including hours fished, type of fish caught, catch, prices, equipment used, and changes in effort and catch over time. The vendors provided information about prices and quantities of different types of fish and invertebrates being sold from both the estuary and near-shore environment.

4.8 FIELD ACCOMMODATION

Five venues were used as accommodation:

- Beira Terrace Hotel, Beira, +258 23 325 942.
- Hotel Kapulana, Gorongonza, +258 84 304 4429.
- Hotel Amirana, Chimoio, +258 25 123 334.
- Hotel Inter Chimoio, Chimoio, +258 84 433 6310
- Gordons Select B&B, Mutare, +263 20 67200.

4.8.1 Hotel Beira Terrace

Number of rooms:	>40
Price per room:	MT 4 950/night
Breakfast included:	Yes
Average price per meal:	MT 1500
Standard of food:	Good
Halaal?	Yes
Breakfast start time:	06:30
Packed lunches:	Did not request
Dinner start time:	18:00
Room size:	Large
Cleanliness, comfortability:	Very good
Hot water and pressure:	Good
Free wifi:	Yes, unlimited
Forex service:	Yes
Taxi transfer to Beira airport:	Yes.

4.8.2 Hotel Kapulana

Number of rooms:	21
Price per room:	MT 3 395/night
Breakfast included:	Yes
Average price per meal:	MT 800
Standard of food:	Good
Halaal?	No
Breakfast start time:	06:00
Packed lunches:	Yes
Dinner start time:	19:00
Room size:	Medium
Cleanliness, comfortability:	Very good
Hot water and pressure:	Good
Free wifi:	No
Forex service:	No.

4.8.3 Hotel Amirana

Number of rooms:	>30
Price per room:	MT 9 944/night
Breakfast included:	Yes
Average price per meal:	MT 800
Standard of food:	Good
Breakfast start time:	06:30
Packed lunches:	No
Dinner start time:	19:00
Room size:	Large
Cleanliness, comfortability:	Very good
Hot water and pressure:	Good
Free wifi:	Yes, limited
Forex service:	No.

4.8.4 Hotel Inter Chimoio

Number of rooms:	>30
Price per room:	US $ 100/night
Breakfast included:	Yes
Average price per meal:	N/A
Standard of food:	Good, based on breakfast
Breakfast start time:	07:00
Packed lunches:	Did not request
Dinner start time:	N/A

Room size:	Large
Cleanliness, comfortability:	Very good
Hot water and pressure:	Good
Free wifi:	Yes
Forex service:	Yes.

4.8.5 Gordons Select B&B

Number of rooms:	7
Price per room:	US $ 80/night
Breakfast included:	Yes
Average price per meal:	N/A (no restaurant)
Halaal?	No
Standard of food:	Good, based on breakfast
Breakfast start time:	06:45, upon request
Packed lunches:	Did not request
Dinner start time:	N/A
Room size:	Medium
Cleanliness, comfortability:	Very good
Hot water and pressure:	Good.
Free wifi:	Yes, unlimited
Forex service:	No.

5 SCOPING OF EXISTING DATA AND KNOWLEDGE

This section covers information currently available to the team, and identifies possible data gaps, data sources and effort required to access data. The team requires the latest long-term daily hydrological records (daily flow values > 30 years). For water quality, sediments and groundwater, similar long-term data sets would be ideal. If they are not available, an approximation will be developed based on whatever data are made available for use in the EFlows DSS. It is requested that the hydrological data used are consistent across related projects, e.g., flood hazard and vulnerability mapping, and the Southern African Development Community Groundwater Management Institute (SADC-GMI) project on the hydrogeology of the Buzi, Pungwe and Save basins.

5.1 SOCIO-ECONOMICS

5.1.1 Objectives

The main objectives of the socio-economic component of the study are to describe the socio-economic context and quantify the current value of the Pungwe River Basin and the way in which changes in the river, estuarine and marine systems may impact on people living in the basin. The modelling will entail estimating the relationship between key ecological and socio-economic indicators. The descriptions and modelling assumptions are based on first hand observations and information collected from key informant interviews undertaken on the reconnaissance trip, as well as available information downloaded from online sources and collated from relevant government departments. The socio-economic study focuses on the EFlows zones, including the estuary and the nearshore marine environment.

5.1.2 Population and socio-economic status

Administratively, the Pungwe River Basin covers part of the Mutasa and Nyanga districts in Manicaland province in Zimbabwe, and large parts of Sofala and Manica provinces in Mozambique (12 districts). The population of the Pungwe River Basin is ~2.34 million persons, with ~2.24 million (96%) in Mozambique (WorldPop 2020). The split between males and females is similar across the two countries, with just under 52% of the population recorded as female (51.9% in Zimbabwe, 51.7% in Mozambique). The mean population density for the basin is ~59 persons per km^2 (Figure 5.1), and is slightly higher in Mozambique (59.2 persons/km^2) than in Zimbabwe (52.2 persons/km^2).

Settlements in the basin consist predominantly of scattered rural village communities with a few larger urban centres. The central northern parts of the Basin are generally sparsely populated, with higher population densities in the lower eastern parts. Most of the urban centres are located on the N1, N6 and N7 roads that cross the basin, connecting southern and northern Mozambique, and Mozambique to Zimbabwe. Along these roads there are a series of trading centres and towns, and ribbon development along much of the main N6 highway that connects the port city of Beira in Mozambique with the city of Mutare in Zimbabwe (Figure 5.1). Beira is the largest urban industrial centre in the basin. Other notable towns in Mozambique are Chimoio, Inchope and Gorongosa.

Poverty levels are high across much of the Basin, especially in the more remote areas in Mozambique where economic activities are limited and where inequalities exist; with the allocation and use of land and water favouring men over women (SWECO 2004). This was particularly noticeable in the rural village communities surrounding Gorongosa National Park. The levels of education are relatively low in the rural parts of the Basin in Mozambique with the more remote areas being particularly poorly served in terms of formal education. By comparison, the majority of the population residing in the Zimbabwean part of the basin has a formal education.

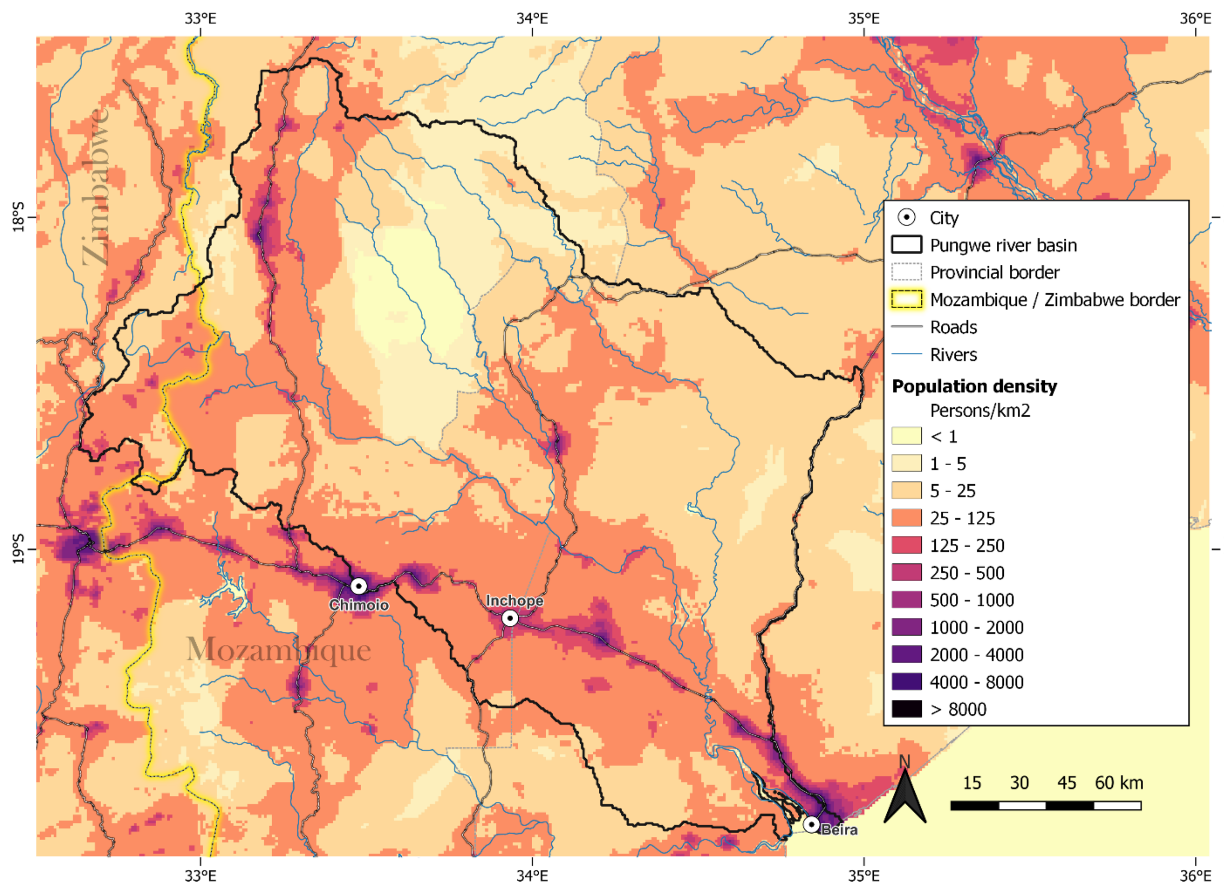

Figure 5.1 Population density (persons/km^2) across the Pungwe River Basin (WorldPop 2020)

Across the Basin, people harvest wild plant and animal resources for nutrition, health, energy and raw materials, particularly where other economic opportunities are limited. Resources are harvested predominantly by poorer households on a subsistence basis or to generate small cash incomes. The use of traditional building materials is prevalent in the Basin and most structures in the rural areas are made from mud, poles, reeds and thatching grasses. These resources tend to be harvested by men. Modern building materials appear more prevalent in the Zimbabwean portion of the catchment, in the main urban centres and in some of the smaller towns where houses are also constructed with brick or cement and with iron sheets for roofing. In keeping with most of rural sub-Saharan Africa, firewood is the dominant source of cooking energy in the Basin, mostly collected by women. However, there is a growing demand for charcoal, which is a major source of cooking energy in the urban centres. The production of charcoal is undertaken by men and young boys. Reeds and papyrus are important plant resources commonly harvested by men and used to make sleeping mats, fences and baskets. Sleeping mats and fences are usually made by the men and the baskets are made by the women. These are used by the household but are also sold or bartered. While households do harvest wild foods and medicines for health and nutrition benefits, information on the collection and use of such resources is limited.

Most households in the basin rely on boreholes or shallow wells for their drinking water. However, in the remote rural areas of the basin, there are a number of villages that rely solely on the water collected from rivers and streams. In some households, female household members travel long distances to fetch water, especially in the dry season. In Zimbabwe, there are some small piped water supply schemes, but individual house connections and treated water supplies remain poorly developed across the Basin. Rivers and streams are also used for washing clothes and for bathing (Figure 5.2). Sanitation is poor, with most households in the Basin lacking adequate sanitation facilities. Traditional pit latrines are used in the rural villages and in some urban centres. In the larger cities, such as Beira and Hauna, water-based systems have been developed.

Figure 5.2 Women from the village of Mukupe, Zimbabwe washing clothes in the Pungwe River

5.1.3 Livelihood activities

Economic activities in the Pungwe River Basin continue to be largely based on agricultural production, fishing and the use of forestry and wildlife resources, as reported in 2004 (see SWECO 2004). Ecotourism is important for some communities that border the Nyanga National Park in Zimbabwe and Gorongosa National Park in Mozambique. The resurgence of Gorongosa National Park and associated tourism has the potential to stimulate significant economic development in the basin. However, particularly in Mozambique, tourism remains limited due to issues around safety, access and appropriate infrastructure.

Agriculture is a mixture of dryland subsistence and irrigated crop farming. Smallholder (or subsistence) farmers[4] dominate the landscape across most of the basin. Smallholder farmers living in close proximity to rivers tend to keep dryland fields as well as floodplain gardens which they plant during the low flow season. Both men and women, as well as young girls, are involved in farming. Throughout the Basin, maize is the dominant staple crop and appears to be grown by the majority of households who engage in crop production. Other important crops include sorghum, sugarcane, sesame, tomatoes, beans, sweet potatoes, yams and green leafy vegetables.

In the upper Basin in Zimbabwe agriculture is relatively intensive with smallholder farms on communal lands, and large-scale commercial farms and forestry plantations. The smallholder farms focus on banana and sugarcane, with some horticultural produce such as tomatoes, yams and beans also grown. Smallholder farmers, both men and women, transport and sell their produce at markets in Harare. Commercial farms produce coffee and tea, as well as high value crops such macadamia nuts and avocado pears being more recently cultivated in the study area (Figure 5.3).

Figure 5.3 Recently planted macadamia nut trees on a commercial farm in the Honde Valley, Zimbabwe which

[4] These farmers comprise a continuum between subsistence production and crop production for market.

was previously Katiyo Tea Estate.

The middle parts of the Basin in Mozambique are relatively undeveloped and sparsely populated. However, in sections along the main N6 and N7 roads in Manica Province, there is large-scale irrigated commercial farming. Maize and horticultural products appear to be the main crops being cultivated here. Smallholder farms in the middle and lower basin in Mozambique produce mainly maize, sesame and sorghum with some vegetables grown in small gardens on the river channels. Large scale commercial sugarcane farms are situated in the lower basin in the floodplain areas that surround the estuary. Among households which keep ruminant livestock, goats appear to be the most abundant type, especially in Mozambique where communities in the central and western parts of the basin report that cattle are rarely kept due to Tsetse fly disease and theft. Some cattle are kept in the upper basin in Zimbabwe. Generally, men are responsible for rearing livestock.

Fishing is a dominant activity throughout the Basin from the rich coastal waters off Beira to the estuary and on the main Pungwe River and its tributaries. Fishing is undertaken predominantly by men. However, women might be involved in the processing and sale of the fish at markets. In Beira, there are industrial, semi-industrial and artisanal fishermen who operate offshore and, in the estuary, catching a wide variety of fish, prawns, squid and other shellfish such as clams (Figure 5.4). Inland fishing is an important source of protein for households as well as for household income. Fishing is more productive during the high flow season.

Figure 5.4 A wide variety of fish are sold on the beach at Mercado Praia Nova in Beira

Alternative livelihood activities in the basin include gold panning, firewood harvesting and charcoal production, all of which are major contributors to environmental degradation and erosion. Gold panning and charcoal production are undertaken by men and young boys. Poverty is a key driver of these destructive activities, which are viewed as additional or alternative income sources by local residents, and for some are significant. The other key driver is the growing demand for charcoal and building materials from urban markets (Figure 5.5).

Figure 5.5 Charcoal is sold along most of the main roads in Mozambique and is transported to the urban centres where it is the main cooking fuel.

5.2 HYDROLOGY AND WATER-RESOURCE MODELLING

Several hydrological studies have been undertaken in the Pungwe River Basin. The most relevant of these are:

- Assessing water resources availability in headwater sub-catchments of the Pungwe River Basin in a changing climate (Gumbo 2021):
    - Based on Pitman Monthly Model calibrations at 10 flow gauging stations
    - Uses several downscaled climate change models to quantify future changes in water resources
    - Applied deltas to historical rainfall derived from differences between the control and scenario rainfall
    - Model period from 1951 to 2016
    - Although there is useful data in the report, the model is not useful as it was only configured for the headwaters.
- Hydrological analysis and modelling of the Pungwe River Basin, Mozambique (Terink 2014):
    - This model uses the SWAT (Soil and Water Assessment Tool) hydrological model to simulate daily flows. Note that SWAT is designed to predict the impact of management decisions on water, sediment and water quality. The purpose was to evaluate the effect of irrigation development on down-stream water resources
    - This study undertook a comparison of daily rainfall and evaporation sources (Global

Summary of the Day (GSOD), ARA Central measurements, and the satellite-based products FEWS (Famine Early Warning System) and TRMM (Tropical Rainfall Measuring Mission)
  - Focused on modelling period 2001 -2010, with calibration undertaken at four flow gauging stations. The model is therefore not suitable due to the short model period
  - Useful data is available from the report, i.e. Mean Annual Precipitation (MAP), Mean Annual Evaporation (MAE), water-use and flow gauge reliability
- Assessment of climate change impact on water resources of the Pungwe Basin (Losjö et al. 2006; Andersson 2011):
  - Uses HBV (Hydrologiska Byråns Vattenbalansavdelning) hydrological model which is a simple hydrological "bucket" model
  - Focus on climate change not hydrology so will not be used
- Integrated Water Resources Management. Case Study: Pungwe River Basin in Mozambique (SWECO 2008):
  - Uses indicators to identify importance of various sectors associated with water resources
  - Can provide useful background information
- Hydrology of the Lake Urema wetland (McCartney and Owen 2007). A descriptive report with some useful information.
- A Monograph of the Pungwe River Basin (Governments of the Republics of Mozambique and Zimbabwe 2006). A descriptive report with useful information on water-use and hydrological statistics.
- Development of the Pungwe River Basin Joint Integrated Water Resources Management Strategy (IWRMS) (SWECO 2004):
  - Data accumulated using the period 1960-1980
  - Descriptive with useful statistics such as water-use, MAP, MAE, MAR.

Several of the above-mentioned reports have been obtained and provide useful input data to the Pitman Model (see Section 8.2.4) for preparation of baseline hydrology. The SWAT Model (Terink 2014) was configured for the entire Pungwe Basin but only modelled a short period (2001-2010) and will not be useful. Neither will the recent study (Gumbo 2021) as this was only configured for the upper Pungwe sub-catchments. No existing hydrological models will therefore be used in this study.

5.3 ECOHYDRAULIC AND HYDRODYNAMIC MODELLING

5.3.1 River sites

No existing river ecohydraulic models could be sourced for the Pungwe Basin, and so the site based modelling will be developed from scratch in this project. Topographical and hydraulic surveys will be undertaken at each EFlows site, in accordance with best international practices. Discharges will be computed using the velocity-area method and use of suitable instrumentation for a wadeable channel / boat access. The required data will be collected at river EFlows sites during river surveys. Where EFlows sites are located near hydrometric gauging stations, attempts will be made to survey and correlate recent high-flow/flood levels with gauged discharges, augmenting the rating (or stage-discharge) field dataset.

From an EFlows assessment perspective, the relevant outputs from the hydraulic modelling are rating relationships for the cross-sections at EFlows sites. These, together with surveyed cross-section geometry and sediment size classes, are used to produce text tables for import and use in the DRIFT DSS. An ecohydraulics computational model such as HABFLO (Habitat Flow simulation model; Birkhead 2010) will be used to develop hydraulic text tables for selected cross-sections at the EFlows sites. Additional information in Section 8.2.

5.3.2 Estuarine and near-shore zones

The main objectives of the estuarine and near-shore hydrodynamic modelling are to quantify, to the extent possible, the distributions of salinity, turbidity and nutrients in the Pungwe Estuary and the near shore environment under prevailing freshwater flow conditions and potential future flows scenarios.

5.3.2.1 Estuary

Several analytical (e.g., Graas and Savenije 2008; Abas and Hagedooren 2017) and numerical modelling (Nzualo *et al.* 2018) studies for the Pungwe Estuary have been undertaken. Although most of these focussed on the relationship between river flow and the extent of upstream penetration of saline waters, they provide guidance in the set-up of the hydrodynamic model for this study and, provided the raw data can bet accessed, a source of calibration and validation data.

Graas and Savenije (2008) used a steady-state model to investigate the upstream penetration of saline waters and the consequences of abstraction of water from the estuary. An important finding was that sand banks in the middle zone of the estuary prevented the saline waters from penetrating further upstream, which meant that the actual salinity levels in the upper reaches of the estuary were lower than those initially predicted by the model. This effect occurs during the ebb of neap and average tides and can reduce the extent of upstream intrusion of saline waters by ~10 km.

Abas and Hagedooren (2017) used both a steady-state and a non-steady state model, based on the cross-section data in Figure 5.6. They estimated the upstream penetration of saline waters as ~78 km upstream from the mouth of the Pungwe Estuary for a river discharge of 16 m^3/s, which is a representative value during a dry season with a return period of five years, and combined abstraction rates of 7 m^3/s, which resulted in a discharge of 9 m^3/s in the river downstream of the intake. This was less conservative than measured field data for this study, which showed a salt intrusion length of 71 km for a river discharge of 32 m^3/s and an extraction of 4 m^3/s, i.e., 28 m^3/s downstream.

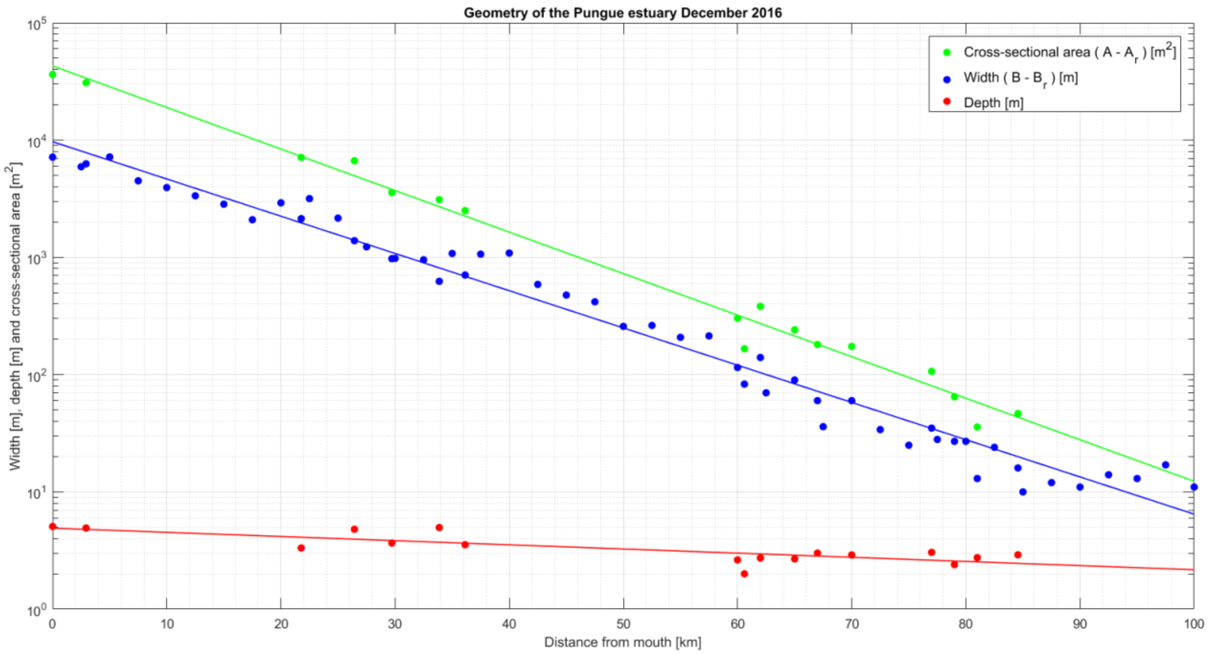

Figure 5.6 River widths, depths and cross-sectional areas used in the models of Abas and Hagedooren (2017)

Abas and Hagedooren (2017) also investigated scenarios of changing river discharge (drought) and/or abstraction rates and the consequences of bend cut-offs in the estuary. Several mitigation measures were proposed to minimise the intake of unacceptably saline waters, including relocation of intakes further upstream and/or variable pumping operations. They also identified potential sources of saline waters upstream of the intakes that that may need to be considered in the hydrodynamic modelling for the EFlows study (Figure 5.7 and Figure 5.8).

In the EFlows study, a more detailed 2DH hydrodynamic model is being set-up to better characterise the tidal flows characteristics and their influence on the bed morphology of the estuary mouth region. These model results indicate tidal duration asymmetry (time difference between rising and falling tide) and tidal velocity asymmetry (unequal magnitudes of flood and ebb peaks currents), which do not appear to be significantly affected by river discharge. The observed fortnightly inversion in the tidal duration asymmetry can be explained by the presence of channels and sandbanks, with the tidal velocity asymmetry acting as a positive feedback mechanism for bank formation and sediment retention.

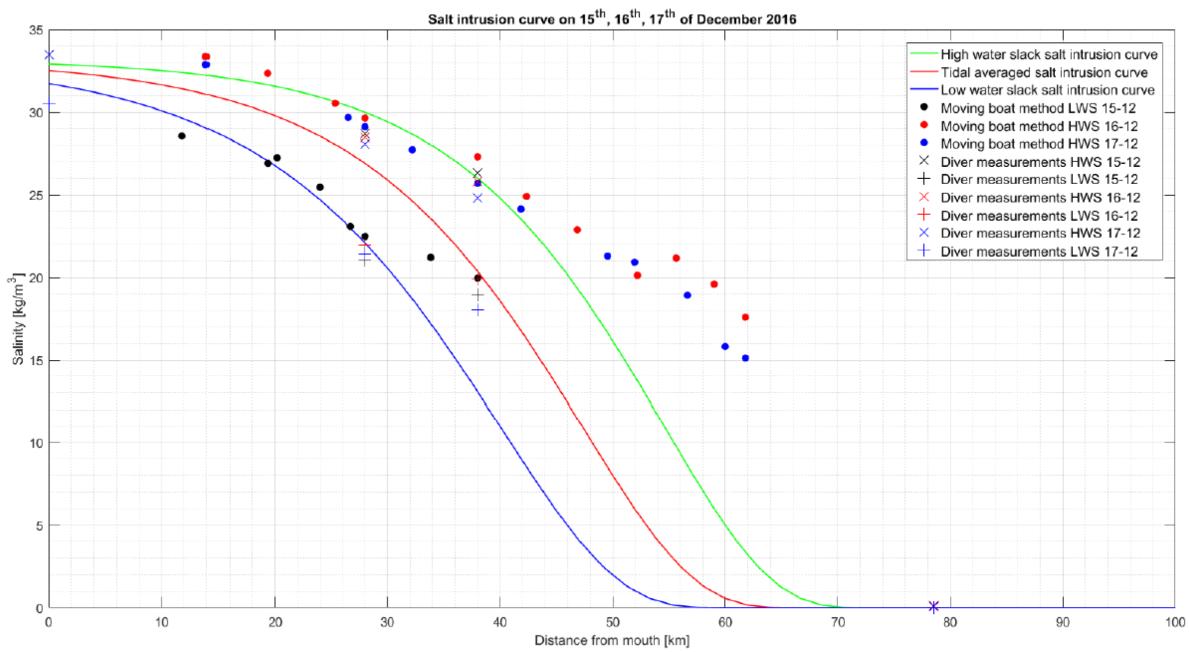

Figure 5.7 Steady state simulation and moving-boat measurements on the 15th, 16th and 17th of December 2016 (Abas and Hagedooren 2017)

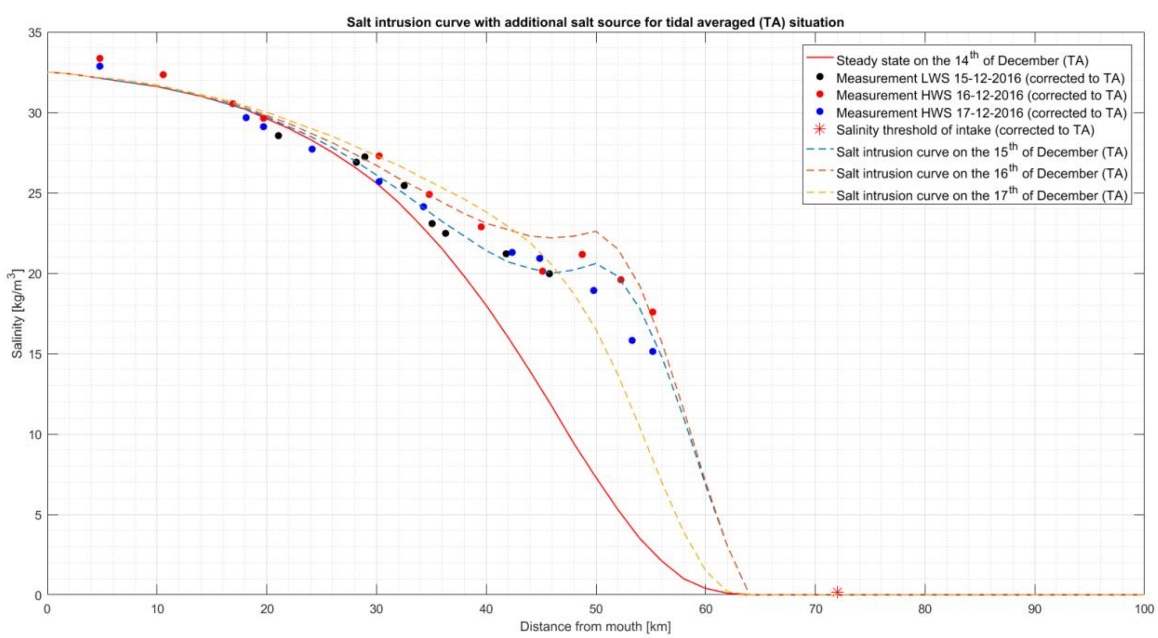

Figure 5.8 Unsteady-state model including an additional salt source (Abas and Hagedooren 2017)

5.3.2.2 Near-shore marine

The dynamics of the Sofala Banks have been the subject of several studies, including tidal dynamics (Chevane *et al.* 2016), wind-driven dynamics (Nehama and Reason 2021) and the influence of large-scale offshore flows on the shelf areas (Roberts *et al.* 2014; Malauene *et al.* 2018). Of particular relevance to the EFlows assessment are the evolution of river plumes for various river discharges onto the shelf (Siddorn *et al.* 2001, Nehame 2012, Nahame and Reason 2015a, b). Given the large-influence of the offshore plume of the Zambezi River, it is likely to be difficult to isolate the influence of Pungwe River plume on the local coastal and shelf ecology. Consequently, it is envisaged that the hydrodynamic model will focus mainly on local tidal and wind-driven dynamics of freshwater plumes from the Pungwe River onto the adjacent shelf (Figure 5.9).

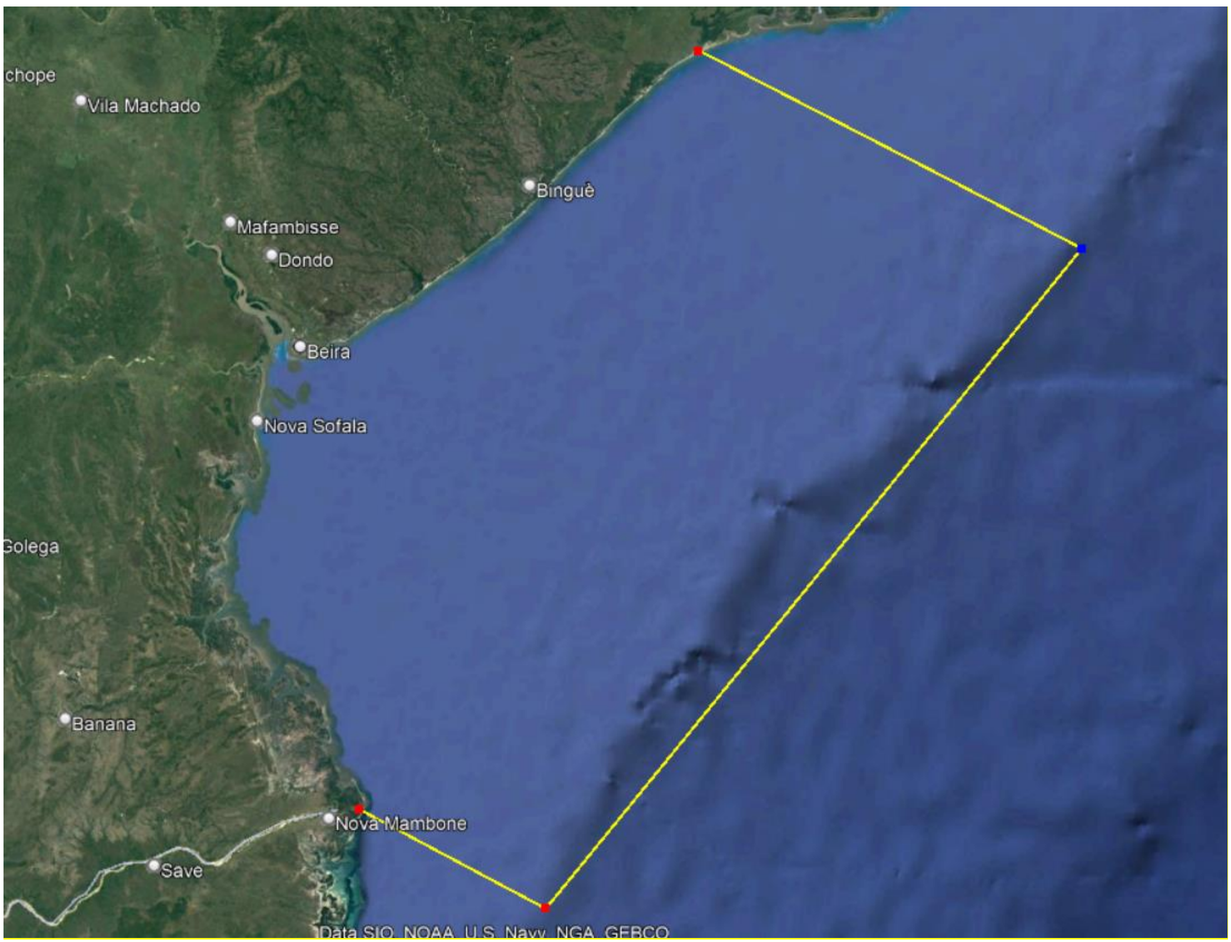

Figure 5.9 Indicative proposed model domain for the offshore river plume simulations

The results of previous hydrodynamic studies indicate that importance of the bathymetry used in the any hydrodynamic model, as are the water level imposed at the offshore boundary and the freshwater inflows at the upstream boundaries. Thus, it is important that the data used in the set-up and forcing of the hydrodynamic model for the EFlows study are adequate in this regard. Similarly, the data required to calibrate and validate the hydrodynamic model are important; these are expected to include water levels and salinity distributions along the length of the estuary (and possibly also velocity at locations within the estuary), and ideally wave and current timeseries over the adjacent shelf region should these be available.

The full suite of data required includes:

- Bathymetry data for both the estuary and adjacent shelf, data which should be available from recent initiatives to set-up such a bathymetry data base in the region (Hoggarth *et al.* 2012) as well as past and more bathymetry survey (and charts) by INIHINA (INAHINA 2021). If possible such data needs to be supplemented by limited field measurements, DEM data, where available, and similar measurements from other studies in the region (e.g., Graas and Savinije 2008; Abas and Hagedooren 2017; Delft TU and Deltares)
- River runoff, comprising both monthly data (for at least 30 years at E67 (possibly E66) or at nearby river gauge stations that possibly could be obtained at Ara-Sul) and daily flow data from measurements of modelling studies to inform model scenarios
- Tidal water level data (see Table 5.7). Ideally tidal water levels should be measured if salinity data are collected during project specific field surveys. Ideally water levels should be measured for 15 days, however more realistic is likely to by a full tidal cycle over one or two days
- CTD or similar data both in the estuary and in the offshore region. Such data, in principle, are available from previous studies (Graas and Savinije 2008; Abas and Hagedooren 2017; Table 4.3. If possible additional salinity and other water quality data should be measured during the field trip
- Suspended solids data has been collected primarily at stations near the estuary mouth, but also at upstream locations. There might be historical data available (du Preez *et al.* 2010)
- Current data should be measured during the field trip if at all possible
- Representative meteorological data (possibly required for estimated evaporative fluxes, etc.).

The available data and likely data sources (contact persons) are summarised in Table 5.7. A major challenge is that, to be useful for the calibration and validation of the hydrodynamic model, water level, current, salinity and flow data should be measured concurrently. At this stage, it is not known whether this is the case or not. Should it not be the case, it will significantly complicate the calibration and validation of the model.

In summary, the purpose of the modelling is to inform the EFlows studies at two primary scales, viz. the estuary (and mangrove) scale, and; the adjacent shelf environment at scales that will be able to inform the effects of catchment flows on coastal and marine ecosystems. It is envisaged that two models will be required to efficiently simulate existing and future flow scenarios at these two vastly different scales.

5.4 RIVER ECOSYSTEM

The main drivers of river ecosystem condition are hydrology, hydraulics, sediment and water quality. Thereafter, geomorphology and fish ecology are arguably the most important disciplines in an EFlows assessment because the first provides information on how the habitat template is likely to respond to changes in the main drivers and responses of the second reflect an integration of most disciplines used in

EFlows (*viz*. hydrology (habitat and life history cues), hydraulics (habitat and life history cues), water quality (habitat and life history cues), geomorphology (habitat), vegetation (habitat and/or food) and invertebrates (food)).

Overviews of the disciplines of geomorphology, water quality, vegetation, macroinvertebrates and fish are provided in Sections 5.4.1 to 5.4.5.

5.4.1 Geomorphology

The Pungwe River rises in the Eastern Highlands of Zimbabwe at around 2 165 masl. The longitudinal profile and demarcated macroreaches are shown in Figure 5.10. The headwaters of the Pungwe are deeply incised into granite with local dolerite dykes. Further downstream the river flows over gneiss of the basement complex before crossing the Holocene alluvium of Urema Rift. The lower Pungwe River is confined on the left bank by sandstones of the Cheringoma Plateau. Further details of the geology can be found in the report by the Governments of Mozambique and Zimbabwe (2006), Steinbruch (2010) and Scoon (2016).

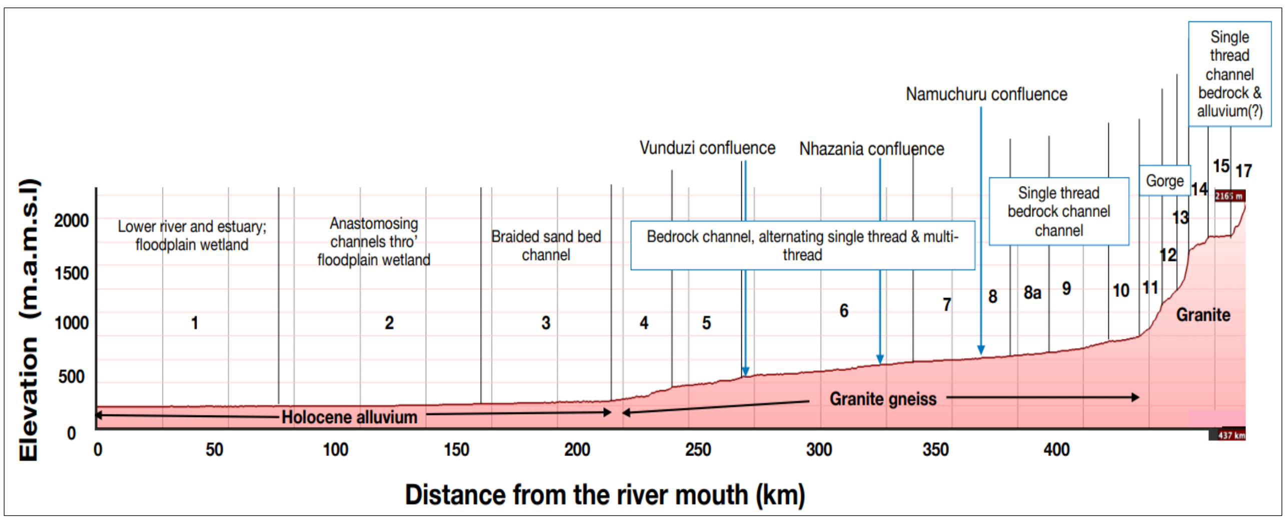

Figure 5.10 Longitudinal profile of the Pungwe River

Chitikira and Nyikadza (2020) present data on sediment loads for the Pungwe River for hydrological gauging station F22. The source of presented data is given as the Zimbabwe National Water Authority (ZINWA) Sediment Load Database. Annual loads are presented for the eight hydrological years 2001/02 to 2012/13. Loads were generally between 12 000 and 37 000 tonnes with an exceptionally low load of 1 352 tonnes in 2006/07 and two extremely high loads exceeding 118 000 tonnes in 2003/04 and 2005/06. There was no relationship to annual runoff and shorter-term storm characteristics probably caused the extremes. It would be useful to follow up the data source used as this could provide details of sub-annual load variation.

The longitudinal profile of the Nhandugue River, i.e. EFlows Zone 4, is shown in Figure 5.11.. Five macro reaches are identified. The river is considerably shorter than the Pungwe River and lacks the elevated headwaters. No further information is available at present.

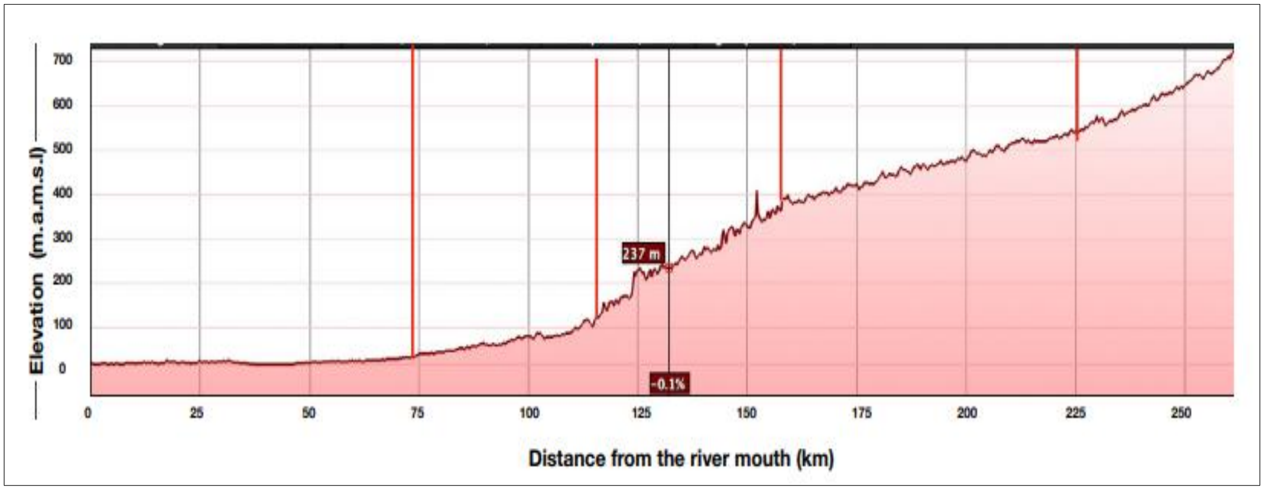

Figure 5.11 Longitudinal profile (unsmoothed) of the Nhandugue River. Red lines indicate macroreach breaks.

5.4.2 Water quality

Information shown below is taken from the Pungwe Monograph prepared by the Governments of the Republics of Mozambique and Zimbabwe (2006). The main sources of pollution are as follows:

- Rural and urban settlements
- Agriculture
- Afforestation
- Artisanal and Small-scale Gold Mining (ASGM)
- Saltwater intrusion (natural, but exacerbated by water abstraction during low flow).

The headwaters of the Pungwe in Zimbabwe are near pristine as human settlement is forbidden in the Nyanga National Park, where the river rises, and the water at EFlows Site 1 (Figure 5.12) is clear water, despite settlements, villages and extensive cultivation in the Honde Valley.

Figure 5.12 The Pungwe River in EFlows Zone 1 in Zimbabwe

However, the situation changes dramatically by EFlows Site 2, which is just downstream of the Nyamukwarara River, a tributary in Mozambique, where there is extensive ASGM in the river, which releases large quantities of sediment. The reconnaissance survey of June 2022 verified the input of sediments from this system into the Pungwe at EFlows Site 2 (Figure 5.13). In addition to formal mining, there also appears to be a significant increase in informal gold mining activities, with the impact spreading from Manica Province as far downstream as the Muda River in Sofala Province. Figure 5.14 shows the sites of informal and official gold mining sites in 2006 (Dondeyne *et al.* 2009).

Figure 5.13 The Pungwe River at EFlows Zone 2 in Mozambique

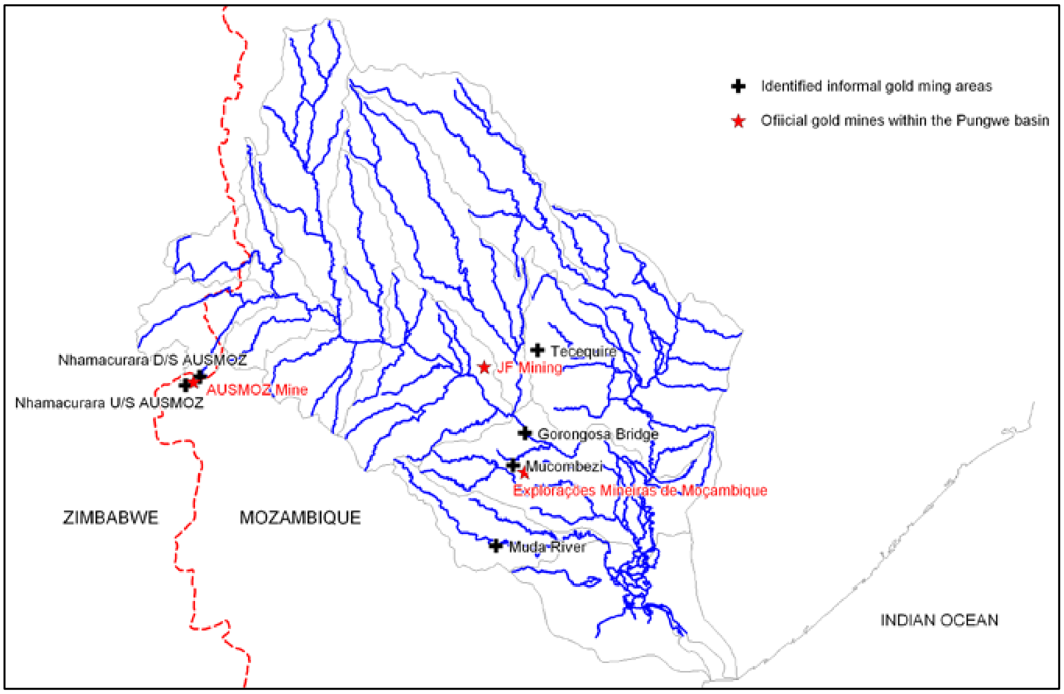

Figure 5.14 Gold mining sites in Mozambique (Governments of the Republics of Mozambique and Zimbabwe 2006)

In 2006, ASGM was seen as the only serious source of pollution in the Pungwe Basin (Governments of the Republics of Mozambique and Zimbabwe 2006). Reports prepared in 2018 and 2020 (SIDA 2018; 2020) showed deterioration in water quality in the Basin. Initially water quality issues were identified due to pollutants from mercury and suspended sediments from artisanal gold panning, but ten large companies conducting gold mining in the basin were identified in 2018, further aggravating pollution.

Mercury (Hg) is used in ASGM because it simplifies the process of gold recovery at a low cost. An estimated six tons of Hg are used annually by illegal gold mining in Zimbabwe. ASGM releases Hg in two forms, Hg vapour and metallic Hg. Both forms affect aquatic habitats and enter the food web, although the impacts on the Pungwe River are unknown at present.

ASGM also significantly increases sediment loads in the water column, as a result of Intensive and direct panning activities in the riverbed, unintentional release of tailings into waterways through erosion and runoff, dumping of tailings directly into the river, diversion of river and stream courses to allow access to mineralized alluvial gravel deposits on the existing riverbed, trenching paleo-channels and floodplains increasing connectivity and sedimentation into the channel and washing stockpiles of abandoned gold mines in the river.

The negative impacts of ASGM on water quality are numerous (Mujere and Isidro 2015):

- Reduced grazing, ground cover and biodiversity
- Increased release of toxic heavy metals, especially Hg, sodium of cyanide, silver and arsenic
- Direct dumping of tailings and effluents into the river
- Damage in alluvial areas and degradation of riverbanks, riparian zones and water source areas
- Increased river siltation and turbidity, which consists mainly of reddish-brown silt and clay, with a negligible proportion of sand. The fine sized sediment particles remain in suspension, exhibiting a red (ochre) colour
- Stripping of the vegetation cover and catchment degradation due to deforestation, erosion and loss of ecosystem function
- Local and downstream users affected. The suspended sediments render the water unsuitable for drinking, washing and irrigation
- Suspended sediments coat habitats and block the penetration of light into the water, thus reducing the efficiency of photosynthesis. Aquatic biota that are sensitive to sediment-laden waters are adversely affected.

For the downstream Basin, surrounding land-use and sanitation practices also play a major role on the water quality. Land-use is primarily:

- Rural domestic consumers through piped schemes and undeveloped abstraction facilities
- Urban domestic and industrial consumers of Beira/Dondo and Mutare cities
- Small and large-scale irrigators
- Forestry.

5.4.2.1 Water quality monitoring

ARA-Centro, the Regional Water Administration of Central Mozambique, is responsible for the strategic monitoring network, and collects:

- pH
- temperature
- electrical conductivity
- dissolved oxygen
- turbidity (used for indirectly calculation of total suspended solids).

According to the Pungwe bilateral agreement ARA-Centro should be monitoring at least an additional 12 parameters on a regular basis:

- Alkalinity
- Biological Oxygen Demand
- Chemical Oxygen Demand
- Chloride
- Coliforms
- Electrical Conductivity
- Nitrate
- Nitrite
- Phosphates
- Sodium
- Sulphates
- Total Dissolved Solids.

Data are currently being sourced from ARA-Centro.

Water quality data may also be available from studies done in GNP, specifically the 2007 long-term planning for hydrological research (Beilfuss *et al.* 2008). The intention was for the water quality network, closely linked to the hydrometric network, to provide spatial and temporal data for evaluating changes in water quality associated with soil erosion, gold mining and agrochemical applications in the catchment in particular. These data have been requested from GNP.

5.4.3 Riverine vegetation

An extensive Google Scholar search for data and literature about the riverine vegetation of the Pungwe River revealed one short description of two different woodland communities: riverine forest in Zimbabwe and riverine thicket in Mozambique (SWECO 2004). All the other descriptions of vegetation of the Pungwe River Basin found were for terrestrial plant communities, a situation commonly encountered when searching for riverine plant studies on African rivers. Mr Tongai Castigo, formerly a botanist at Gorongonza National Park, stated he did not know of one single study of riverine vegetation. Thus there are currently no data on riverine vegetation of the river in hand. Data will be collected during the data collection field trip in August 2022.

A list of riverine vegetation expected to occur along the river has therefore been compiled from multiple sources, including those from other sub-Saharan rivers in Zimbabwe and Mozambique (Table 5.1).

Table 5.1 Plant species expected to occur in the riverine vegetation communities

Community	Species	Reference
Riverine Forest on channel banks, Zimbabwe	*Newtonia buchananii, Trichelia emetica, Khaya anthotheca* and *Albizia adianthifolia, Breonadia salicinia.*	SWECO (2004)
Riverine Thicket on channel banks, Mozambique	*Ficus sycamorus, Diospyros mespiliformis, Mimusops fruticose, Trichelia emetica, Eckebergia capensis, Khaya nyasica, Kigelia africana, Bombax rhodognaphalon, Cordyla africana, Cordia goetzie, Diospyros senensis, Erythroxylum emarginatum, Lecaniodiscus fraxifolius and Oncoba spinosa.*	SWECO (2004)
Generic Riverine plants on in-channel alluvial deposits	*Faidherbia albida*	Bohme (2005), Timberlake (2000a, b)
	Typha latifolia, Phragmites mauritianus, Panicum maximum, Sesbania sesban, Ficus capreifolia,	Cunliffe (2002)

5.4.4 Freshwater macroinvertebrates

Macroinvertebrates play a key role in the ecological functioning of rivers through processing organic matter, either by breaking down detritus or grazing algal biofilms. Macroinvertebrates are in turn food for fish and birds and are therefore important in the transport of energy along the stream channel both longitudinally and laterally into both floodplain and terrestrial habitats (Boulton and Lake 2008).

Macroinvertebrates of the Pungwe Basin and their adaptations to the flow regime are largely unstudied, particularly within Mozambique. While not specific to understanding macroinvertebrates in the Pungwe River per se, Kadye *et al.* (2013) investigated the impact of non-native rainbow trout on ecosystems of streams of the Eastern Highlands of Zimbabwe. Their study compared macroinvertebrate community responses to the presence of trout and catfish, thus providing a list of macroinvertebrates of the several mountain streams of the Nyanga mountains, including the source of the Pungwe River. Of particular interest, Kadye *et al.* (2013) provide a quantified account of the substratum composition their study sites, together with mean depth and velocity thus describing the physical habitat characteristics of rivers that support these aquatic biotas.

The macroinvertebrate species list provided by Kadye *et al.* (2013) indicates a higher diversity of data during September (a total of 14 species recorded), comparted with June, when only six species were recorded. Species recorded belonged to the Ephemeroptera, Trichoptera, Odonata and Diptera. These data are representative of the community found in experimental cages open to fish predation (indicative of the status quo), situated on a pebble substrate at a depth of 0.2-0.5 m. Thus, it is likely that this species list is only a subset of that present in all habitat types throughout the upper reaches of the Pungwe River.

In 2013, Black Crystal Consulting undertook an Environmental Impact Assessment (EIA) of a proposed HPP on the Pungwe River (referred to as Pungwe B Hydroelectic Power Scheme), downstream of its confluence with the Nyazengu River in the Eastern Highlands of Zimbabwe (Black Crystal Consulting 2013). Their study included an assessment of the water quality and aquatic ecology of the potentially affected river reach. Also, they describe the substratum and flow characteristics of the Pungwe River, with an emphasis on the importance of flow for the maintenance of instream habitats for aquatic biota. This report refers to a previous survey of aquatic macroinvertebrates of the Upper Nyangombe River undertaken in 1998 for the "Pungwe A EIA" by Minshull (1998). A summary of that report provides a useful account of the macroinvertebrate taxa found in different aquatic biotopes similar to that of the Pungwe River. While the taxonomic composition of the Pungwe was found to be similar to that of the Nyangombe River in the 2013 study, the authors note that, in the absence of development upstream on the Pungwe, compared to the Nyangombe River, the aquatic macroinvertebrate fauna is significantly less abundant (Black Crystal Consulting 2013). Despite these descriptions, the report does not provide any information on the actual taxa found in the Pungwe River during the 2013 study and it is unclear whether any macroinvertebrate data were collected during their field survey. The study also includes water quality data and lists of bird, plant and fish species in the Pungwe River, suggesting that primary data were collected in the 2013 study.

Streams and rivers of the Eastern Highlands of Zimbabwe were also the focus of a recent ecological assessment by Dalu *et al.* (2016) who investigated the distribution and abundance of two crab species in 51 rivers in relation to various environmental conditions. Besides the collection of biota, they collected physico-chemical variables and water samples for nutrient analysis, as well as recording habitat and basin characteristics such as channel width, canopy cover, littler and macrophyte cover, substratum and water depth. While not specific to the upper Pungwe River, the map of sampling locations includes numerous sites within the Nyanga Highlands where the Pungwe originates and thus it is likely that their study includes the upper Pungwe system. They found that *Potamonautes mutareenis* was largely restricted to less impacted areas in high mountainous streams, occurring in shallow, fast flowing habitats whereas *Potamonautes unispinus* was found mostly in low lying areas in deeper, slow flowing biotopes and was more tolerant of sewage pollution. Also, there is some evidence that *Potamonautes unispinus* may extend into Mozambique. Thus, the Dalu *et al.* (2016) study provides some insight into the sensitivity of specific aquatic macroinvertebrates to water quality and habitat availability, both potentially affected by changes in the flow regime, within the mountain streams of the Nyanga Highlands. Interestingly, the summary of Minshull's aquatic macroinvertebrate survey of the Nyangombe River (Minshull 1998), specifically notes the presence of the Crab, *Potomonautes perlatus,* not mentioned by Dalu *et al.* (2016*).*

Besides the upper reaches of the Pungwe Basin within the eastern highlands of Zimbabwe, the only other relevant literature includes taxonomic collections and description of Odonata (dragonflies and damselflies) in both Zimbabwe and Mozambique. As early as the 1980's, a checklist of the Odonata of Mozambique was compiled by Pinhey (1981). More recently, a list of Mozambican species was compiled by Dijkstra and Clausnitzer (2014). Bernard and Badowski (2020) describe several species of dragonfly collected at 11 localities in Mozambique, including the Gorongosa National Park. They describe the adult, non-aquatic specimens representing 30 dragonfly species belonging to six families, namely the Calopterygidae, Chlorocuphidae, Coenagrionidae, Aeshinide, Libellulidae and Gomphidae. Prior to work of Bernard and Badowski (2020), *Atoconeura biordinata,* a species belonging to the Libellulidae, was described as a species limited to the "fast flowing stony/rocky streams in bush or forested mountainous areas at an elevation higher than 1000m" characteristic of the eastern highlands of Zimbabwe (Dijkstra 2006). Bernard and Badowski (2020) collected this species from a much lower altitude range in the Gorongosa National Park. They also describe a Gomphid, *Gomphidia quarrei* as a species limited to "strong flowing waters", suggesting the importance of fast flowing aquatic habitats for their survival.

Besides the cursory reference to macroinvertebrates within the Pungwe River and the hydraulic characteristics favourable for their survival, there is currently very little information to inform the identification of macroinvertebrate indicators and predict flow-related changes specific to the Pungwe River. Considering the size of the Pungwe Basin and the ecoregional changes from the Eastern Highlands of Zimbabwe to the coast at Beira, it is likely that water quality, flow and habitat conditions will vary considerably across the four EFlows zones selected for this assessment. Thus, collection of primary data within the four zones will be fundamental to the macroinvertebrate component of the EFlows assessment.

5.4.5 River fish

Information and data on fish of the Pungwe Basin are available from the following sources (all sources include point data):

- Spatial shifts and habitat partitioning of ichthyofauna within the middle–lower region of the Pungwe Basin, Mozambique (Desai *et al.* 2019)
- Evidence of hidden diversity and taxonomic conflicts in five stream fishes from the Eastern Zimbabwe Highlands freshwater ecoregion (Chakona *et al.* 2018)
- Detecting the impact of introduced rainbow trout within Afro-montane streams in eastern Zimbabwe (Kadye *et al.* 2013)
- An Ichthyological and Bio-monitoring Survey of Fish Assemblages in the Vunduzi River from it Source on Gorongosa Mountain to its Lower Reaches in the Gorongosa National Park, Mozambique (Sara *et al.* 2012).

5.5 ESTUARINE AND MARINE ECOSYSTEMS

5.5.1 Estuarine water quality

The main water quality issue in the estuary is high turbidity. In the rainy season, between November and April, turbidity of the water at the secondary intake can be as high as 500 NTU, with an average value of 400 NTU. Outside of the rainy season, the turbidity levels at the secondary intake range between 60 and 100 NTU (Moron 2014). Table 5.2 shows the average effluent water quality data taken from DWTP Mutua between the months of January 2013 and July 2013. These measurements are conducted at the FIPAG Beira regional offices at Munhava. Total and faecal coliforms were sampled at 0.00 mg/L and 0 CFU/100ml, respectively (Moron 2014).

Table 5.2 Assumed intake water at Mutua Water Treatment Work (Jan-Jul 2013) about 70-75 km upstream (Moron 2014)

	Cond (mhmo/cm)	pH	TDS (mg/l)	Turbidity (NTU)	NH_4^+ (mg/l)	Chlorides (mg/l)	Ca^{2+} (mg/l)	Cl (mg/l)	Mg^{2+} (mg/l)	SO_4^{2-} (mg/l)	TOC (mg/l)
Min	88.71	6.64	44.57	1.20	0.02	4.29	7.03	0.20	1.14	4.56	0.60
Average	118.29	7.33	59.39	6.54	0.18	6.97	8.51	0.48	3.09	12.31	1.00
Max	187.43	8.19	90.57	17.97	0.73	9.50	11.86	1.05	5.40	21.36	1.66

Water quality collected in lower estuary and bay during 1997 are presented in Table 5.3 and Table 5.4 (JICA 1998). Sediment data are presented in Table 5.5. Station locations are presented in Figure 5.15.

Table 5.3 WQ data from Pungwe Estuary collected during wet and dry season in 1997 (JICA 1998)

Date	Season	Stn	Tide		Temp	Sal	DO (ml/l)	pH	Turbidity (NTU)	TSS (mg/l)	COD (mg/l)	Tot N (ug/l)	Tot P (ug/l)	Org Hg (ug/l)	Org P (mg/l)	Cyanogen (mg/l)	PCB (ug/l)	DDT (ug/l)	BHC (ug/l)
Feb & Jul 1997	Dry/ Wet	1-10	Low & High	Min	21.3	0.0	2.7	5.9	0.1	26.0	0.2	151.0	9.0	<0.02	0.01	<0.05	<0.02	<0.02	<0.02
				Ave	25.8	18.3	5.3	8.1	62.0	220.4	1.9	427.1	162.9	<0.02	0.15	<0.05	-	-	-
				Max	30.1	32.8	7.8	8.6	270.0	1120.0	8.2	1633.0	810.0	<0.02	0.64	<0.05	<0.15	<0.15	<0.15

Table 5.4 WQ data from Pungwe Estuary collected during wet and dry season in 1997 (JICA 1998) (Continue)

Date	Season	Stn	Tide		Temp	Hg (unfil) (ug/l)	Cd (unfil) (ug/l)	Cd (fil) (ug/l)	Pb (unfil) (ug/l)	Pb (fil) (ug/l)	As (unfil) (ug/l)	Cu (unfil) (ug/l)	Cu (fil) (ug/l)	Zn (unfil) (ug/l)	Zn (fil) (ug/l)	Cr (VI) (unfil) (ug/l)
Feb & Jul 1997	Dry/ Wet	1-10	Low & High	Min	0.3	<0.02	<0.27	<0.27	0.8	<2.8	<0.24	<1.48	<1.03	<0.57	<0.57	<0.6
				Ave	22.3	-	-	-	-	-	2.0	6.5	1.5	17.1	6.6	-
				Max	33.6	<0.03	0.84	<0.57	16.4	<4	7.6	30.4	2.2	91.8	37.42	42

Table 5.5 Sediment quality data from Pungwe Estuary collected during 1997 (JICA 1998)

Date	Station		Ignition Loss (%)	Hg (ug/g)	Cd (ug/g)	Pb (ug/g)	As (ug/g)	Cu (ug/g)	Zn (ug/g)	Cr VI (ug/g)	Org P (ug/kg)	Org Hg (ug/kg)	Cyanogen (ug/kg)	PCB (ug/kg)	DDT (ug/kg)	BHC (ug/kg)
1997	1-10	Min	0.2	0.0	0.1	0.9	0.0	0.4	1.1	0.1	0.0	0.0	0.0	0.0	0.0	0.0
		Ave	3.2	0.0	0.1	7.0	0.4	10.7	22.6	0.1	0.0	0.0	0.0	0.0	0.0	0.0
		Max	8.4	0.0	0.1	18.1	1.0	33.3	65.9	0.1	0.0	0.0	0.0	0.0	0.0	0.0

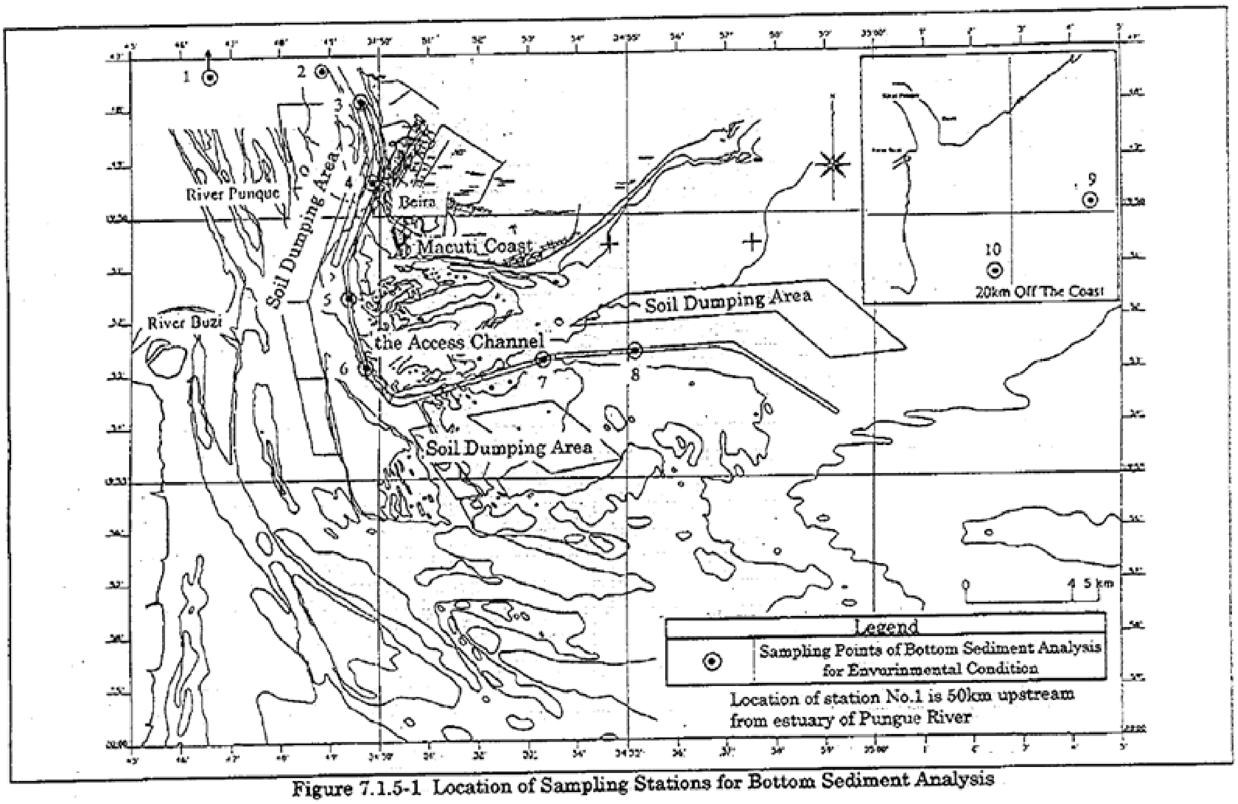

Figure 5.15 Location of WQ station during 1997 surveys (JICA 1998)

5.5.2 Estuarine and marine macrophytes

Globally, Mozambique ranks 13th in terms of mangrove extent, with an area of ~3 054 km^2. Central Mozambique hosts the most productive forests (Bosire *et al.* 2012; Tretin *et al.* 2016). In the north mangroves grow mainly along the mouth of the rivers, bays and islands. In southern Mozambique mangroves are scant, with the most important areas being Maputo Bay, Inhambane Bay, Inhassoro-Vilanculos and the Save River Delta (Barbosa *et al.* 2001; Macamo *et al.* 2016).

The Pungwe-Buzi River mangrove system is part of the swampy Central Coast System. Mangrove communities occur on the margins of the river and inter-riverine islands and on the mudflats of the Pungwe-Buzi Estuary. Five of the nine mangrove species that occur in Mozambique have been identified in these forests, viz. *Avicennia marina. Heritiera littoralis, Sonneratia alba, Bruguiera gymnorhiza* and *Xylocarpus granatum*. Menoussanga *et al.* (2020) estimated that the mangrove cover of the Beira District, which covers a large part of the Pungue River mangroves, reduced from 8 587 ha to 7 133 ha between 2009 and 2019 (17 % reduction; Figure 5.16). Part of this loss was related directly to Cyclone Idai (2019), Storm Eloise (2020) and Cyclone Chalane (2021), which all made landfall in the region (Macamo *et al.*, 2016; Macamo *et al.*; unpublished data). Other important macrophyte habitats in the Pungwe Estuary include salt marsh and sea grass. Extensive seagrass habitats are found within the estuary and in Sofala Bay (Gullstom *et al.* 2021).

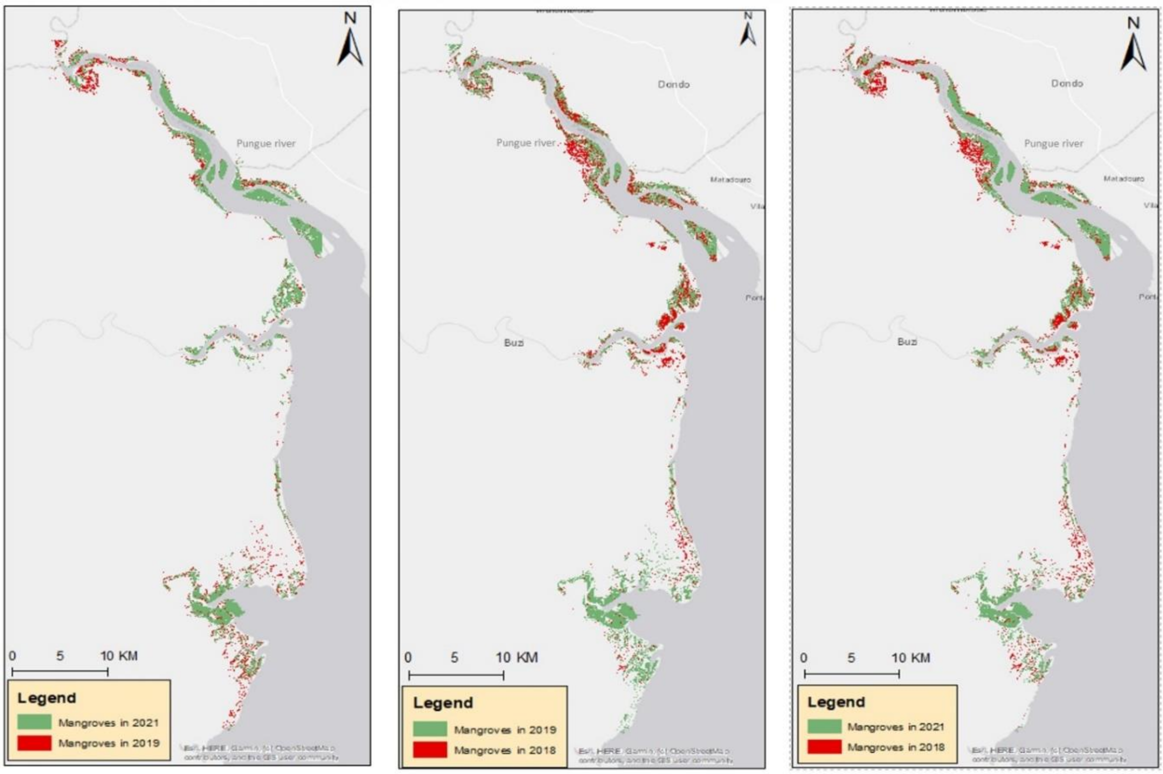

Figure 5.16 Mangroves losses between 2018 and 2021 as a result of extreme events at the Búzi and Pungwe estuaries, central Mozambique (Menoussanga *et al.* 2020)

Mangroves are important for the local communities as they provide, *inter alia*, coastal protection, water quality control, climate regulation, biodiversity and nursery areas for fauna (including species of economic value). Socio-economically, mangroves provide food security, wood resources. The mangrove areas are also used for salt extraction, honey production, fishing, invertebrate harvesting and others.

Mangroves are threatened by both human activities and natural causes, although the anthropogenic threats are greater. These include urban expansion, extraction of wood and logging, coastal development and pollution. The impact of river flow in mangrove ecosystems is barely studied in Mozambique and publications covering this aspect are scarce. The mangrove of the Limpopo estuary was negatively impacted by the 2000 floods, which resulted in massive die back of ~400 ha of forest following its submergence for ~45 days (Bandeira and Balidy 2016), although >120 ha of the lost forest have since been restored. River flow studies were conducted in the Incomáti Estuary in 2009, but focused on the impact of salinity and forest condition on shrimp biomass (Monteiro and Marchand 2009), rather than on macrophytes ecology.

Climate change also poses a significant risk to these ecosystems. Rising sea levels will likely threaten biodiversity, while increased frequency and strength of storms and tidal surges will likely increase damage and variation of sediment transfer in river flows. Climate change in combination with environment degradation (e.g., deforestation, land degradation) increases risk to ecology and local communities (GEF 2021-2024). Mangroves could be key to strategies addressing the mitigation of climate changes through carbon storage. However, little is known regarding the carbon stocks of these ecosystems, particularly below-ground.

The estuaries in the region, and their associated mangroves, are also ecologically connected to the Banco de Sofala, the fish and prawns resources of which are the most important in Mozambique. Current exploitation levels in the Sofala Area (Pungwe-Buzi River Estuary region), in combination with the destruction of mangroves and the practice of trawling on seagrass beds, are expected to lead to dramatic decreases in shrimp and fish biodiversity and abundance (GEF 2021-2024).

5.5.3 Estuarine and marine invertebrates

There are few, if any, studies that have focussed on the ecology of estuarine invertebrates of the Pungwe Estuary or nearby systems (e.g., Buzi, Zambezi, Bons Sinais). Without existing data to characterise the estuary, information on the physical aspects of the estuary, such as bathymetry, grain size distribution and characteristics and dynamics of the overlying water column will be used to characterise the macrobenthic habitat.

The community will be characterise based on existing species and biogeographic distribution records from similar habitats in biodiversity repositories such as the Ocean Biodiversity Information System (OBIS - //obis.org), the Global Biodiversity Information Facility (GBIF - //GBIF.org) and the World Register of Marine Species (WoRMS - //marinespecies.org), and existing knowledge from comparable, but smaller, systems in South Africa such as the fluvially dominated and permanently open estuaries of Subtropical KwaZulu-Natal. Field sampling will be aimed at validating the bottom type and the taxa that in the estuary, focussing on those that are indicators of estuary health and are sensitivity to environmental change.

In 1998, the Japanese International Cooperation Agency (JICA) funded a study to improve the access and maintenance of Beira Port (JICA 1998). This yielded some descriptions of the sediment habitats in the lower reaches, which ranging from gravel to mud. The sediment distribution was recorded as being predominantly silty mud upstream and patchy sand and mud at the mouth. The sediment communities associated with these environments, which are influenced by strong tidal flows, sediment movement and high turbidity are likely to be low in species richness and abundance. Species traits (movement, feeding preference, reproduction mode) from localities elsewhere on the south-eastern African coast will also be used to provide an indication of invertebrate response to a changing environment in the Pungwe, particularly as sediment type and salinity are such important drivers of macrobenthic communities.

The macrocrustacea, which comprise the larger invertebrate in the system, are targeted by artisanal fisheries. These include various prawns (Penaeidae), the mangrove mud crab, *Scylla serrata,* and cephalopods (squid and octopus). Prawns are an important component of the estuary and support the large fisheries on the adjacent Sofala Bank. Until 2013, *Penaeus indicus*, *Metapenaeus monoceros*, *P. monodon*, *M. stebbingi, Marsupenaeus japonicus* and *P. semisulcatus* (Gammelsrod 1992). *P. indicus* and *Metapenaeus monoceros* represented `90% of the total catch (Malauene *et al.* 2021). From 2013, there were media reports that an invasive species, known as the 'Rainbow prawn', *Mierspenaeopsis sculptilis* (Heller 1862), was being caught near the estuary mouth, and currently catches of this species are higher than those of than the native penaeids. *M. sculptilis* (Heller 1862) is from South-East Asia tolerant of a wide range of habitats (sand and mud, and mangroves) and presumably outcompetes native species for food and space.

There is also unverified information that there is a bivalve fishery (Veneridae: *Meretrix* sp.). These saltwater clams can constitute a large component of the estuarine invertebrate biomass and being filtrators can bioaccumulate pollutants associated with a port.

As with the estuarine invertebrates, there have been no published studies on the ecology of the nearshore benthic ecosystem of the Sofala Bank. However, there is high similarity between this ecosystem and the shallow marine, far more limited in size mudbanks off the uThukela Estuary on the east coast of South Africa and for which there is a fair amount of knowledge (see Green and MacKay 2016; Untiedt and MacKay 2016; MacKay *et al.* 2016). There will likely be overlap of species and community types and given both shelf ecosystems are adjacent to large fluvial estuaries supporting similar habitats, the invertebrates are expected to display similar functional traits.

The species of key focus in the marine realm have been the Penaeidae (mentioned for the estuary) because they support artisanal, semi-industrial and industrial fisheries on the Sofala Bank. Sub-adults and adults are distributed on the continental shelf on sandy mud and/or muddy sand sediments (FAO 1979) usually in the 20 to 50 m depth zone (inner shelf) where they feed on plankton and detritus. The two main species (*P. indicus* and *M. monoceros*) spawn year-round on the Bank, but there are spawning peaks associated with seasonality. Juveniles migrate into estuaries where they mature and then return to the sea. The connection between estuaries (with mangroves) and the sea, and river outflow is a critical component of their life cycle.

5.5.4 Estuarine and marine Fish

There are few readily available data on the fishes of the Pungwe Estuary. Institutional databases such as those hosted by the South African Institute for Aquatic Biodiversity (SAIAB) and the Universidade Eduardo Mondlane) will be sourced as far as possible, but the list of fish species for the system will need to be drawn up from expert opinion, based on researched distributions of estuarine fishes on the Mozambique coast and fishing records. This will be augmented by field sampling and visits to local fish markets in the area.

Desai *et al.* (2019) recently surveyed river sites in the lower river reaches. They do not provide GPS locations for the sites they sampled, but from rudimentary map work based on figures presented, their lowest site was at least 130 km from the estuary mouth. The species they present include several freshwater fishes with distributions that extend into the estuary waters, however, apart from the Anguillid eels, they have no dependency on estuarine or marine habitats. Information from artisanal fishing in the estuary and its mouth (Darkey and Turatsinze 2014) provides insight into the most common species targeted by fishers but not a comprehensive fish species list (Table 5.6).

Table 5.6 Estuarine and marine fish species

Scientific name	Common name	Predominant affinities
Anguilla marmorata	Giant mottled eel	Marine catadromous
Carcharhinus leucas	Bull shark	Marine estuarine
Coptodon rendalli	Redbreast tilapia	Freshwater estuarine
Enteromius paludinosus	Straightfin barb	Freshwater
Enteromius trimaculatus	Threespot barb	Freshwater
Enteromius viviparus	Bowstripe barb	Freshwater
Epinephelus malabaricus	Greasy grouper	Marine estuarine
Glossogobius callidus	River goby	Freshwater estuarine
Glossogobius giuris	Tank goby	Freshwater estuarine
Hilsa kelee	Kelee shad	Marine estuarine
Johnius dussumieri	Bearded croaker	Marine estuarine
Megalaspis cordyla	Torpedo scad	Marine straggler
Microphis fluviatilis	Freshwater pipefish	Freshwater estuarine
Mugil cephalus	Flathead mullet	Marine estuarine
Oreochromis mossambicus	Mozambique tilapia	Freshwater estuarine
Otolithes ruber	Tigertooth croaker	Marine estuarine
Parastromateus niger	Black pomfret	Marine estuarine
Plicofollis dussumieri	Blacktip sea catfish	Marine estuarine
Pomadasys kaakan	Javelin grunter	Marine estuarine
Sardinella gibbosa	Goldstripe sardinella	Marine estuarine
Scomberomorus commerson	Narrow barred Spanish mackerel	Marine estuarine
Sillago sihama	Silver sillago	Marine estuarine
Stolephorus indicus	Indian anchovy	Marine estuarine
Thryssa setirostris	Orangemouth thryssa	Marine estuarine
Trichiurus lepturus	Largehead hairtail	Marine estuarine

5.5.5 Estuary and marine fisheries

The Mozambique coastline provides people good access to a variety of habitats and abundant fish and shellfish resources, and in so doing creates opportunity for a diversity of fisheries that underpin livelihoods of many people in Mozambique (Darkey and Turatsinze 2014; Mutombene *et al.* 2014). However, poor implementation of controls means that most fisheries are effectively open-access. As a result serial-overfishing is ubiquitous. The fisheries are also under pressure from climate change and other anthropogenic or environmental influences. An understanding of the influences of these pressures on the fisheries is important as they can mask other responses, such as those linked to alterations of the river flow regime.

Fisheries in Mozambique are sub-divided into three main sectors: industrial; semi-industrial, and; artisanal (or small-scale). There an estimated 250 000 fishers currently reliant on fisheries as their primary source of livelihood, of which >50% are in the artisanal sector (Darkey and Turatsinze 2014; Mutombene *et al.* 2014; Zeller and Pauly 2018). The industrial and semi-industrial sectors target primarily shrimp and line fish, while the artisanal sector targets a range of pelagic and demersal linefish species, as well as crustaceans such as shrimp and crab (Laissane *et al.* 2011). Artisanal fisheries primarily exploit shallow-water demersal and pelagic species in the coastal zone, while industrial and semi-industrial exploit shallow- and deep-water shrimp, and pelagic migratory fish species (e.g., tuna and swordfish). The latter occurs mainly in deep waters extending across the Exclusive Economic Zone (EEZ) and is mostly operated by foreign-owned vessels (Benkenstein 2013; Oceanic Développement, MegaPesca Lda 2014).

The Pungwe Estuary, its adjacent nearshore and the Sofala Bank are fished by a substantial proportion of these fishers. There are 300 to 400 registered gillnets and an unverified similar number of illicit gillnets (Oliver 2014). Both registered and unregistered nets are increasingly being made with smaller mesh-sizes (Oliver 2014). There are also a line-fishery and a number (60-80) of beach-seine nets of 800 – 1 600 m in length, although it is difficult to distinguish between these and registered gillnets from the available literature (Oliver 2014; Zeller *et al.* 2021). There are also in excess of 1 000 illegal *chicocota* nets in the Beira precinct (Oliver 2014). These are essentially cone shaped fyke-nets constructed using Mosquito mesh and are ≤800 m long. Over 80 % of the *chicocota* catch is a gelatinous mass of fish and invertebrate larvae that is discarded. Beach-seine and gillnet CPUE in the Pungwe, Beira region is **~**20 kg·kWday$^{-1;}$ similar to elsewhere in the country (Zeller *et al.* 2021). Demersal and predatory species have all but disappeared and catches are dominated by *Thryssa vitrirostris* and other small-pelagic species (Zeller and Pauly 2008; Zeller *et al.* 2021).

Overfishing can be disaggregated into growth, recruitment and ecosystem overfishing. Growth overfishing occurs when fish are harvested before they reach their full reproductive potential, recruitment overfishing is when most breeding adults have been removed from the population and ecosystem overfishing is when whole trophic levels, e.g., large predators have been removed from the system. Mozambique's effective fishing effort increased from <1 kWday X 10^6 in 1950 to 2 kWday X 10^6 by 1980, and then to >10 kWday X 10^6 by 2016 (Zeller *et al.* 2021). This has resulted in CPUE crashing from >275 kg·kWday^{-1} in 1950 to 75 kg·kWday^{-1} in 1980 to < 20 kg·kWday^{-1} in the 2021 (Zeller *et al.* 2021). Predators and high-value, long-lived, large-bodied fish such as Sciaenidae (kobs, croakers) have been removed from the ecosystem with catches now dominated by short-lived, early-maturing small-pelagic species (e.g., orangemouth anchovy, *Thryssa vitrirostris*). Similar has occurred with the more sought-after but shorter-lived invertebrates e.g. the tiger prawn *Penaeus monodon* that have been removed by illicit small-meshed gillnets and mosquito-net seines. In the Pungwe Estuary and nearshore, this has resulted in an invasive penaeid rainbow prawn *Mierspenaeopsis sculptilis* occupying an empty niche that is also devoid of predators. This new addition is of much lower economic value than the indigenous species.

5.6 DATASETS IDENTIFIED FOR POTENTIAL USE IN THE ASSESSMENT

Existing datasets identified for potential use in the assessment are listed in Table 5.7. Sourcing of these data will be prioritised in Phase 1. The data and reports (Table 5.7) will be augmented with information from numerous scientific papers (not listed) on the LKSC and in broadly similar areas elsewhere.

Table 5.7 Existing datasets identified for potential use in the assessment

Discipline	Title	Location	Type of data/information	Format	Dates (where applicable)	Point data or time-series (time step)	Reference/Contact
Topographical							
Land-use	Copernicus Global Land Service: Land Cover 100m.	Basin	Land cover	GIS	2019		Buchhorn et al. (2020).
	Report	Mutasa district (Zimbabwe)	Land cover changes	Report	1984-2014	Time series	Masaka et al. (2017)
Social	National census	Zimbabwe, Mozambique	Population census data at ward level for Zimbabwe; district level for Mozambique	Excel spreadsheet (Zimbabwe) and PDF reports (Mozam)	Zimbabwe 2012 Mozambique 2017	Point data	ZimStat, Instituto Nacional de Estatística
	Social indicators	Mozambique (provincial)	Demographic and social information: population, education, health and social assistance	Report	2013-2014	Both	Instituto Nacional de Estatística (2017)
	Social indicators	Zimbabwe (Provincial, District)	Population, Economy, Finances, Health	Database, reports and graphs		Both	World Bank Data Portal ZIMSTAT
	Socio-economy	Pungwe River Basin	Social, demographic, conditions, water and sanitation	Report	2004	Both	SWECO (2004)
	Census Geography	Zimbabwe Mozambique	Census areas spatial	GIS	-	-	-

Discipline	Title	Location	Type of data/information	Format	Dates (where applicable)	Point data or time-series (time step)	Reference/Contact
Ecosystem Services	Tourism	Mozambique by province	Tourism statistics	Report	2017-2019	Both	Instituto Nacional de Estatística (2019)
	Tourism	Sofala Province	Tourism statistics	Report	2020	Both	Instituto Nacional de Estatística (2020)
	Tourism	Global	Geotagged photographs	GIS, Flickr	2017	Point data	Through Flickr and the InVEST platform. InVEST Recreation Model 3.5.0 (www.naturalcapitalproject.org).
	Tourism	Nyanga National Parks	Tourism statistics	Database and Reports		Both	Zimbabwe Parks and Wildlife Management Authority (Head Office) Zimbabwe Tourism Association (ZTA)
	Fisheries	Mozambique	Fisheries sector: production, types, prices, effort	Report	2021	Time series	Capaina (2021)
	Fisheries	Zimbabwe Nyanga National Park (Pungwe River)	Types and catches	Database and Reports		Both	Zimbabwe Parks and Wildlife Management Authority (Mugaviri -ZimParks Officer) Desai *et al.* (2019)
	Agriculture Census	Mozambique Province	Agric statistics, type, production, prices	Report	2011	Both	Instituto Nacional de Estatística (2017)
	Agriculture Statistics	Mozambique District level	Agric statistics, type, production, prices	Report	2021	Both	Ministério da Agricultura e Desenvolvimento Rural (MADER) 2021. Inquérito Agrário Integrado 2020. República de Moçambique
	Agricultural Statistics	Zimbabwe Mutasa Nyanga -District level -Village Level -Ward level	Production statistics, crops, and trends	Reports		Time series	Ministry of Lands, Agriculture, Fisheries, Water and Rural Development Agritex Mutasa Rural District ZIMVAC (2021) Nyanga Rural District Council
	Water resources	Zimbabwe Basin level Pungwe River for Mutare City Council	Water Abstraction and pricing	Database and reports	Time series	Both	Dept. Water Resources Development and Utilisation (Gerald Mundondwa-Hydrologist) Zimbabwe National Water Authority (ZINWA Tendai Muyambo (Save Catchment Manager) Nyikadzino *et al.* (2014)

Discipline	Title	Location	Type of data/information	Format	Dates (where applicable)	Point data or time-series (time step)	Reference/Contact
	Use of natural resources	Region	Harvesting of natural resources to support livelihoods: types, use, participation	Reports, papers			Literature review
Water quality	Monitoring data from ARA-Centro	Mozambique	Data	Excel	Unknown	Unknown	Mr Castro Junior
	General WQ	Eastern Highlands, Zimbabwe	EIA specialist report; published paper	pdf	2013/2016	Point data	Black Crystal Consulting (2013); Kadye *et al.* (2013); Dalu *et al.* (2016)
	Artisinal gold mining WQ	Revué River, Mozambique; Ngwabalozi River, Zimbabwe	Published book chapter	Pdf; data tables	~2014	Point data	Mujere and Isidro (2015)
River: Geomorphology	None identified as yet						
River: Vegetation	None identified as yet						
River: Macroinvertebrates	Species lists	Eastern Highlands, Zimbabwe	Published papers	Published papers	1998	Species lists	Minshull (1998)
	Species lists	Eastern Highlands, Zimbabwe	EIA specialist report; published paper	pdf	2013/2016	Species lists	Black Crystal Consulting (2013); Kadye *et al.* (2013); Dalu *et al.* (2016)
	Odonata	Zimbabwe and Mozambique, including GNP	Published papers	Published papers	Number of surveys	Species lists	Dijkstra and Clausnitzer (2014) and Bernard and Badowski (2020):
River: Fish	Listed in text (Section 5.4.5)						

Discipline	Title	Location	Type of data/information	Format	Dates (where applicable)	Point data or time-series (time step)	Reference/Contact
Estuary: Bathymetry/ Topography	INAHINA	Pungwe Estuary and adjacent coastal region	Bathymetry and possible DEM	Unknown	Compilation of survey and satellite derived bathymetry and DEM data	Unknown	Hoggarth *et al.* (2012)
	INAHINA	Pungwe Estuary and adjacent coastal region	Pre- and Post IDIA bathymetry surveys.	Unknown ASCII data	Compilation of survey and satellite derived bathymetry and DEM data	Unknown	INAHINA (2021)
Estuary: Hydrodynamics	Physical oceanography data	Pungwe Estuary	RCM	Excel	15-20/6/2009	10 min, at fixed position in the estuary	SEED (2009)
	Salinity profiles	Pungwe Estuary	Unknown, assumed to be CTD profiler	Unknown	3 Oct 1993, 12 Oct 1993, 16 Oct 1993, 31 Jan 2002, 27 Feb 2002. 1 Mar 2002.	Sites along the length of the estuary.	Savenije (1993) Savenije (2005) Graas and Savenije (2008)
	HINAHINA	Port of Beira	Tidal water levels	Excel compatible	Long –term time series 1 Oct 1999 to 31 Dec 1999	Hourly time series	-
	University of Rio de Janeiro	In the mouth of the estuary.	ADCP measured Current and water level data at 4 locations	Unknown	May 15 to 24, 2009	Hourly time series of current and water level	Fernandes da Silva (2011)

Discipline	Title	Location	Type of data/information	Format	Dates (where applicable)	Point data or time-series (time step)	Reference/Contact
Estuary water quality	Physical oceanography data	Port of Beira	CTD, sediments	Excel	15-20/6/2009	Once, longitudinal section in the estuary	SEED (2009)
	Physical estuarine data	Temperature and salinity profiles and water levels	Moving boat survey with profiles every 5-10 km upstream and CTD divers at five locations along the estuary	Unknown	17 to 17 Dec 2016	Moving boat survey and CTD divers	Abas, & Hagedooren (2017) MSc Thesis
	Turbidity	Mouth of the estuary and other location within 100km radius of Beira	Turbidity data from water samples (99 WQ samples and sediment samples)	Unknown	December 2005 to February 2007	Turbidity data from 5 marine sampling sites supplemented by measurement sites further upstream	Du Preez *et al.* (2010)
Estuary macrophytes	Pungwe Mangrove maps	Pungwe Mangrove	Spatial	GIS	On-going	Time-series	Dr Celia Macamo

Discipline	Title	Location	Type of data/information	Format	Dates (where applicable)	Point data or time-series (time step)	Reference/Contact
Estuary and marine invertebrates	Spawning areas of two shallow-water penaeid shrimps (*Penaeus indicus* and *Metapenaeus monoceros*) on the Sofala Bank, Mozambique	Sofala Bank. Pungwe Estuary	Publication	pdf	2003-2017	Time series	Malauene *et al.* (2021)
	Population structure and recruitment of Penaeid shrimps from the Pungué River Estuary to the Sofala Bank Fishery, Mozambique	Sofala Bank. Pungwe Estuary	Publication	pdf	2004	Short time series	Brito Pdena (2007)
	Variation in Shrimp Abundance on the Sofala Bank, Mozambique, and its relation to the Zambezi River Runoff	Sofala Bank. Pungwe Estuary	Publication	pdf	1974-1988	Time series	Gammelsrod (1992)

Discipline	Title	Location	Type of data/information	Format	Dates (where applicable)	Point data or time-series (time step)	Reference/Contact
Estuary and marine fish and fisheries	Small-scale fisheries in Mozambique	Pungwe estuary and adjacent coastal region	Policy Brief	PDF			Benkenstein (2013)
Marine bathymetry	INAHINA surveys	Pungwe estuary and adjacent coastal region	Pre- and Post IDIA bathymetry surveys.	Unknown	n/a	Compilation of survey and satellite derived bathymetry and DEM data	INAHINA (2021)
Marine hydrodynamics	Wave and current data	CSIR	Mooring offshore of Beira	ASCII time series	Wave (and possibly current) time series) in 1997	Most likely hourly to 3 hourly data.	Theron and Barwell (2012)

6 POTENTIAL ECOSYSTEM INDICATORS FOR THE EFLOWS ASSESSMENT

A preliminary list of indicators for the EFlows assessment is provided in Table 6.1. This list will be refined and updated based on understanding gained and information gathered from the literature during the course of the study, the field visits and information gathered from Stakeholders.

Table 6.1 Potential ecosystem indicators for the EFlows assessment

Discipline	Potential indicators
DRIVERS – from modelling external to DRIFT	
Hydrology	Onset of seasons, duration of seasons, mean dry season discharge, minimum 5-day discharge, mean wet season discharge, wet season volume, number and magnitude of freshets and floods
Hydraulics	Mean velocity, wetted area, wetted perimeter, inundation of riparian zones
Sediments	Sediment load (grain size fractions)
Water quality	Turbidity, dissolved oxygen, nutrient concentrations
RIVER ECOSYSTEM – modelled in DRIFT	
Geomorphology	Suspended sediment concentration, Erosion, Exposed sand bars, Inchannel bed sediment size, Embeddedness of main channel habitat, Backwaters with fine sediment, Suitability for fish nests, Frequency of activation of secondary channels
Vegetation	Algae: benthic, Algae: suspended, Wet bank coloniser/stabiliser, Aquatic perennials, Lower dry bank canopy, Upper dry bank canopy, Dry bank ground cover
Macroinvertebrates	Flow sensitive scraping insects; Flow sensitive filter-feeding insects; Filter feeders, Marginal veg non-airbreathing insects; Territorial crustacea; Odenata
Fish	Guarders, Bearers, Rocky specialists, Generalists
ESTUARY ECOSYSTEM – modelled in DRIFT	
Hydrodynamics	Water levels, retention, salinity, mixing tracer (that can be used as a dilution proxy for other calculations)
Water quality	Salinity, turbidity, dissolved oxygen, nutrient concentrations
Physical habitat	Intertidal area extent, supratidal area extent, subtidal area/volume extent, mean sediment grain size
Macrophytes	Mangrove extent, intertidal saltmarsh extent, supratidal saltmarsh extent, species diversity
Invertebrates	Penaeidae prawns, mud crab *Scylla serrata; Mierspenaeopsis sculptilis*, species diversity
Fish	Marine species, marine vagrants, estuarine-associated species, estuarine breeders, freshwater species
MARINE ECOSYSTEM – modelled in DRIFT	
Hydrodynamics	Salinity, mixing tracer (that can be used as a dilution proxy for other calculations)
Water quality	Salinity, turbidity, nutrient concentrations
Physical habitat	Sediment grain size
Invertebrates	Penaeidae prawns, *Mierspenaeopsis sculptilis*
Fish	Marine species, estuarine-associated species, estuarine breeders
SOCIO-ECONOMIC – modelled in DRIFT	
Drinking water	Salinity, dry season volume, water quality
Subsistence resources	Extent of riverbank gardens, reeds, papyrus, medicinal plants, mud and sand, woody vegetation
Fisheries	Species of commercial interest

Some of the indicators selected represented physical and chemical DRIVERS of the river ecosystem and their predicted changes will emerge from the modelling exercises. Others are ECOSYSTEM indicators that respond to the drivers and each other, and whose predicted changes will be provided through response curves created by the EFlows team.

7 STAKEHOLDER ENGAGEMENT STRATEGY

Stakeholders are ‘individuals, groups or institutions that are concerned with, or have an interest in the water resources of the Pungwe Basin and their management. They include all those who affect and/or are affected by the policies, decisions, and actions of the system. That means not only direct water users but those affected by water management (including waste-water management). They include those involved in water-resource development, management and planning, including public-sector agencies, private sector organisations, and NGOs and external (such as donor) agencies’ (Warner (2006).

The EFlows project is part of a much bigger process with various Stakeholder fora; and the role of the EFlows Assessment team is to provide information and inputs that enhance the outcomes of that process. Thus, the GWPSA Stakeholder engagement for this project will build on an earlier stakeholder mapping exercise during Prodoc development (IUCN and GWPSA). The listing of the stakeholders (at institutional level, individual focal points still to be identified) that were identified as relevant for various purposes of the EFlows assessment and subsequent planning and implementation, e.g., for consultation, raising awareness, contributing inputs and data, technical reviews is provided in Table 7.1. GWPSA will mobilise these stakeholders on various platforms as needed during the delivery of this assignment: virtually, in workshops and meetings, but also for the main field data collection trips to the river and estuary. As part of the broader project implementation framework for stakeholder engagement, the issue of gendered participation is cross-cutting and the GWPSA gender expert will liaise with the EFlows team’s socio-economic experts on the adequate handling of this aspect of the work.

For the hybrid, physical and virtual meetings, GWPSA will mobilise and invite stakeholders in consultation with the EFlows team, i.e., agree on participation list, meeting format, and modalities. The key points in the project timeline for engagement with stakeholders are:

Phase 0:

- Recce trip (see Section 4)
- Inception Meeting, including an introduction to DRIFT EFlows

Phase 1:

- Model selection workshop

Phase 2:

- Main data collection trips:
    - River
    - Estuary
- Scenario selection and verification of indicators for use in the assessment

Phase 3:

- Scenario results, and the way forward.

The dates for these activities are included in the schedule in Section 9. In addition, there will be close contact between the EFlows team and the SADC GMI responsible for the groundwater studies in the basin.

Table 7.1 Preliminary list of project Stakeholders

Sector	Name	Role in project	Location
GOVERNMENT	Ministry of Land, Environment and rural development (MITADER) - ND of Environment	Involved in activities aiming at environmental protection, including EFlows	Mozambique
	Agência nacional de Controlo de Qu alidade Ambiental	Involved in activities regarding environmental enforcement strengthening	Mozambique
	Instituto Nacional de Investigação P esqueira	Involved and benefits from characterisation of ecosystems and consideration of their needs in terms of water regime	Mozambique
	Gaza, Inhambane, Sofala and Manica Provincial offices	Involved in national meetings, information dissemination and community awareness on early warning systems; ; potential for provision of data	Mozambique
	Massangena, Inhassoro, Govuro, Ma bote, Machanga, Machaze District Councils		Mozambique
	Chimoio, Beira, Dongo Municipalities		Mozambique
	Environment Management Agency (EMA)	Involved in activities aiming at environmental protection, including EFlows	Zimbabwe
	Nyanga National Park	Involved and benefits from characterisation of ecosystems and consideration of their needs in terms of water regime	Zimbabwe
	Rural District Councils	Involved in national meetings, information dissemination and community awareness on early warning systems; ; potential for provision of data	Zimbabwe
	Mutare City Municipality		Zimbabwe

Sector	Name	Role in project	Location
LOCAL DECISION AND MANAGEMENT BODIES/INSTITUTIONS	Basin Committees (Pungwe and Save)	Involved in national meetings, and in particular for TDA/ SAP Involved in flood management plans elaboration and water sharing procedures for EFlows	Mozambique
	Sub-basin Committees (Nhazonia, Gorongosa)	Involved in flood management plans elaboration, and water sharing procedures for EFlows	Mozambique
	Comites Locais de Gestao e Risco de Calamidades		Mozambique
	Comites de gestão de Recursos naturais (CRN)	CRN consulted for assessing key ecosystems status and EFlows	Mozambique
	Catchment Councils (Save Catchment Council) (Honde Sub-catchment)	Involved in national meetings, and in particular for TDA/ SAP Involved in flood management plans elaboration (1.3) and water sharing procedures for EFlows	Zimbabwe
	6 sub-catchment councils	Involved in flood management plans elaboration and water sharing procedures for EFlows)	Zimbabwe
NON-GOVERNMENT AND COMMUNITY ORGANISATIONS, CIVIL SOCIETY	Comites locais de gestao d e riscos (CLGRC)	Involved in flood management plans elaboration, and water sharing procedures for EFlows	Mozambique
	Comites de gestão de Rec ursos naturais(CRN)	Involved in flood management plans elaboration, and water sharing procedures for EFlows	Mozambique
	Southern Alliance for Indigenous Resources (SAFIRE)	Involved in water sharing procedures for EFlows	SADC
	Bio-Innovate Zimbabwe (BIZ) (to check for Program geographical footprint		Zimbabwe
	Sustainable Agriculture Technology (Wildlife in Livelihood Development: WILD)		SADC
	Frankfurt Zoological Society (FZS)		International

Sector	Name	Role in project	Location
PRIVATE SECTOR	Farmers	Involved in water uses assessment and water sharing procedures for EFlows, also custodianship of the rivers	Mozambique and Zimbabwe
	Extractive mining companies	Interested in environmental enforcement strengthening	Mozambique
	Gold panners	Interested in environmental enforcement strengthening	Mozambique
	Fishermen	Consulted for local knowledge on species and resource utilisation, assessing key ecosystems status and EFlows	Mozambique and Zimbabwe
	Parque Nacional de Gorongosa (Carr Foundation)	Consulted for local knowledge on species and resource utilisation, assessing key ecosystems status and EFlows; also on EFlows study team	Mozambique
RESEARCH/ACADEMIA	University of Zambezi	Involved in roadmap for environmental issues	Mozambique
	Eduardo Mondlane University	Involved in ecosystems status and needs assessment; also on EFlows study team	Mozambique
	University of Zimbabwe	Involved in roadmap for environmental issues; also on EFlows study team	Zimbabwe
	Africa University		Zimbabwe
	WaterNet	Involved in EFlows assessment (BRIDGE operator)	SADC
	Oregon State University	Local scientific knowledge and data collection; interested party	International
	SADC-GMI	Responsible of groundwater inputs to EFlows	SADC
DONORS AND COOPERATING PARTNERS	Grid-Arendal	Co-financing Involved in the establishment of a funds mobilization roadmap	International
	GIZ	Co-financing Involved in the establishment of a funds mobilization roadmap	International
	DFID-CRIDF	Co-financing Involved in the establishment of a funds mobilization roadmap	International
	GEF	Co-financing Involved in the establishment of a funds mobilization roadmap	International

In engaging with Stakeholders, the communication strategy for the project is as follows:

1. Present project information in a transparent way
The aim is to share information on the project in a factual and easy to comprehend format so that Stakeholders are able to comprehend the aims of the project, the expected outcomes, what their role is, and how the outcomes may affect them.

2. Communicate with Stakeholders in the manner that works best for them
Select the most suitable communication channel for each group of Stakeholders (email, phone, in-person meetings; forum meetings).

3. Incorporate Stakeholders knowledge, information and concerns
There are several ways in which Stakeholders information and concerns will be included in the project. These are:

1. Inviting input of Stakeholders to decisions during field trips, including location of EFlows zones
2. Ensure that the indicators used reflect Stakeholders use of and concerns about the system
3. Ensure that relevant Stakeholder knowledge is incorporated into the Response Curves in the DRIFT model (Section 2.1.1.3), such as the life-histories and responses to changes in flows
4. Ensure that the scenarios assessed reflect Stakeholder concerns so as to highlight trade-offs and opportunities for optimising use of the Basin's water, promoting aquatic ecosystem functioning, and including non-flow related issues, such as over-fishing.

The success of the project is reliant on close cooperation with Stakeholders. Apart from meetings and reporting, we will seek assistance in accessing data and undertaking field surveys both in terms of their knowledge of local conditions, and availability of equipment that could enhance data collection.

4. Provide feedback to Stakeholders on how their interests and issues are addressed
The project reports and presentations at meetings will provide an opportunity to feedback to Stakeholders on how their information and concerns have been included in the project (as per point 3 above). A particular focus of this will be feedback on implications of the aquatic ecosystems of the scenario assessment and options for future flow and other management of the Pungwe River, Estuary and near shore coastal environment.

8 PHASES AND TASKS

The assignment has been divided into four phases (Inception [Phase 0]; Phase 1, 2 and 3) and a set of activities that is integrated into all four phases (Integrated Phase). The tasks and sub-tasks for the rivers, estuary and marine aspects of the EFlows assessment are separate but arranged into the phases, as these must happen in synchrony with one another.

8.1 PHASE 0: INCEPTION

See Section 1.3.1.

8.2 PHASE 1: DELINEATION AND STATUS

Phase 1 comprises the following tasks and deliverables:

Task #	Name of task	Deliverable
1.1	Hydrological, ecological and socio-economic delineation	Delineation Report
1.2	Desktop selection of potential EFlows zones	
1.3	Preliminary selection of indicators for EFlows zones	
1.4	Desktop status and trends assessment for EFlows zones	
1.5	Preparation of baseline hydrology	
1.6	Write-up Delineation Report	

8.2.1 Task 1.1: Hydrological, ecological and socio-economic delineation and confirmation of EFlows zones

The objectives of this task are to:

- divide the river into relatively homogeneous longitudinal zones in terms of biophysical characteristics (reach analysis) and land-use;
- select homogeneous sampling areas for socio-economic surveys;
- harmonise the biophysical river zones and social areas so that the social and ecological data focus on compatible zones;
- select EFlows zones for:
    - holding EFlows (see Task 3.3: Development of Holding EFlows for key remaining parts of the Pungwe Basin)
    - detailed EFlows assessments
- develop simple (GIS) base maps for use as required
- write-up a Delineation Report.

The information generated in this task will be used throughout the study, to contextualise the predicted response of different parts of the river ecosystem.

Delineation of the study area and profiling of the river will consider:

- Ecology:
    - Hydrology
    - Geomorphology
    - Chemistry and temperature
    - Biology
- Socio-economics:
    - Population
    - Land use
    - Use of water
    - Household use of aquatic resources
- Harmonisation of ecological and socio-economic zonations.

This desktop description of the ecological and socio-economic context will also inform the selection of indicators and the sampling approach for the field work.

8.2.2 Task 1.2: Preliminary selection of indicators for EFlows zones

DRIFT uses input data from several external sources, which generate the relevant time-series information for the baseline and other scenarios. The foundation data are baseline hydrological, hydrodynamic and hydraulic time-series, and simulations of how these are expected to change with infrastructure and its operation, abstractions and climate change. These are translated in DRIFT into a suite of socially- and ecologically-relevant summary statistics (indicators), such as onset of the wet season or minimum 5-day dry season flow.

Ecosystem and social indicators are a set of indicators that reflect important aspects of the riverine ecosystem and the livelihood of the people who depend on it. They are deemed to be sensitive to a change in the driver indicators by changing in one of the following ways:

- Abundance/size, e.g., fish
- Extent (area), e.g., cover of riparian tree community on the upper dry bank
- Concentration, e.g., sediments and nutrients.

Discipline-specific indicators and the links between driving and responding indicators will be derived by the EFlows team. Some of the driving indicators will be those generated outside of DRIFT. Others will be ecosystem indicators whose predicted changes are provided through response curves in DRIFT.

Indicators are selected to represent each one of the disciplines, with due consideration of their relevance for other disciplines. For instance, the geomorphological indicator 'Availability of exposed sandy habitat in the dry season' was selected because it represents a prominent channel attribute as well as an important habitat for birds.

8.2.3 Task 1.3: Desktop status and trends assessment for EFlows zones

A status and trends assessment will be done for the main aquatic ecosystems in the Pungwe Basin. To the extent possible this assessment will identify and document past and current pressures:

- describe the current (2022) status of the river ecosystem in terms of its major components (hydrology, water quality, geomorphology; vegetation, fish, water birds and large mammals)
- describe the past status for up to three past periods, such as 1950-60, 1980-90 and 2005-10, and; identify the main drivers of change
- provide an indication of the trends in ecological condition.

Component specific status assessments will be provided, based on existing information, and augmented by field observations (Task 2.2: Collection of ecologically-relevant data at EFlows Zones). The status and trends assessment will establish the historical context for the condition of the aquatic ecosystems of the Pungwe Basin, and build a common understanding of how the river has responded to past pressures.

The overall condition of the ecosystems will be described in terms of A-F Ecological States that is widely used to classify the ecological condition of rivers in Southern Africa. This will be used to select a Baseline Ecological Status (BES) against which predictions of change can be expressed. The BES will be finalised through project meetings, individual meetings with Stakeholders and Sub-task I.2.1: Stakeholder engagement to identify aspects to be included in scenarios for analysis.

8.2.4 Task 1.4: Preparation of baseline hydrology

The Water Resources Simulation Model (WRSM) will be used to simulate monthly flows at identified nodes on tributaries and the main stem of the Pungwe River. The WRSM has been used extensively in Southern Africa and provides the best tool to simulate monthly hydrology. The WRSM will be calibrated on observed flow gauge data. This process will require accessing monthly rainfall, evaporation and flow data from the respective government organisations. In addition, all significant utilisation of surface water must be identified and quantified. From an initial investigation it appears that there are numerous flow gauges in the Basin, the data from which could be used for calibration purposes (Figure 8.1).

The calibrated WRSM will be used to generate monthly time series of natural and baseline monthly flows. These will be generated for the period for which rainfall is available. The WRSM will be configured to generate monthly flows at all the EFlows zones. For the baseline scenario, monthly water demand will need to be estimated for the incremental sub-catchment upstream of each EFlows zone.

The WRSM will also be used to generate natural and current-day monthly flows at the selected EFlows zones, which will be converted to daily flows. This will be achieved using an appropriate daily observed flow record to dis-aggregate the monthly hydrology. If observed flow records are not suitable the Pitman Model (daily version) will be used to generate daily flows using available point daily rainfall and/or the global CHIRPS daily rainfall database.

The same model will be used to generate the hydrology for the scenarios that are selected for analysis in the DRIFT model.

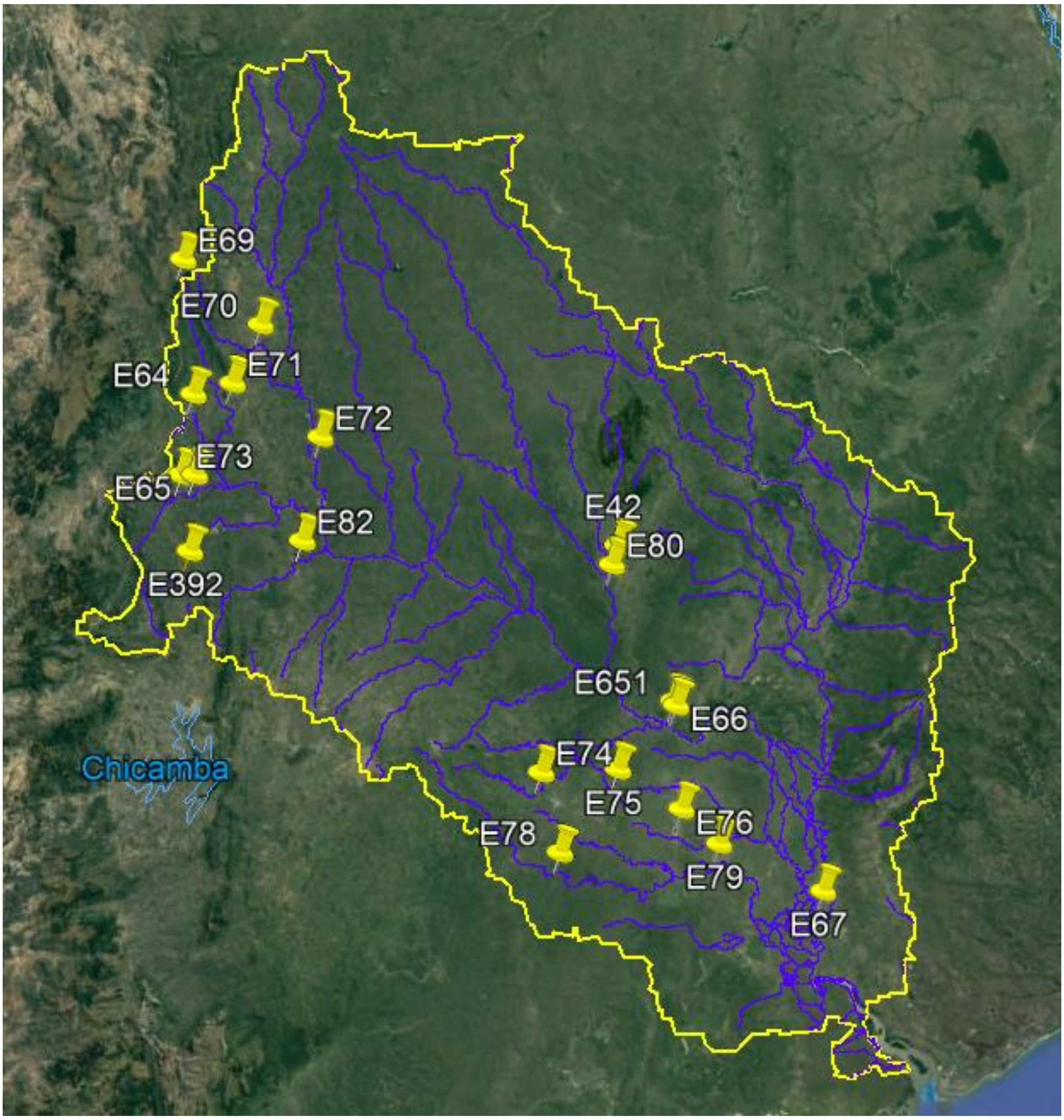

Figure 8.1 Flow gauging stations in the Pungwe Basin

8.2.5 Task 1.5: Write-up Phase 1 Reports

Phase 1 has one report:

- Delineation Report

8.3 PHASE 2: FIELD WORK AND MODEL SET UP

Phase 2 comprises the following tasks and deliverables:

Task #	Name of task	Deliverable
2.1	Topographic and bathymetric data collection	Field Trip Reports
2.2	Collection of socially- and ecologically relevant data at EFlows Zones	
2.3	Sectoral use of water	Socio-economic Report
2.4	Ecosystem services assessment	
2.5	Hydraulics and hydrodynamic modelling for EFZones	Hydraulics and hydrodynamic Modelling Report
2.6	Set-up and calibrate EFlows model for rivers	Specialists' Report; DRIFT-Pungwe
2.7	Set-up and calibrate EFlows model for estuary	
2.8	Write up Phase 2 Reports	Capacity Building Report

The bulk of the field data collection will need to be conducted in the dry season. The remaining surveys will be done in the transitional seasons, i.e., between dry and wet. No wet season surveys are planned as access is difficult and dangerous in the wet season.

8.3.1 Task 2.1: Topographic and bathymetry surveys

Topographical and hydraulic surveys will done at each EFlows site. Cross-section surveys will be done using a Leica TC307 total station (or similar). Active channel (low-flow) cross-sections may need to be surveyed with raft-mounted Acoustic Doppler Profiler (ADP) if safe access into the river is not possible (e.g., presence of crocodiles and/or excessive depth). Discharges will be computed using the velocity-area method and use of suitable instrumentation for a wadable channel / boat access (e.g., OTT C31 current and/or Marsh-Mcbirney electromagnetic meters), or alternatively using the ADP.

Surveys at river EFlows sites will provide the following information:

- single or multiple cross-sectional profiles (depending on the local morphology and hydraulic conditions and habitat), showing the positions of:
- right and left bank (and intermediate for in-channel bars/backwaters) waters' edges
- riparian vegetation species and/or zones on selected cross-sections
- longitudinal thalweg riverbed profiles, with particular importance downstream of pools for determining the stage of zero discharge (i.e. providing pool depth when flow ceases)
- water levels (stages) along the reaches EFlows sites and on each cross-section at the date of the survey/s
- discharge measurements at the date of the survey/s.

Where EFlows sites are located near hydrometric gauging stations, attempts will be made to survey and correlate recent high-flow/flood levels with gauged discharges, augmenting the rating (or stage-discharge) field data-set.

No new topographic/bathymetric or hydraulic surveys will be undertaken for the estuary or nearshore marine environment. The study will rely on available historical information or model results.

8.3.2 Task 2.2: Collection of ecologically-relevant data at EFlows Zones

Data will be collected in each of the EFlows zones in the dry season so that details of the channel and habitats can be seen and measured; partly in conjunction with the team doing the topographic and bathymetry surveys. The Technical DRIFT workshops will also be conducted during these trips.

The field data collections for the river and estuary will be conducted separately as there is some overlap between the two sets of specialists. The dates for these trips are:
River: 24th August – 1st September 2022
Estuary: 24 – 28th October 2022.

River data collection will comprise once-off field data collection and in-field training undertaken in August 2022 for the following components:

- *Hydraulics:* Cross-sections will be undertaken at each river site so as to gather water level and flow information to determine rating relationships and gather the information required to develop hydraulic tables and compute discharge, maximum and average depth and velocity, surface width and wetted perimeter, and velocity-depth classes. An acoustic doppler will be used where required, and the river crossed by boat.
- *Water quality:* The water quality assessment will depend on existing and available data as time-series, rather than point data, are required for present state assessments. Data collected in the field therefore depends mostly on qualitative assessments, relying on surrounding land use and visual cues to identify driving water quality indicators. *In situ* measurements will be taken for variables such as pH, temperature, Dissolved Oxygen and Electrical Conductivity.
- *Geomorphology:* Data collection will focus on sketching morphological features at each site, e.g., available habitats, bed and bank material; walking transects across the channel (where possible) and banks; measurements of mobile material and sediment size classes to determine the relationship between flow and bed mobility; and the completion of data sheets recording site conditions.
- *Riparian vegetation:* Vegetation zones, e.g. marginal, lower, upper, macro-channel bank and floodplain zones will be delineated. Vegetation transects and surveys will be undertaken per vegetation zone. Key riparian indicator sub-populations will be surveyed at the same time, and as close to the hydraulic profile of the transect/s at the site. This enables accurate placement of the upper and lower limits of chosen sub-populations onto the profile. The rating curve or look-up table for each transect is then used to determine the flows at which sub-populations become activated or inundated. Schematic drawings will be completed per site, and fixed-point photographs taken of surveyed transects and vegetation in different zones.
- *Fish:* Most of the sites assessed during the River Reconnaissance Survey showed habitats where electrofishing will be possible. A barricade/net downstream will be required to capture fish due to the fast flow rate/s at most sampling sites. Short fyke nets will also be used where required. Crocodile and hippo reports at some sites mean extra care will be required when electrofishing or sampling in those areas. A range of habitats will be sampled at each EF site,

i.e. riffles, runs and pools.

- *Invertebrates:* A range of habitats will be sampled for invertebrates, i.e., gravel/sand/mud, riffles, runs and marginal vegetation, using standard methodologies and sampling gear. All data will be recorded on data sheets. Habitat assessments will be conducted.

Estuary data collection will comprise:
Once-off field data collection and in-field training undertaken in October 2022 for the following components:

- *Hydrodynamics:* Longitudinal salinity profiles to be collected on the high tide as far upstream as possible (aim for 50 km or zero salinity mark if estuary depth allow). Observations will also be made on cross-section dimensions and relative depths to assist with the validation of estuary model results. If appropriate sites can be found, instrumentation will be deployed to record water level(s), otherwise, relative observations will be made in the field to validate published data.
- *Water quality:* Data will be collected along the estuary length (high tide) for *in situ* system variables (salinity, temperature, turbidity, SS, DO and pH) and dissolved nutrients.
- *Microalgae*: As the microalgae need water quality input, this survey will be conducted simultaneously with the water quality survey.
- *Macrophytes*: One survey to be conducted during which the macrophyte plant communities along the estuary will be identified and mapped.
- *Fish and Invertebrates.* Fish and Invertebrates will be sampled along the entire length of the system. The field data will be augmented by that found in the published and unpublished literature and fish market(s) in the area.

Field Trip Reports will be produced after the river and estuary data collection trips that capture relevant observations and data (see Sub-task I.1.2: Field trip reports).

8.3.3 Task 2.3: Sectoral use of water

Information will be collated on major sectoral users of water in the basin, such as plantation forestry and irrigated agriculture. As far as possible, we will describe the economic contribution of these water users, and their prospects for growth in the basin. This will be based on a combination of satellite data, government reports and the literature.

8.3.4 Task 2.4: Ecosystem services assessment

This task will involve analysis of the social survey data followed by the modelling, mapping and valuation of aquatic ecosystem services. The services to be mapped and valued will include provisioning services such as fisheries and other harvested resources, and cultural services such as recreation and tourism, and regulating services such as carbon storage, pollination and water quality amelioration. These services will be assessed with the use of Anchor's spatial GIS mapping tool for provisioning services, and the use of InVEST software. The ecosystem services team will liaise with the hydrology team on hydrological services.

Ecosystem services will be quantified in physical terms where appropriate and valued in terms of US dollars per hectare per year. Our approach is spatial because values depend on context and vary in space as well as time. The landscape capacity to supply services varies with topography, climate, ecosystem type, and condition, and the human demand for services also varies spatially, with population density, infrastructure, and location. The estimation of ecosystem services will therefore be based on a range of layers that pertain to the landscape capacity to supply the service and the demand for the service. For the former, this will include land cover and vegetation, forest cover, biomass and biodiversity patterns, as well as the aquatic ecosystem delineations produced for this study. For the latter, we will use global and regional datasets on population characteristics and livestock density in conjunction with the data gathered in the field surveys. The focus will be on services from the aquatic ecosystems.

A range of services will be quantified and valued as follows:

- Fisheries: Fisheries value will be estimated on the basis of government statistics and existing studies on the fisheries of this and similar areas..
- Provision of harvested wild resources: The study will estimate the small-scale use of wild biomass resources, wild plant foods and medicines, fuel wood, and raw materials such as poles, reeds and sedges. The stocks of these resources (will be estimated and mapped based on habitat characteristics, and adjusted for their availability based on land tenure. The demand for the resources will be mapped based on population density, household characteristics, and livelihoods from census data and the literature, taking livelihood zones into consideration. The use of resources will be estimated and mapped using a spatial model in which aggregate use was limited by the availability of resources within a typical range of collection. Welfare values will be estimated based on market prices and input costs.
- Livestock forage: This service will be quantified in physical terms as the amount of production (in large stock units) supported, based on spatial data on livestock stocking rates. The annual production was valued using the average gross value added per large stock unit (LSU) derived from national accounts.
- Nature-based tourism: Benefits to Zimbabwe and Mozambique will be estimated in term of the direct GDP contribution of attraction-based tourism, derived from national-level statistics and mapped to the aquatic ecosystem areas within the study area using densities of geotagged photographs uploaded to the internet. To do this, the initial mapping is done at national scale. Benefits to foreign visitors will be estimated in terms of their consumer surplus, which is their willingness to pay over and above what they were required to pay, based on existing studies from the region. National tourism statistics will also be used where available.
- Biodiversity existence: Ball-park estimates will be made based on an existing meta-analysis of stated preference studies and relatively simple assumptions about the spatial allocation of this value in relation to global patterns of species richness to arrive at a ballpark estimate of regional and international willingness to pay for the conservation of biodiversity.
- Water quality amelioration: The contribution of aquatic ecosystems to the removal of anthropogenically elevated phosphorous and nitrogen outputs will be estimated in order of magnitude terms using InVEST. This will take into account the production of these nutrients by land use activities in the landscape, and the removal capacity of aquatic ecosystems, and will be valued using models of water treatment costs.
- Carbon storage: Global datasets will be used to estimate the above- and below-ground biomass and soil carbon. The carbon retention value of these stocks will be calculated in terms of the

avoided losses of economic output by the countries in the landscape as well as the rest of the world using recent published estimates of the global and disaggregated country-specific damage effects of climate change (social cost of carbon).

8.3.5 Task 2.5: Hydraulics and hydrodynamic modelling for EFlows zones

From an EFlows assessment perspective, the relevant outputs from the hydraulic modelling are rating relationships for the cross-sections at EFlows sites. These, together with surveyed cross-section geometry and sediment size classes, are used to produce text tables for import and use in the DRIFT DSS. An ecohydraulics computational model such as HABLFO (Habitat Flow simulation model; Birkhead, 2010) will be used to develop hydraulic text tables for selected cross-sections at the EFlows sites. HABFLO computes ecologically-relevant parameters as a function of discharges, including maximum and average depth, maximum and average velocity, surface width and/or wetted-perimeter, and velocity-depth classes which is a useful 'combined' hydraulic-habitat indicator for quantifying changes in available fish habitat.

The approach taken for the modelling for the estuary hydrodynamics is given in Section 5.3.2.

8.3.6 Task 2.6: Set-up and calibrate EFlows model for rivers

The DRIFT DSS will be set so that it can be used to run scenarios reflecting management options for the rivers and/or wetlands. This involves:

- detailing the project name, Client and consultants involved in the study
- setting up the system description, including:
- EFlows zones and 'Arcs' (river reaches) between EFlows zones
- photographs of EFlows zones
- defining the ecosystem indicators
- linking each ecosystem indicator to its driving indicators
- importing the baseline hydrological data for the EFlows zones, and calculating the seasonal flow indicators
- importing the baseline sediment and hydraulic data for the zones, and calculating the seasonal indicators for each
- generating the response curves for each indicator
- entering explanations of the response in each indicator to a change in each linked indicator
- testing and adjusting through the evaluation of the outputs for a series of Testing Scenarios.

For each EFlows zone, there will be a maximum of eight indicators allowed for each discipline (preferably no more than five excluding hydrology and hydraulics), *viz*.: water quality, geomorphology, vegetation, fish, ecosystem services. The use of available/relevant information on descriptions of the representative species; distribution and abundance (in particular, flow-related limitations to spatial distribution); habitat requirements in terms of water depth, water velocity and substratum type; life histories (e.g., spawning times); anticipated sensitivity to change in the flow regime, harvesting times and volumes, and; any additional relevant information. These will be used to describe links between each identified indicators and its biophysical drivers, such as water flow, habitat availability and food sources. This information will be used to generate response curves that link each indicator with its driving (linked) indicators (e.g., Figure 8.2). Changes in ecosystem services will be expressed in terms of percentage change in welfare gains or losses in monetary terms.

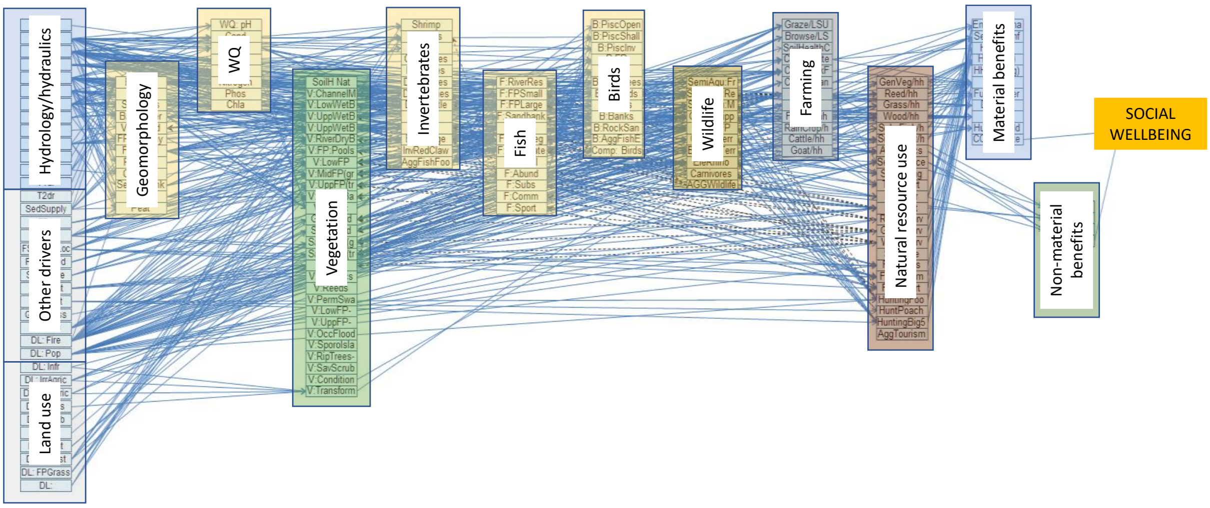

Figure 8.2 Example of a discipline-level assessment framework for one EFlows site in the DRIFT. Each line represents a response curve.

The response curves and supporting evidence/reasoning for each response curve will be housed in the DRIFT DSS. In addition, the background, literature review, status and trends assessments, motivation of indicator and link selection, and response curves with supporting evidence/reasoning will be included in the Specialists' Report (Task 2.8: Write-up Phase 2 Reports).

Assumptions used in the models will be based on available information and expert opinion, and will be explained. The bulk of the discussions/workshops for response curve construction will be done using remote connections.

Once set-up and calibrated, the DRIFT model will be used to run scenarios of change for the Pungwe River in this project, but will also be available for future projects, including assistance with management decisions for the basin.

The budget assumes that at least part of the development for response curves will be done in a workshop setting, where the whole team is together. Depending on the preference of the Client, this workshop could be in Cape Town, or in Beira. Regardless, access to excellent wifi will be a prerequisite.

8.3.7 Task 2.7: Set-up and calibrate EFlows model for estuary

This will follow a similar process as for Task 2.4, but will focus on the estuary, and will use estuarine specialists to set-up and calibrate DRIFT. As for Task 2.6, the socio-economic team will handle the fishery and other ecosystem services valuation aspects.

8.3.8 Task 2.8: Write-up Phase 2 Reports

Phase 2 has four reports:

- Hydrology, Hydraulics and Hydrodynamics Report
- River Specialists' Report
- Estuary Specialists' Report
- Resource Economics Report.

8.4 PHASE 3: ASSESSMENT AND EFMP

Phase 3 comprises the following tasks and deliverables:

Task #	Name of task	Deliverable
3.1	Analyse the scenarios	Scenario Analysis Report
3.2	Marine EFlows assessment	Marine EFlows Report
3.3	Develop Holding EFlows for key remaining parts of the Pungwe Basin	EFlows basin configuration model/balance model
3.4	Develop an EFlows basin configuration model/balance model	
3.5	Write up Phase 3 Reports	

8.4.1 Task 3.1: Analyse the scenarios

The scenarios will potentially affect flow patterns, inundation levels and durations, sedimentation, water quality, as well as the instream/in lake and riparian habitat characteristics, with knock-on effects on productivity and biodiversity of the system. All of these translate into changes in the capacity of the system to supply ecosystem services, ultimately affecting the wellbeing of local communities and people living further afield.

The flow and other time-series for each zone under each scenario will be inputted into the DRIFT DSS, and the predictions of change will be outputted. The predictions will be assessed, amended where necessary and approved by the team, before being compiled into the EFlows Assessment Report.

The DRIFT model predictions will cover the river ecosystem and the estuary.

The scenario analysis will generate:

- semi-quantitative change in the ecosystem and ecosystem service indicators for each scenario (Figure 8.3) for a pre-set time horizon, i.e., same as the length of the hydrological record used in the assessments
- qualitative change in condition of each discipline.
- impact on overall ecosystem condition in each zone (Figure 8.4) or for a whole basin (Figure 8.5) for each scenario for a pre-set time horizon.

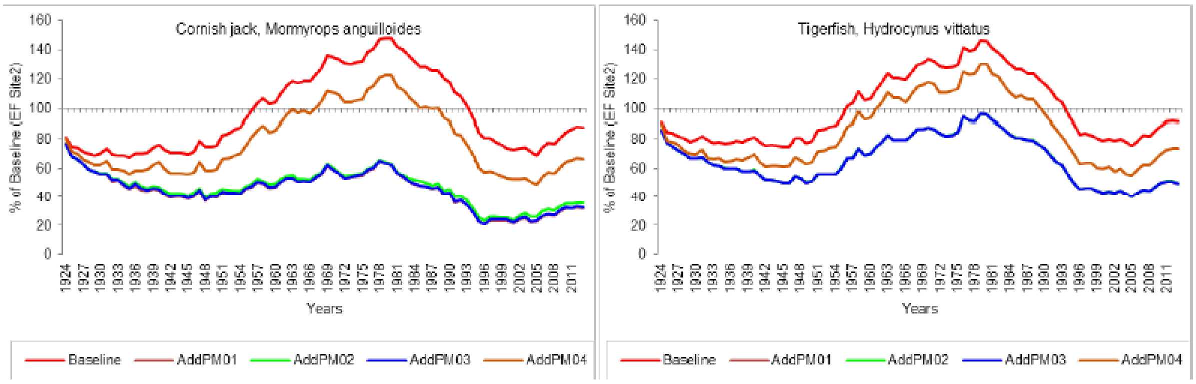

Figure 8.3 Example of DRIFT output for change in indicators (in this case fish) for four scenarios, plus Baseline

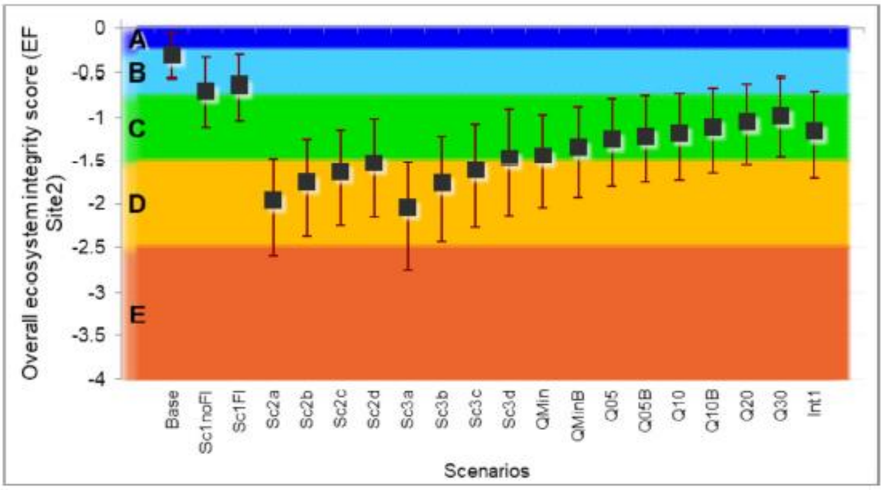

Figure 8.4 Example of DRIFT output for impact river condition per zone for 19 scenarios

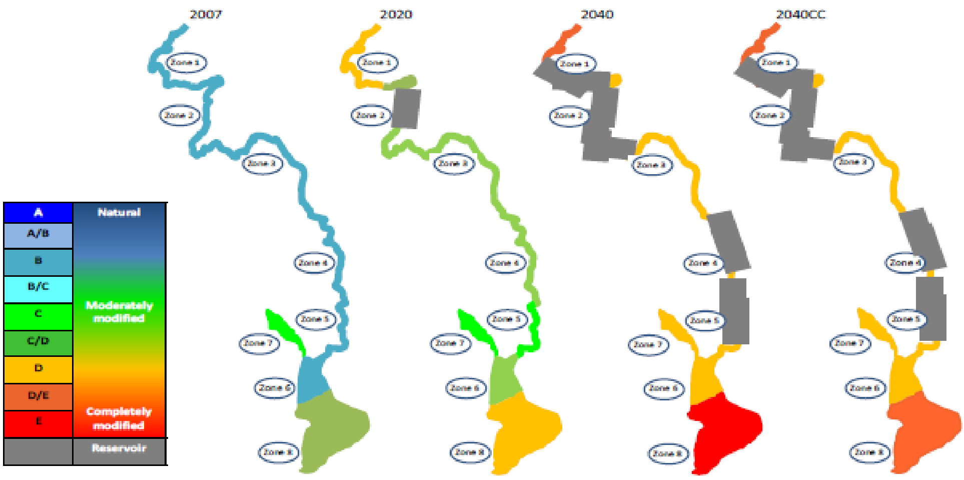

Figure 8.5 Example of output for impact on basin ecological condition for four scenarios

Provision has been made for the selection and evaluation of 10 scenarios overall, including the baseline scenario.

The outcome for these scenarios will be used as the basis for discussion with Stakeholders and the selection of a scenario that will become the agreed 'Objective" flows for the Pungwe Basin as represented by the EFlows zones.

8.4.2 Task 3.2: Marine EFlows assessment

The outputs of the scenario analysis will be used for the marine ecosystems EFlows assessment. The following aspects will be addressed during the marine EFlows assessment.

- Define the study boundaries (marine ecosystem extent) to be assessed considering legislative obligations, ecosystem extent, key ecosystem functions, and resource utilisation (e.g., fisheries)
- Based on the field visit and published literature select keystone/indicator species to minimise the complexity of the assessment
- Identify life-cycle and habitat requirements of keystone species to determine relevant abiotic processes that need to be evaluated (Lamberth *et al.* 2009)
- Describe implications of the present flow regime on selected abiotic processes and biological components (i.e., indicators)
- Assess the impact of future flow scenarios on selected abiotic processes and biological components (i.e., indicators)
- Link to fisheries
- Determine (provisional) EFlows requirements and recommend resource targets (e.g. freshwater flow, river water quality). This step will be informed by whether or not there is sufficient understanding and/or data to translate management and environmental quality objectives into specific freshwater requirements or target values. Given that this is a screening-level assessment of the marine EFlows requirements, results may only be set in broad terms and may need future refinements if highly sensitive to predicted flow changes.

Supporting specialists reports will be prepared for the abiotic (mainly hydrodynamics and broad water quality features such as turbidity) and biotic (mainly focus on commercially important fisheries species) components. These reports will include an assessment of available data in relation to changes in river runoff and assist with developing flow response relationships/curves. This will also include the development of a resource monitoring programme. Note, however, that the assessment of the marine environment EFlows will be at a 'screening level' and thus not at the same level of detail as the Estuary and Rivers EFlows assessments.

8.4.3 Task 3.3: Development of Holding EFlows for key remaining parts of the Pungwe Basin

The EFlows basin configuration/balance model will be set up for a minimum of 12 nodes in the Pungwe Basin.

8.4.4 Task 3.5: Develop an EFlows basin configuration model/balance model

A Pungwe EFlows basin configuration model/balance model will be developed using the results of the DRIFT assessment, and the outcomes of Eflows assessments for similar rivers.

8.4.5 Task 3.5: Write-up Phase 3 Reports

Phase 3 has three reports and two databases:

- Reports:
    1. Scenario Assessment Report for Rivers and Estuary
    2. Marine EFlows Report
- Databases
    1. DRIFT-Pungwe DB, and associated files
    2. EFlows basin configuration model/balance model

8.5 INTEGRATED TASKS

The following tasks and deliverables are integrated across all the phases:

Task #	Name of task	Deliverable
I.1	Project Management: - Semesterly Progress and Financial Reports - Field Trip Reports - Client Meetings	Progress Reports/Field Trip Reports
I.2	Stakeholder engagement: - Stakeholder engagement to identify aspects to be included in scenarios for analysis - Stakeholder engagements to finalise a suite of scenarios for analysis - Stakeholder engagements to present study outcomes - Stakeholder engagement to select a scenario(s) for implementation	Presentations prepared for Stakeholder meetings
I.3	Capacity building - 0.5-day virtual Stakeholder Workshop: Introduction to EFlows (Phase 1) - online - 1-day Team Workshop: Introduction to EFlows (Phase 1) – probably online - On-project learning on applying specialist knowledge in a DRIFT setting (Phases 1/2/3)	DRIFT User Manual

8.5.1 Task I.1: Project management

8.5.1.1 Task I.1.1: Mid-way Progress Reports

There will be one mid-way progress reports, which will include:

- Progress on tasks
- Budget updates

- Identification of issues or opportunities
- Feedback on the on-project learning.

8.5.1.2 Sub-task I.1.2: Field trip reports

Field trip reports will be prepared by each team that undertakes a field trip, including the Reconnaissance Visit Report. These will provide itinerary, weather conditions, team members, relevant observations with photographs, a description of the data collected, and a discussion of any challenges encountered.

8.5.1.3 Sub-task I.1.3: Client meetings

We have budgeted for Client meetings in Inception and to present the draft results, as well as a meeting in the 6th and another in the 12th months. These will all be held virtually. The project leader will also be available for several *ad hoc* meetings (virtual) on a needs basis during the course of the project.

8.5.2 Task I.2: Stakeholder engagement

GWPSA PMU will take responsibility for identification of stakeholders, organisation of stakeholder meetings, attendant documentation such as attendance sheets and minutes, and introductory presentations. The consultants' team will be responsible the presentation of technical information, and responding to technical questions.

The consultants' team will also be responsible for sharing the itineraries and or schedules of key events such as meetings and field trips at least two weeks ahead of schedule to allow the PMU adequate time to appraise the stakeholders to attend. This should be clear and streamlined in the revised Inception Report workplan and/or on a needs basis where timelines cannot be factored in advance.

See Section 7.

8.5.2.1 Sub-task I.2.1: Stakeholder engagement to identify aspects to be included in scenarios for analysis

Stakeholders will also be consulted on the selection of EFlows zones; indicators, scenarios, criteria for evaluating scenarios, evaluation of outcomes and selection of preferred scenarios. This should be an iterative and consultative process that recognises the need to balance water demands and supplies, including those for environmental maintenance and related social structures.

Scenarios help us to explore options for the future, outlining the predicted benefits and costs of each. They help governments and other Stakeholders identify through negotiation and decision-making what the desired trade-off between resource protection and resource development. It follows that the choice of scenarios should be made by the Stakeholders, with help from the PMU and the EFlows team. The scenarios may include (but not limited to) operating rules (either considered or existing) for existing and proposed water-resource developments, targets for protection of key species, water quality abatement measures, and; climate change predictions.

Provision has been made for the selection and evaluation of 10 scenarios overall, including baseline.

Linked in with the selection of scenarios is the choice of criteria that will be used to evaluate their outputs, and the indicators that will inform this evaluation, such as a limit to the drop in ecological condition for development scenarios, or a target change in any one species/guild/social use. The indicators include those that have meaning/relevance for Stakeholders in the evaluation of scenarios, but must also be responsive to changes between the scenarios include driving and responding indicators that capture ecosystem function, and thus are needed to calculate other indicators. The EFlows team will suggest an initial suite of evaluation criteria, indicators and linked indicators, which will be refined through project meetings and meetings with Stakeholders. The lists may also be adjusted as the project proceeds and the information available for making predictions is assessed.

8.5.2.2 Sub-task I.2.2: Stakeholder engagements to finalise a suite of scenarios for analysis

As above.

8.5.2.3 Sub-task I.2.3: Stakeholder engagements to present study outcomes

The agenda at these engagements will focus on the DRIFT outputs for the scenarios in various formats, including how they fare with respect to evaluation criteria, with the aim of gauging preference of one or more of the scenarios. The Stakeholder engagements will be divided into different sessions, some virtual and others in person, to ensure maximum participation/feedback.

8.5.3 Task I.3: Capacity building

EFlows Assessments offer opportunities for hands on learning in every facet, including: collection and preparation of hydraulic/hydrodynamics data; developing specialist inputs in geomorphology, water quality, ecosystem functioning, fisheries, wildlife and social sciences, and interpreting the outputs.

Two information sharing workshops are planned.

1. The first is a four hour virtual workshop that was originally conceived as a DRIFT training workshop, but following comments on an earlier draft of this report, and on the presentations made at the Inception Meeting (02.08.22), has been reconceived as a discussion of the pros and cons of the models that will be applied in the EFlows assessment.
2. The second is a one-day project workshop aimed at the EFlows project team to provide the regional river and estuarine specialists with an understanding of the inputs they will need to provide for the EFlows assessment using DRIFT.

The other capacity building will be through on-project training and mentoring for members of the EFlows team. This will be two way training, with regional specialists providing insights on their local ecosystems, and the international specialists providing insight on applying that knowledge in a DRIFT setting.

Key project activities in this regard are:

- Literature reviews and report writing
- Status and trends assessments
- Indicator and links selection

- Field data collection
- Response curve development
- Scenario analysis.

8.5.3.1 Sub-task I.3.1: Workshop 1 = 0.5-day virtual Stakeholder Presentation: The use of models in the EFlows assessment

A half day of non-technical presentations that will cover:

- For each of the models
    - Purpose
    - Examples of three similar models
        - Pros and cons of each (the three similar ones and the one chosen)
    - Motivations for selecting the model
    - Examples of its application elsewhere
    - Input data
    - Output data
- Data flows between the models in the EFlows Assessment
- What will

The sessions will be a mixture of PowerPoint Presentations, open discussion and information sharing.

8.5.3.2 Sub-task I.3.2: Workshop 2 = 1-day Workshop: Technical DRIFT

This is an advanced course aimed at the EFlows specialist team (Table 8.1). The course will be limited to **eight** people, and will focus on familiarising the EFlows specialists with use of DRIFT to construct response curves.

Objectives:

- to provide participants with a working understanding of the DRIFT EFlows software from the perspective of a participant in an EFlows assessment.

The sessions will be a mixture of PowerPoint Presentations, open discussion and information sharing, and a series of hands-on training sessions that will introduce the DRIFT DSS, and use DRIFT User Manual to navigate the different modules and routines in the DSS. Every participant will need a laptop computer with them at the course that meets the minimum requirements listed below:

Operating system:	Windows 7, 8 or 10.
Minimum RAM:	4 GB.
Recommended:	Intel I5 2 GHz.
Disk space required:	10 MB for software, and a minimum of 600 MB for the data files.
Other software:	In order to view the maps in the SETUP section of the DSS, Google Earth must be installed on the computer.

Table 8.1 Preliminary Agenda for 1-day Workshop: Technical DRIFT

Time	Item

8:30	Overview of the DRIFT process
8:45	Input data for DRIFT set up and scenarios
9:00	Indicators and linked indicators
9:20	Loading the DRIFT DSS onto personal computers, and saving data for sending to Knowledge managers
10:00	Introduction to the DSS
10:30	COFFEE/TEA BREAK
11:00	Hands-on practical: Navigating the DSS
12:00	Hands-on practical: KNOWLEDGE CAPTURE
13:00	LUNCH
14:00	Hands-on practical: KNOWLEDGE CAPTURE
15:00	COFFEE/TEA BREAK
15:30	Hands-on practical: ANALYSIS AND POST-PROCESSING
16:50	Summary and next steps

8.5.3.3 Sub-task I.3.3: On-project learning

Training courses and workshops are important aspects of Capacity Building. True understanding of the managerial and technical aspects of an EFlows Assessment, however, comes from working through the process with an EFlows team, either as a coordinator or a specialist, under the guidance of an experienced EFlows practitioner.

With this in mind, the project team (Table 2.2) includes eight regional specialists, one in each of the following positions:

- DRIFT DSS Operation (river and estuary), incl. formatting and organising hydrological data
- Ecohydraulics (river)
- Water quality (river)
- Riparian and aquatic flora (river)
- Macroinvertebrates (river)
- Freshwater fish (river)
- Resource economics (river and estuary)
- Hydrodynamics (estuary)
- Macrophytes (estuary)
- Estuarine and near-shore fish and fisheries (estuary and marine).

The regional team members are specialists in their subject areas, but do not necessarily have experience in EFlows assessments or DRIFT. Their assigned roles and responsibilities in this assignment are the same as specialists in any DRIFT EFlows assessment, except that they will receive guidance in fulfilling any roles that are unfamiliar to them from other members of the EFlows team. In this regard, responsibility for the above-mentioned specialisations will be shared by a regional and an international specialist as per Table 5.4. For their part, the international specialists have experience in applying their area of expertise in EFlows assessments, but do not necessarily have hand-on experience in the Pungwe Basin. In this regard, they will receive guidance from the regional specialists in the EFlows team.

Having GWPSA staff and local scientists who are familiar with activities in the Basin on the study team is an enormous benefit to the project, and will serve to enhance the understanding of the EFlows team of the unique context and complexities of the Pungwe Basin.

There will also be opportunities for discussion on other disciplines and on general management of an EFlows assessment. The hope is that the core skills for future EFlows assessments will remain in the basin after project completion.

Table 8.2 EFlows team arrangement for two-way on-project learning

Area	Regional specialist	International specialist
DRIFT DSS Operation	Herminio Mulungo/Jose	Alison Joubert/Hassan Bukhari
Ecohydraulics	Herminio Mulungo	Drew Birkhead
Water quality	Tamuka Nhiwatiwa	Patsy Scherman
Geomorphology	-	Kate Rowntree
Macroinvertebrates	Tamuka Nhiwatiwa	Justine Ewart-Smith
Riparian and aquatic flora	Ricardo Guta	Karl Reinecke
Fish	Lightone Marufu	Steven Lamberth
Water quality/Physico-chemical	Antonio Hoguane	Lara van Niekerk and Susan Taljaard
Macrophytes	Celia Macamo	Janine Adams
Fish and fisheries	Bernardino Sérgio Malawene	Steve Weerts, Fiona MacKay and Steven Lamberth
Resource Economics	Lindah Mhlanga Bernardino Sérgio Malawene	Jane Turpie, Gwyn Letley

9 DELIVERABLES AND SCHEDULE

9.1 DELIVERABLES

There are 11 main deliverables for the assignment, plus two progress reports and a project completion report (Table 9.1). A calendar showing schedule of the tasks required to produce the deliverables is show in Table 9.2.

Table 9.1 Deliverables

#	Title	Delivery date of first draft
	Inception Phase	
1	Inception Report	June 2022
	Phase 1	
2	Delineation Report	October 2022
3	Preliminary Status and Trends Report	October 2022
	Phase 2	
-	Financial and Technical Progress Reports	December 2022
-	Field Trip Reports (river & estuary)	October & November 2022
4	Hydrology, Hydraulics and Hydrodynamics Report	December 2022
5	Resource Economics Report	December 2022
6	River supporting Specialists' Report	March 2023
7	Estuary supporting Specialists' Report	March 2023
8	Marine EFlows Assessment Report	April 2023
	Phase 2	
-	Financial and Technical Progress Reports	June 2023
9	Scenario Assessment Report for Rivers and Estuary	July 2023
10	Updated EFlows basin configuration model/balance model	September 2023
11	DRIFT-Pungwe DB, and associated files and User Manual	September 2023
-	Project Completion Report	October 2023

9.2 WORK SCHEDULE

A calendar showing schedule of the tasks required to produce the deliverables is show in Table 9.2.

Table 9.2 Schedule of tasks required to produce the deliverables

Phase	Task #	Name of task	2022								2023									
			Inception		Phase 1			Phase 2						Phase 3						
			1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
			M	J	J	A	S	O	N	D	J	F	M	A	M	J	J	A	S	O
Inception Phase	0.1	Literature review																		
	0.2	Data and model review																		
	0.3	Selection of EFlows zones																		
	0.4	Recce field visit		SE																
	0.5	Workplan																		
	0.6	Inception Report																		
		Inception Meeting			SE															
		Presentations: Introduction to EFlows (virtual)			SE															
Phase 1	1.1	Hydrological, ecological and socio-economic delineation																		
	1.2	Final selection of EFlows zones																		
	1.3	Preliminary selection of indicators for EFlows zones																		
	1.4	Desktop status and trends assessment for EFlows zones																		
	1.5	Preparation of hydrology timeseries																		
	1.6	Holding EFlows for key parts of the Pungwe Basin																		
	1.7	Write up Phase 1 Reports																		
		1 day workshops: Technical DRIFT (in person)																		
		Progress Report Back																		
Phase 2	2.1	Topographic and bathymetry surveys				SE														
	2.2	River main data collection trip				SE														
		Estuary main data collection trip						SE												
	2.3	Sectoral use of water																		
	2.4	Ecosystem services assessment																		
	2.5	Hydraulics and hydrodynamic modelling																		
	2.6	Set-up and calibrate EFlows model for rivers																		
	2.7	Set-up and calibrate EFlows model for estuary																		
	2.8	Write up Phase 2 Reports																		
		Progress Report Back																		
Phase 3	3.1	Analyse the scenarios																		
	3.2	Assess marine flows																		
	3.3	Holding Flows																		
	3.4	Develop an EFlows basin configuration model/balance																		
	3.5	Write up Phase 3 Reports																		
		Present scenario results															SE			
		Present EFlows basin configuration																	SE	
Integrated	C.1	Client Meetings	Client meetings shown in green in above schedule																	
	C.2	Stakeholder engagement	See SE annotations in above schedule for engagement opportiunities																	
	C.3	Capacity building	On-project learning ongoing. Workshops shown in red above schedule																	

9.2.1 Main field data collection dates

River: 24th August – 1st September 2022

Estuary: 24 – 28th October 2022.

10 FINANCIAL MANAGEMENT

The project total budget is USD 612 492.38. The schedule of payment and deliverables is indicated in Table 10.1.

Table 10.1 Payment schedule

#	Deliverable	Proposed payment
Inception Phase		
1	Inception Report	20%
Phase 1		
2	Delineation Report (including Status and Trends)	10%
Phase 2		
-	Field Trip Report	10%
3	Hydrology, Hydraulics and Hydrodynamics Report	10%
4	River supporting Specialists' Report	10%
5	Estuary supporting Specialists' Report	10%
6	Resource Economics Report	10%
Phase 3		
7	Scenario Assessment Report for Rivers and Estuary	10%
8	Marine EFlows Assessment Report	-
9	DRIFT-Pungwe DB, and associated files	10%
10	Updated EFlows basin configuration model/balance model	

11 RISK ASSESSMENT

The risk matrix presented in Table 11.1 has been developed which describes the type of risk, likelihood of the risk and the mitigation or control actions that can be taken for the individual tasks outlined for this project. The risk matrix will be updated and monitored on an on-going basis together with input from GWPSA PIU.

Table 11.1 Risk matrix for the assignment

Risk	Level	Management Actions
Timeframe for delivery The timeframe for the project is considered adequate. However unforeseen delays cannot be ruled out.	Low	The Project Team will keep track of the progress of the project and timeously flag any unforeseen delays
Availability of >50 years daily hydrological timeseries	Low	This is a crucial input to the EFlows Assessment, and work has already started on accessing these records
Other data availability Key long-term time-series data are required for hydrology and if possible for water quality (in particular salinity) and sediments. A preliminary list of data requirements is provided in this Inception Report. In the past similar datasets have proved difficult to access	Moderate	Availability of data is considered to a moderate risk against the success of the project. If the latter are not available, an approximation will be developed based on whatever data are available for use in DRIFT Of the requested data, the topographical and bathymetric data, and the data on harvesting of natural resources, are the most crucial
Refusal of permission to access river EFlows sites for data collection	Moderate	This is a distinct possibility as the sites are in or near Renamo territory. The risk can be mitigated by the presence of at least one ARA-Centro official with the project team (as was the case for the Recce), and by advance notice to and permission from police in the areas (for this the project team will also require the support of ARA-Centro).
A secondary aspect of the data availability is the risk that the data (specifically hydrological data) themselves are contested.	Moderate	To avoid this, GWPSA should facilitate consensus between the countries on the hydrological data used in the study
Inadequate stakeholder consultation Key Stakeholders	Low	The GWPSA PIU will coordinate all stakeholder engagements
COVID-19 impact (SADC). Travel restrictions are being relaxed in the region, as such this risk is rated low. However, there remains as chance of the reintroduction of travel restrictions.	Low	Should travel restrictions be put in place the project will revert to online engagements with the Client and with all Stakeholders Provided the restrictions post-date the field data collection, they should not impact on the quality of the technical work. At this stage, it is considered unlikely that COVID restrictions will affect field work

11.1 ASSUMPTIONS AND LIMITATIONS OF DRIFT

Predicting the effect of flow changes on aquatic ecosystems is difficult because the actual trajectory and magnitude of the change is additionally dependent on so many other variables, such as climate, sediment supply and human use of the system. Thus, several assumptions underlie the predictions. Should any of these assumptions prove to be invalid, the actual changes may not match the predicted changes. This does not necessarily make the predictions themselves incorrect or invalid, but simply means that the surrounding set of circumstances that support the predictions has changed.

The following important major assumptions apply:

- The baseline hydrology closely approximates the actual flow conditions in the river over the period of record
- Different drivers and different parts of their regime affect the river ecosystem in different ways. Changing one part of the flow regime will change the river in a different way than will changing another part
- Change is expressed as a percentage move towards or away from Baseline
- Changes include water flow and non-flow related changes
- Predictions are based on the horizon dictated by the hydrological records.

The main limitation is the paucity of data. This is a universal problem, as ecosystems are complex, and we will probably never have complete certainty of their present and possible future characteristics. Instead it is essential to proceed cautiously and aid decision-making, using best available information. The alternative is that water resource development decisions are made without consideration of the consequences for the supporting ecosystems, potentially making management of sustainability impossible. Data paucity is addressed in the DRIFT process by accessing every kind of knowledge available - general scientific understanding, international scientific literature, local wisdom and specific data from the river under consideration or from similar ones – and capturing these in a structured process that is transparent, with the DSS inputs and outputs checked and approved at every step. The Response Curves used (and the reasoning used to construct them) are available for scrutiny within the DSS and they, as well as the DRIFT DSS, can be updated as new information becomes available.

A second aspect of the paucity of data is that it is neither known what the river was like in its pristine condition nor exactly how abundant each ecosystem aspect (sand bars, fish, etc.) was then or is now. To address this, all DRIFT predictions are made relative to the baseline situation (there will be a little more, or a lot less, than today, and so on).

These inherent uncertainties also mean that the trends and relative position of the scenarios are more reliable predictors of the impacts of the scenarios than are their absolute values. Also, DRIFT is designed to predict overall condition, and focusing on one indicator to the exclusion of others, although sometimes required, should be done with caution and an understanding of the uncertainties.

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