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Environmental Flows in Rufiji River Basin Assessed from the Perspective of Planned Development in Kilombero and Lower Rufiji Sub-Basins

Technical Assistance to Support the Development of Irrigation and Rural Roads Infrastructure Project

March 2016 - Final

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Environmental Flows in Rufiji River Basin Assessed from the Perspective of Planned Development in Kilombero and Lower Rufiji Sub-Basins

Technical Assistance to Support the Development of Irrigation and Rural Roads Infrastructure Project (IRRIP2)

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Submitted to:	Thomas Kaluzny, United States Agency for International Development (USAID) Contracting Officer's Representative (COR)
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ES EXECUTIVE SUMMARY

ES.1 Introduction and Study Area

This report presents the environmental flow requirements determined for the Kilombero River Valley, with further consideration of environmental flow needs extending to the Lower Rufiji Basin and its floodplain-delta system. The Rufiji River Basin consists of the Great Ruaha, Kilombero, Luwegu, and Lower Rufiji sub-basins. It is targeted by the Government of Tanzania (GoT) for major socio-economic development over the next two decades as part of the Southern Agricultural Growth Corridor of Tanzania (SAGCOT). Water resources are central to development plans. If targets are met, irrigation water demand will increase by 7 billion cubic meters per year, and 2.4 gigawatts of new hydropower will be installed. A majority of this new development will be in the Kilombero and Lower Rufiji sub-basins, which contain some of Tanzania’s most valued landscapes and ecosystems (**Figure ES.1**).

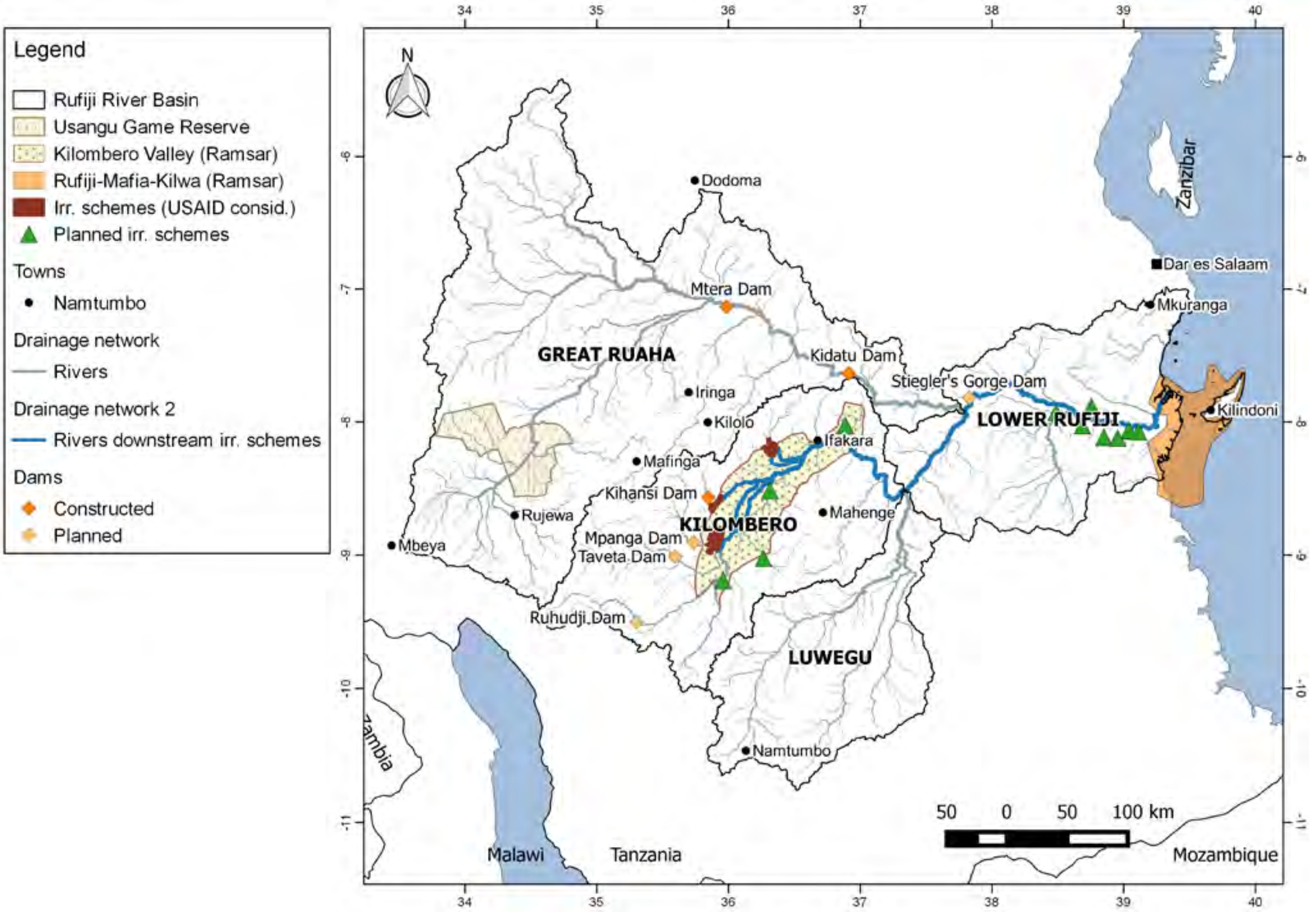
Among the most internationally recognized of these are wetlands, river floodplains, and coastal zones protected under the Ramsar Convention and system of United Nations Educational, Scientific and Cultural Organization World Heritage Sites. These aquatic systems, like others around the globe, provide valuable ecosystem services such as water, food, fiber, and fertile soils that hundreds of thousands of people depend upon for their welfare and livelihoods. These ecosystems and their services are vulnerable to degradation if sufficient quantities of clean water do not continue to flow through them in a seasonal regime to maintain habitats and cue life history processes such as spawning. Development plans for the Rufiji Basin recognize these vulnerabilities and thus feature environmental protections to seek long-term sustainability of social, economic, and environmental components of the basin.

The Water Resources Management Act of 2009 provides the institutional and legal framework for the sustainable management and development of water resources in Tanzania. In the Act, Basin Water Boards are empowered to prepare basin water resources management plans, which are to include, among other things, a water balance for each basin, a classification of water resources, requirements for the reserve for each water resource, and measures for implementation of the plan. In the 2009 Water Act, the reserve is “the quantity and quality of water required for:

1. Satisfying basic human needs by securing a basic water supply for people who are now or shall in the reasonably near future be:
    a. relying upon
    b. taking water from
    c. being supplied from the relevant water resources
2. Protecting aquatic ecosystems in order to secure ecologically sustainable development and the use of relevant water resources

The component of the reserve protecting aquatic ecosystems is equivalent to an environmental flow, which is “the quantity, timing, and quality of water flows required to sustain freshwater and estuarine ecosystems and the human livelihoods and well-being that depend on these ecosystems” (Brisbane Declaration 2007). The main objective of this study is to recommend river flows necessary to meet the reserve and protect aquatic and riparian ecological condition and functions of rivers, with special attention devoted to protecting the ecological services these systems deliver to human communities.

Figure ES.1: Map of Project Geographic Focus from Kilombero River Valley to Lower Rufiji Sub-Basin



Notes: Planned irrigation (IRR) schemes, existing and planned dams, and Ramsar sites are highlighted.
EPSG Projection: 4210 - Arc 1960.
Data sources: Kapetsky (1981) and WREM International (2015i).

We focused our environmental flow assessment (EFA) in select river reaches of the Rufiji Basin that are most vulnerable to the downstream impacts of four irrigation schemes under consideration for development along the northern margin of the Kilombero River Valley. The GoT’s plans for these schemes (Kisegese, Udagaji, Mgugwe, and Mpanga-Ngalimila) originally called for 40,000 hectares (ha) of paddy rice to stimulate economic growth in the region. The United States Agency for International Development recognized the importance of undertaking comprehensive feasibility studies for the proposed irrigation schemes - including an EFA - to arrive at projects that would account for the quantity of available water during the dry season (June to October).

Impacts are expected to be greatest in river reaches immediately downstream of these schemes and in the floodplain area of the Kilombero River, which is also designated as a Ramsar Wetland of International Importance. Because the Kilombero River contributes a majority of discharge to the Lower Rufiji Sub-Basin, these lower reaches of the Rufiji are also potentially affected, and we have devoted special attention to them. We also considered the status of environmental flow recommendations in the Great Ruaha and Luwegu sub-basins.

ES.2 Process for Environmental Flow Assessment

We worked in close cooperation with the Rufiji Basin Water Board (RBWB) and other stakeholders (see Box) to conduct detailed field studies at five sites in the Kilombero River Valley (**Figure ES.2**) and consider the social-ecological significance of environmental flow recommendations in the Lower Rufiji using the Desktop Reserve Model (DRM). The number and locations of detailed study sites were selected based on a preliminary zonation of rivers in the Kilombero River Valley; proximity to planned irrigation schemes; and access, available time, and financial resources. Three of our detailed study sites were located in river reaches directly adjacent to proposed irrigation schemes, and two sites were located upstream and downstream, respectively, of the Kilombero River Valley Ramsar site. Study sites reflected three river zones with distinct flow related social-ecological characteristics. The first and most upstream was the piedmont spawning zone, positioned at the foot of the Udzungwa Mountains on the northern divide of the sub-basin (Udagaji River: Site 2). The second was a transition zone in which fish species migrated between the Kilombero floodplain wetland and the spawning areas (Lwipa River: Site 1 and Mpanga River: Site 3). The third zone was the main Kilombero River floodplain (Sites 4 and 5 on the Kilombero at Ifwema and Ifakara Ferry, respectively), which served multiple ecological functions, including spawning and nursery areas and dry-season refugia.

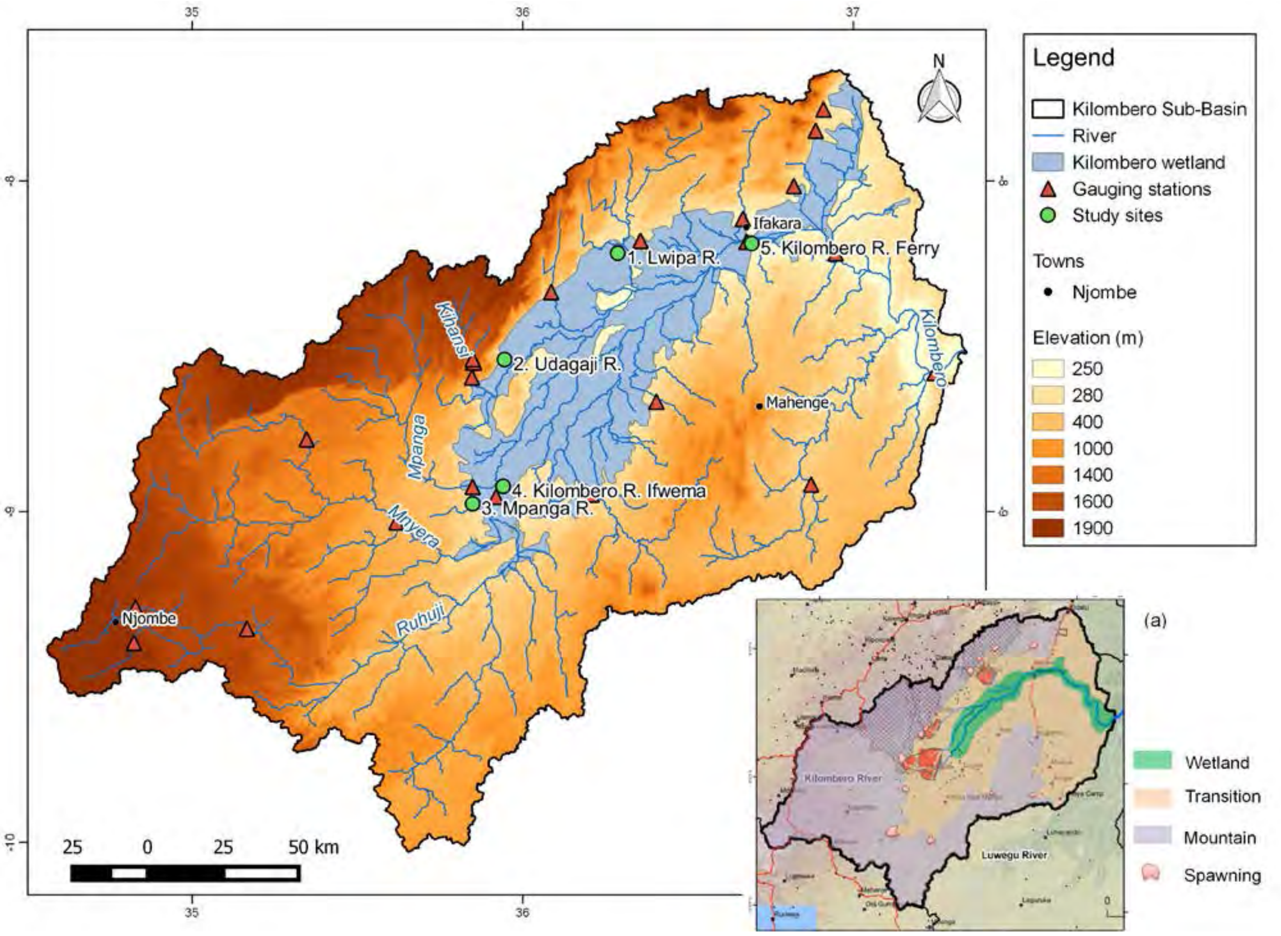
In these zones of the Kilombero River Valley, we applied the modified Building Block Methodology (BBM), which is a whole-ecosystem oriented methodology consisting of five stages (**Figure ES.3**) and addressing different aspects of the entire riverine-floodplain ecosystem, incorporating both ecological and social data and information (including traditional ecological knowledge). The BBM has been widely used and accepted in Tanzania and is familiar to specialists comprising the EFA team. It is based on the inputs of multiple specialists from different disciplines who aim to reach a consensus regarding appropriate flows to meet a set of environmental objectives (represented as an environmental management class). The objectives are developed by consensus among the specialists, reflecting the aspirations and priorities of an extensive stakeholder engagement during the study, and are used to describe the consequences of different levels of modifications to the flow regime. In this study, we applied the method through Stage C, which results in specific environmental flow recommendations. Stages D and E refer to the steps for implementation of the recommendations, which are beyond the scope of this assignment.

Stakeholder Involvement

A wide variety, and large number, of Rufiji Basin stakeholders participated in this EFA. The most intensively involved stakeholders were the RBWB, which is responsible for water resource assessment and management in the basin, and the Ministry of Agriculture, Food Security and Cooperatives, which is the largest consumptive water user in the basin. Personnel from these organizations participated in every activity of the EFA, from the original kick-off meeting, during the fieldwork, in the larger stakeholder workshop, in the objectives setting workshop, and in the flow-setting workshop. Institutional stakeholders that contributed to the project include the Ministry of Water, Vice President's Office, Ministry of Natural Resources and Tourism, RBWB, National Irrigation Commission, Zonal Irrigation Office (Morogoro), Rufiji Basin Development Authority, Kilombero District Council, Kilombero Plantations Limited, and Shahidi wa Maji. Inputs from institutional stakeholders came primarily in a workshop held in February 2015. In addition, local stakeholders representing more than 700 households were engaged in community meetings. The inputs of local and institutional stakeholders determined the specific social-ecological objectives of the EFA. Flow recommendations were made to meet the stakeholder objectives of ecosystem conservation and delivery of ecosystem services.

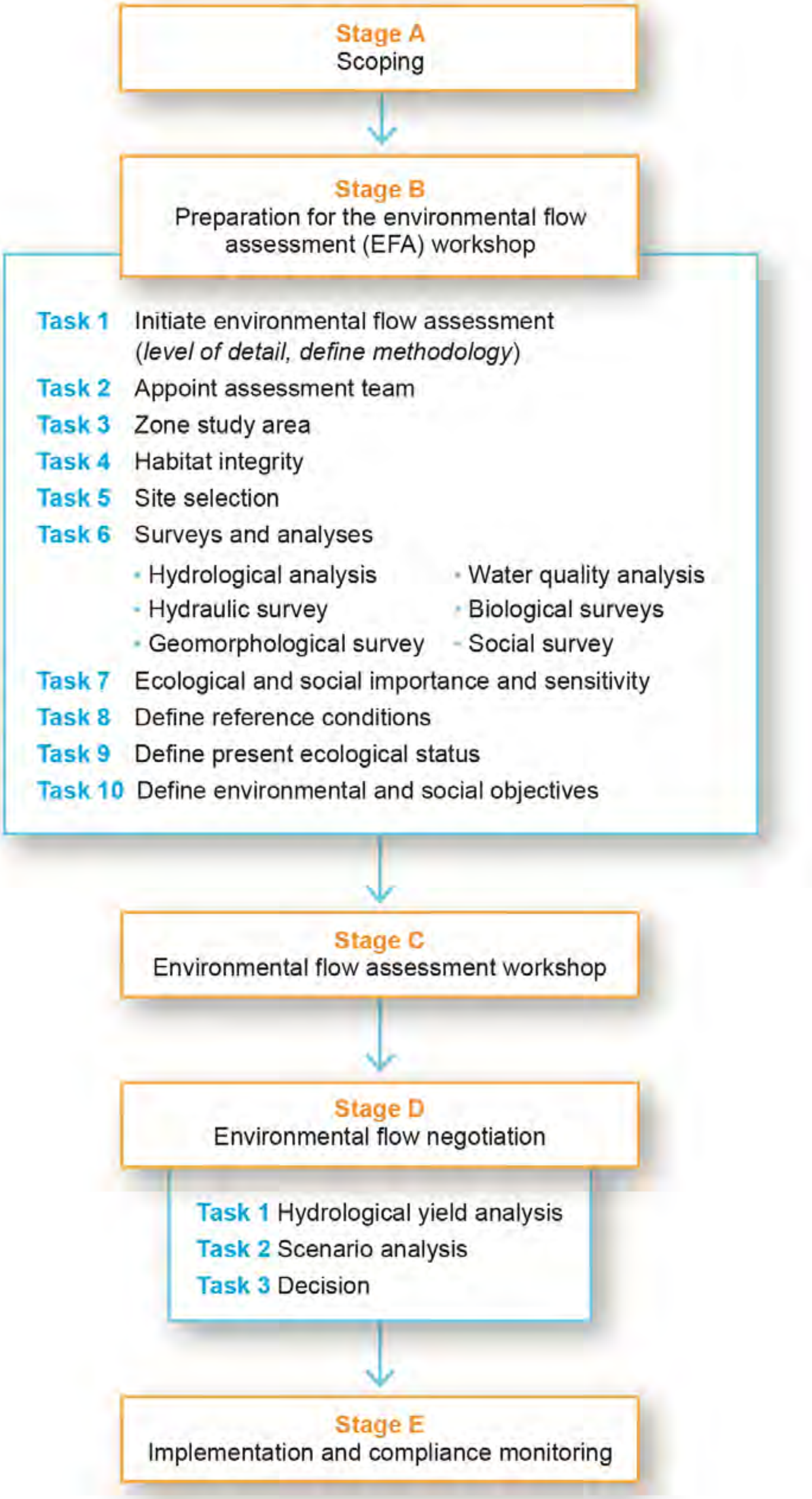
The DRM is based on an assumed relationship between the annual water requirements of different category rivers during both normal (maintenance) years and drought years, derived from the results of some 25 local river EFAs and the same index of hydrological variability developed for South African systems. It is a relatively simple model that was originally designed for very rapid and scoping-level reserve (quantity) determinations based on extrapolations from previous, higher confidence studies. In this project, we adopted results of the DRM applied by WREM International for the Lower Rufiji Sub-Basin and elaborated on the ecological significance of these flow levels based on available literature. Time and resources in the present study did not allow for a more detailed assessment of environmental flows in the Lower Rufiji or other sub-basins of the Rufiji Basin.

Figure ES.2: Location of Main Study Sites for Environmental Flow Assessment of Kilombero River and Tributaries



Inset (a): Schematic of the four spatial zones distinguished in the conceptual model of flow-related dynamics in the Kilombero Sub-Basin.

Figure ES.3: Main Stages and Tasks in Building Block Methodology for Environmental Flow Assessment



ES.3 Results

We recommended monthly environmental flow levels (**Figure ES.4**) and occasional high flow pulses (**Table ES.1**) for the five study sites in the Kilombero River Valley during years with sufficient water to meet social-ecological objectives (maintenance years) and during drought years when survival of species and preservation of basic habitat characteristics motivated recommendations. We also recommended flows for a second “increased use” scenario that allowed aquatic ecosystems to degrade to one class lower than that preferred by stakeholders (see main text for recommendations).

We found the piedmont spawning zone to be vulnerable to water withdrawals, as monthly environmental flow recommendations amounted to 67.6 percent of mean annual flow (MAF) during years of normal rainfall and 41.8 percent of MAF during drought years. We found transition zone river reaches to be less vulnerable to water withdrawals, with monthly environmental flow recommendations of 50.6 and 57.4 percent of MAF during years of normal rainfall and 42.4 and 43.8 percent of MAF during drought years. Finally, in the Kilombero floodplain we again found higher vulnerabilities to water withdrawals, especially in the reach of the Kilombero River at Ifwema, near the upstream margin of the Ramsar site. Here the monthly environmental flow recommendations were 82.3 percent of MAF during years of normal rainfall and 74.6 percent of MAF during drought years. Near the outlet of the Ramsar site at Ifakara Ferry, the monthly environmental flow recommendations amounted to 67.4 percent of MAF during years of normal rainfall and 58.3 percent of MAF during drought years. These recommendations are backed up by considerable (though short-term) field data and detailed motivations by each specialist in the body of the report and its annexes. Under the increased use scenario, recommended environmental flow values in the transition zone decreased by approximately 20 percent while even small decreases in flow recommendations in the floodplain (< 5 percent) led to a drop in environmental management class by one class. In the Lower Rufiji Sub-Basin, the desktop environmental flow recommendations of WREM International (2015i) amount to 50 to 70 percent of MAF to maintain the river in a category B to A environmental management class, respectively.

Figure ES.4: Recommended Kilombero Sub-Basin Monthly Environmental Flows in Maintenance and Drought Years

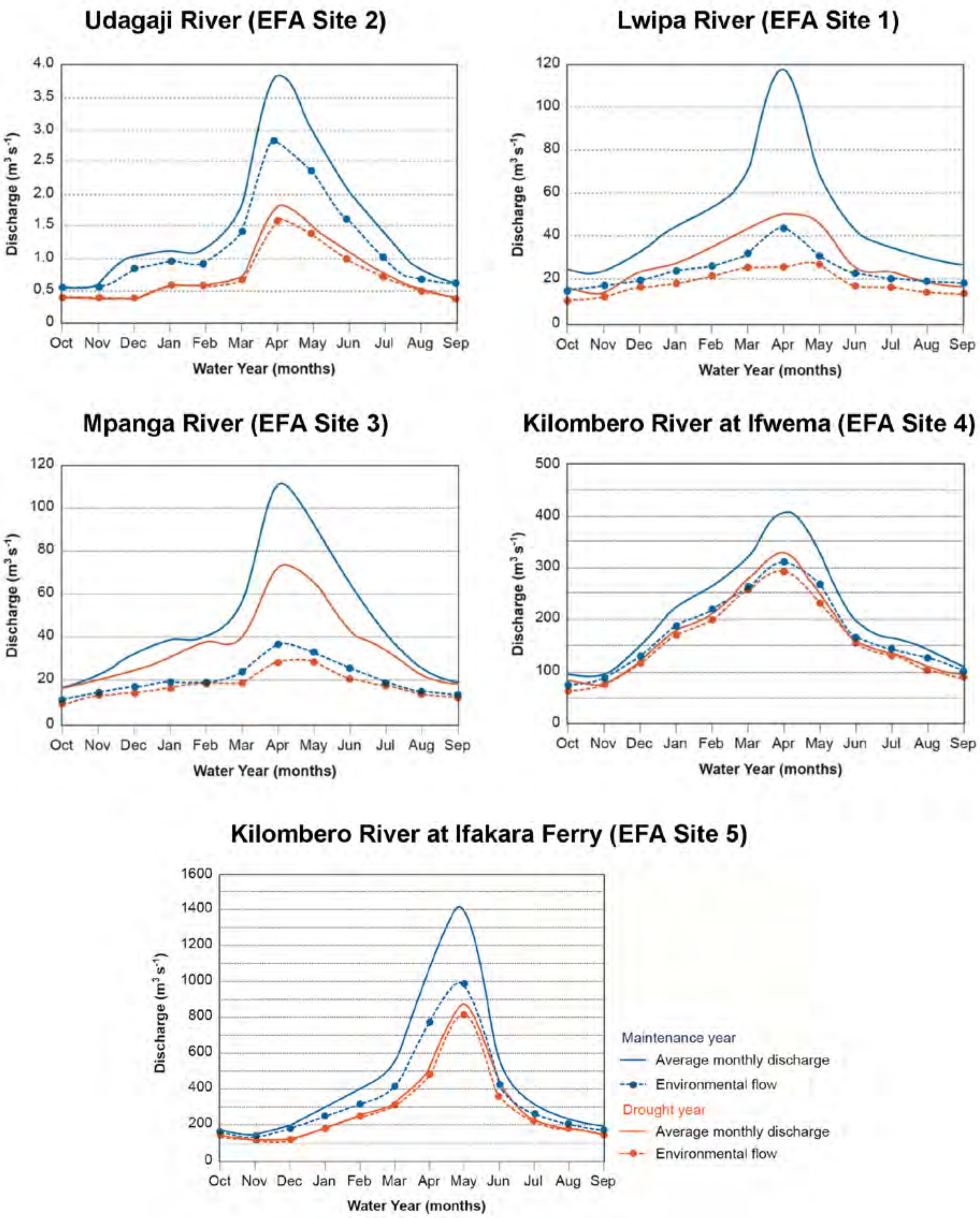


Table ES.1: Recommended Kilombero Sub-Basin High Flow Events for Maintenance and Drought Years

Year	Index	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep
Udagaji (Site 2)													
Maintenance	Magnitude (m^3/s)	1.3	1.3	1.6			7.2	7.2					
	Magnitude (Mm^3)	0.34	0.45	0.69			4.35	4.35					
	Duration (days)	3.00	4.00	5.00			7.00	7.00					
	% MAF	0.6%	0.9%	1.3%			8.2%	8.2%					
	Return period (years)	< year	< year	< year			2 years	2 years					
Drought	Magnitude (m^3/s)			1.3				5.76					
	Magnitude (Mm^3)			0.34				1.99					
	Duration (days)			3.00				4.00					
	% MAF			0.6%				3.8%					
	Return period (years)			< year				1.5 years					
Lwipa (Site 1)													
Maintenance	Magnitude (m^3/s)		40	45			68	115		40			
	Magnitude (Mm^3)		10.37	11.66			23.50	39.74		24.19			
	Duration (days)		3.00	3.00			4.00	4.00		7.00			
	% MAF		0.8%	0.9%			1.8%	3.1%		1.8%			
	Return period (years)		< year	< year			< year	1		< year			
Drought	Magnitude (m^3/s)						46.7	89.6					
	Magnitude (Mm^3)						7.78	7.78					
	Duration (days)						3.00	3.00					
	% MAF						0.6%	0.6%					
	Return period (years)						< year	< year					
Mpanga (Site 3)													
Maintenance	Magnitude (m^3/s)				60	60	79	251					
	Magnitude (Mm^3)				15.55	15.55	47.78	151.80					
	Duration (days)				3	3	7	7					
	% MAF				1.1%	1.1%	3.5%	11.2%					
	Return period (years)				< year	< year	< year	3					
Drought	Magnitude (m^3/s)			30	30		44	80					
	Magnitude (Mm^3)			7.78	7.78		11.40	34.56					
	Duration (days)			3	3		3	5					
	% MAF			0.6%	0.6%		0.8%	2.5%					
	Return period (years)			< year	< year		< year	< year					

Year	Index	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep
Kilombero at Ifwema (Site 4)													
Maintenance	Magnitude (m^3/s)		150.0	109.5			525.0	861.0					
	Magnitude (Mm^3)		38.9	28.4			317.5	520.7					
	Duration (days)		3	3			7	7					
	% MAF		0.6%	0.4%			4.8%	7.9%					
	Return period (years)		< year	< year				2 years					
Drought	Magnitude (m^3/s)				80			400					
	Magnitude (Mm^3)				20.7			241.9					
	Duration (days)				3			7					
	% MAF				0.3%			3.7%					
	Return period (years)				< year			1.5 years					
Kilombero at Ifakara Ferry (Site 5)													
Maintenance	Magnitude (m^3/s)							1,200.0					
	Magnitude (Mm^3)							725.8					
	Duration (days)							7					
	% MAF							4.7%					
	Return period (years)							1.5					
Drought	Magnitude (m^3/s)							533					
	Magnitude (Mm^3)							322.4					
	Duration (days)							7					
	% MAF							2.1%					
	Return period (years)							< year					

m^3/s = discharge; Mm^3 = flow volume

ES.4 Discussion and Recommendations

The environmental flow recommendations are based on field studies conducted over a single 6-month season and on modeling activities dependent on available historical data. These limitations introduce a degree of uncertainty into the results, but based on the generally moderate to high level of confidence expressed by the specialist team in its recommendations, there should be no hesitation in applying the results forthwith. In accordance with the 2009 Tanzanian Water Resources Management Act (Part V, Section 31), these environmental flow recommendations would properly be included in the Rufiji Basin integrated water resource management plan as requirements of the reserve for the water bodies in which the recommendations were made. Part VI, Section 33 of the 2009 Water Act specifies that the Minister shall determine the reserve by notice in the Gazette. Environmental flow recommendations must be reassessed with some regularity as part of a normal adaptive management cycle. The 2009 Water Act calls for integrated water resource management plans to be reviewed at least once per 5-year period, and this schedule is also appropriate for review of these environmental flow recommendations. Proper reassessment will depend on collection of monitoring data to determine whether the objectives of the reserve are being met.

The timing of this EFA, before any significant reduction in flows in the Kilombero Sub-Basin and in the early stages of development across the entire basin, is well planned. For the great majority of rivers, environmental flows are only considered when serious problems are experienced because of over-abstraction and allocation. This is the case already for headwater sections of the Great Ruaha Sub-Basin, but for the Rufiji in general, the early determination of environmental flows may have a decided positive influence on sustainable development. Despite all of the acknowledged uncertainty, our results suggest that most development targets in the Rufiji could be achieved with minimal social-environmental consequences if environmental flow recommendations are met in each basin.

Across the larger Rufiji Basin, there is a need to develop environmental flow recommendations in a hierarchical fashion. This is achieved by establishing simple precautionary recommendations at a basin scale (as done in the Integrated Water Resources Management and Development (IWRMD) Plan), applying desktop approaches in priority areas ahead of any specific development activities, and applying detailed holistic approaches in the context of project feasibility planning (as has been done in the northern tributaries of the Kilombero Valley). The Ministry of Water is in the process of establishing national guidelines for the determination of environmental flows, and these should be applied as soon as possible after being finalized (URT 2016). The application of other international basin-scale approaches, such as the Ecological Limits of Hydrologic Alteration (Poff et al. 2010) may also help to expedite the environmental flow setting process. Currently, there are recommendations based on holistic EFA methodologies in the Great Ruaha (scoping level) and Kilombero (this study) sub-basins, and there are desktop recommendations for the Lower Rufiji. Across the rest of the basin, including the Luwegu Sub-Basin, precautionary recommendations stand, recommending that natural flow regimes not be modified by more than 20 percent.

The information summarized in this report on the flow dependencies of the Lower Rufiji Sub-Basin highlight some of main social-ecological justifications for establishing environmental flow recommendations. They complement the desktop environmental flow recommendations made by WREM International (2015i) using the DRM, which include a range of recommended monthly flows related to different levels of social-ecological protection (A-D). Comparisons between our holistic flow assessment and applications of the DRM in the Kilombero Sub-Catchment revealed a moderate degree of correlation, but our detailed recommendations tended to call for higher flows (on the order of 20 percent higher). Given that the environmental flow requirements of the Lower Rufiji Sub-Basin will ultimately control the total level of water abstractions and regulation possible in other sub-basins, it is imperative to conduct a detailed environmental flow assessment of the mainstem and delta reaches of the Lower Rufiji prior to committing to further major consumptive water allocations or regulation upstream, including in the SAGCOT area.

Members of the Expert Review Panel for this report, in addition to recommending many improvements to the text, were asked to consider next steps needed in implementation. They concur that environmental flow recommendations in this study should be adopted in the IWRMD Plan for the relevant rivers of the Kilombero Valley. They also recommend that additional assessment efforts be carried out in headwater sections of the basin and in the Lower Rufiji Sub-Basin. In the Kilombero Sub-Basin, they recommend additional assessment activities near other long-term hydrological measurement stations such as the Ruhudji River at Mwanamulungu (station 1KB10), the Mnyera River at Taveta (station KB9), and the Lumemo River at Ifakara (station 1KB14A). Members called for clear and understandable communication of the results of this assessment to the widest possible number of stakeholders. They also suggested that the results of the present EFA should be viewed in a wider perspective, basin-scale (e.g., Rufiji IWRMD Plan), nationally (e.g., institutional and legal framework), and internationally (e.g., Ramsar Convention). They considered this to be important in avoiding unnecessary conflicts among the various interests within the basin. Noting the importance of having the draft national EFA guidelines in place as soon as possible, they reiterated the imperativeness of conducting a full EFA in the Lower Rufiji Sub-Basin.

We wish to highlight the importance of linking the results of this EFA back to multiple levels of planning and regulations needed to achieve sustainable development of Tanzania's water resources. These include (1) the Rufiji IWRMD Plan and decision support system, (2) national law/policy, (3) international conventions and commitments such as the Ramsar convention to which Tanzania is a signatory, (4) environmental flows guidelines for Tanzania, and (5) capacity development – technical and institutional. While the main objectives of this study were the detailed assessment of environmental flow requirements of rivers of the Kilombero Valley and review of flow related social-ecological processes in the Lower Rufiji Sub-Basin, consideration was also given to development of local capacity to continue conducting high-quality EFAs. Emphasis should continue to be placed on developing the technical and coordination capacity of Tanzanian professionals in the execution of EFAs.

Environmental flow assessment and future monitoring of the performance of management plans rely on the availability of high quality data about the hydrology, hydraulics, geomorphology, ecology, and socio-economics of river systems. Information about these topics is limited in the Rufiji Basin, and this hampers efforts to provide reliable guidance in planning and regulation of development activities. We recommend that the RBWB and related institutions prioritize efforts to improve data collection and system monitoring. Considerable effort is already being devoted to this, and development partners are stepping in to assist in refurbishing monitoring equipment. We also recommend that the RBWB seek out new and innovative partnerships, especially with Tanzanian and international knowledge institutions that will contribute to continued and coordinated information gathering and knowledge generation about the basin and its resources. Priority areas should include freshwater biodiversity surveys, river health assessments, and state of the basin reporting. Improved information on water abstractions and efficiency of water use is also needed. New information and knowledge should be incorporated into the Rufiji Decision Support System for application in planning and decision-making.

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Using this Report

This report is designed to be accessed at three levels of detail:

The executive summary provides a summary of the main report for those who wish to get a brief overview of the subjects addressed and the main conclusions. Those wishing to understand particular issues in more detail should read the appropriate chapter or section in the main report.

The main report provides a thorough description of the work carried out, including objectives, study area, methodology used, flow recommendations and motivations, implications for the management of the rivers, and recommendations.

The annexes to the main report each provide detail with an aspect of the Kilombero environmental flow process. These are designed to provide all the information and data that were used to generate and support the flow recommendations. The annexes also serve as an archive that can be consulted as a basis for any future implementation or review of this environmental flow assessment or as a template for environmental flow projects on other Tanzanian rivers.

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List of Acronyms and Abbreviations

ASPT	Average Score per Taxon
BBM	Building Block Methodology
bcm	billion cubic meters
bcm yr^{-1}	billion cubic meters per year
DFID	Department for International Development
DO	Dissolved Oxygen
DRM	Desktop Reserve Model
EFA	Environmental Flow Assessment
EIS	Ecological Importance and Sensitivity
EMC	Environmental Management Class
FAO	Food and Agriculture Organization
FDC	Flow Duration Curve
FIU	Florida International University
FR	Forest Reserve
FTF	Feed the Future
GIS	Geographic Information System
GLOWS	Global Water for Sustainability Program
GMTED	Global Multi-Resolution Terrain Elevation Data
GoT	Government of Tanzania
ha	hectare
HEC-RAS	Hydrologic Engineering Centers River Analysis System
IRRIP2	Technical Assistance to Support the Development of Irrigation and Rural Roads Infrastructure Project
ILRI	International Livestock Research Institute
ITCZ	Intertropical Convergence Zone
IUCN	International Union for Conservation of Nature
iWASH	Tanzania Integrated Water, Sanitation and Hygiene Program
IWRM	Integrated Water Resources Management
IWRMD	Integrated Water Resources Management and Development
km	kilometer
km^2	square kilometers
KPL	Kilombero Plantation Limited
m	meter

$m^3\ s^{-1}$	discharge (a measure of flow magnitude)
MAF	Mean Annual Flow (also known as mean annual runoff)
masl	meters above sea level
mcm	million cubic meters
mcm yr^{-1}	million cubic meters per year
MW	megawatt
NGO	Non-Governmental Organization
P	Precipitation
PAR	Population at Risk
PES	Present Ecological Status or State
RBWB	Rufiji Basin Water Board
REMP	Rufiji Environmental Management Project
SAGCOT	Southern Agricultural Growth Corridor of Tanzania
SASS5	South African Scoring System Protocol version 5
SIS	Social Importance and Sensitivity
SOW	Statement of Work
SWAT	Soil and Water Assessment Tool
TAFORI	Tanzania Forestry Research Institute
TCO	Tanzania Country Office
TNC	The Nature Conservancy
UNEP	United Nations Environment Programme
UNESCO	United Nations Educational, Scientific and Cultural Organization
URT	United Republic of Tanzania
USAID	United States Agency for International Development
UTM	Universal Transverse Mercator
WCMC	World Conservation Monitoring Centre
WDPA	World Database on Protected Areas
WUA	Weighted Usable Area
WWF	World Wildlife Fund

1 INTRODUCTION

1.1 Project Scope and Objectives

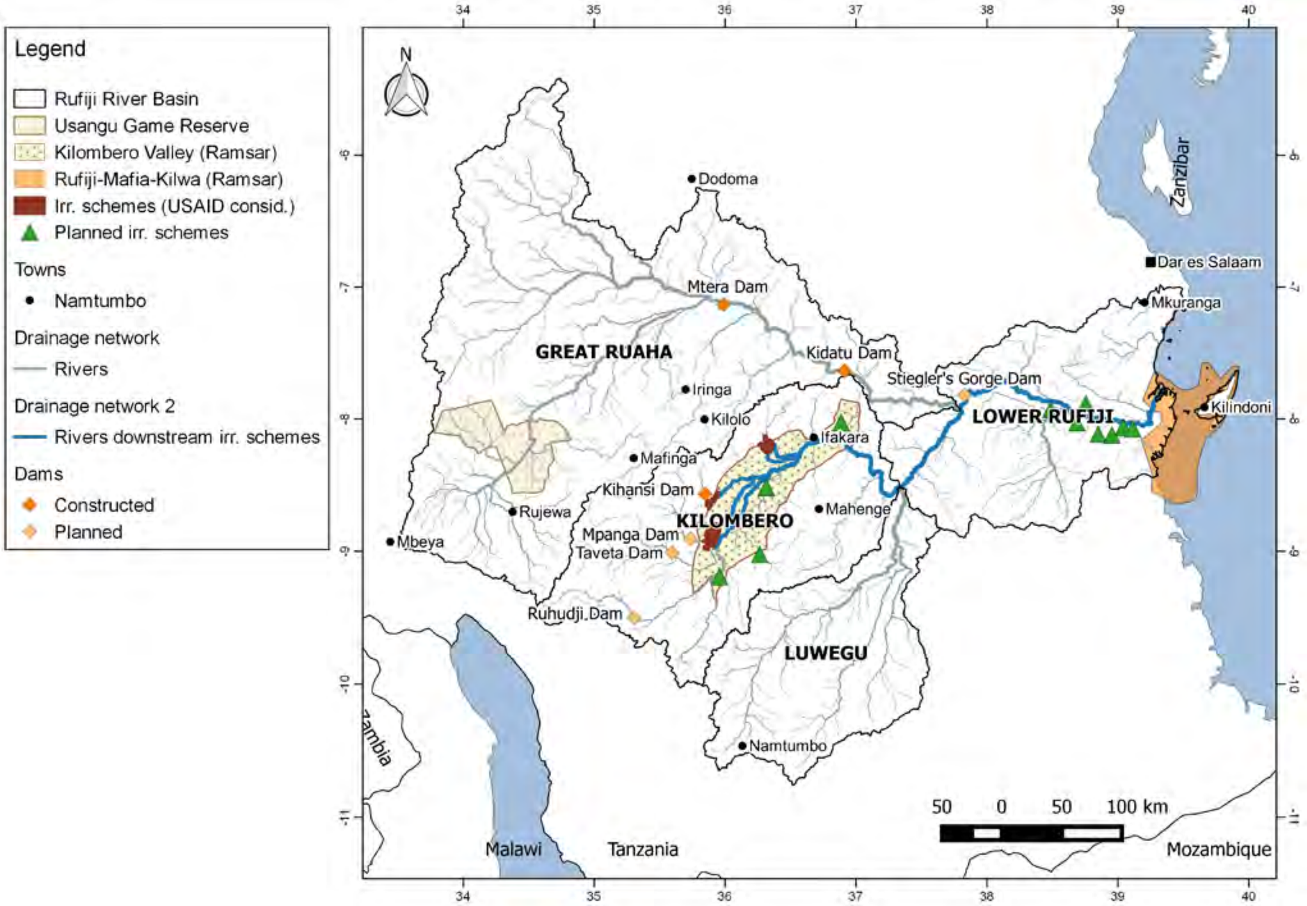
This report presents a detailed assessment of environmental flow requirements in the Kilombero River Valley, with further consideration of environmental flow needs extending to the Lower Rufiji Basin and its delta (**Figure 1.1**). As part of the Southern Agricultural Growth Corridor of Tanzania (SAGCOT) initiative, 16 new irrigation schemes are planned in the Kilombero and Lower Rufiji sub-basins during the next two decades. These schemes represent an expansion of irrigated crops by almost 200,000 hectares (ha) and an increase in consumptive water use of almost 4 billion cubic meters per year (bcm yr^{-1}). By comparison, the extent of irrigated crops and related water use in these sub-basins today is estimated at just 8,000 ha and 142 million cubic meters per year (mcm yr^{-1}), respectively. The Rufiji Basin Integrated Water Resources Management and Development (IWRMD) Plan (WREM International 2015a) also includes plans for three new hydropower stations in the Kilombero Sub-Basin, with associated reservoirs totaling 850 million cubic meters (mcm) of storage. In the Lower Rufiji Basin, plans include the Stiegler's Gorge station beginning in 2025, with a total potential storage of 34 billion cubic meters (bcm) of water by 2035. Water use for hydropower generation is non-consumptive, but operation of the hydropower dams leads to altered magnitude and timing of river flows.

The United States Agency for International Development (USAID) is considering development of four of the planned SAGCOT Kilombero schemes as part of its Feed the Future (FTF) Program (see Section 1.4). As these are the first of the newly planned SAGCOT irrigation developments in the Kilombero Valley, special attention is devoted to setting environmental flow recommendations in river reaches downstream of the schemes. Their development would include diversion of water from seven river catchments, draining a total area of 4,235 square kilometers (km^2). This amounts to approximately 10 percent of the area of the Kilombero Catchment, most of which drains into the Kilombero River Valley Ramsar site, a wetland internationally recognized for its high ecological importance. The Kilombero River is also by discharge contribution the largest tributary of the Lower Rufiji River Basin, which sustains an expansive wetland system of equally high ecological importance, and an estuarine and coastal ecosystem, also designated as a Ramsar site (**Figure 1.1**). Both of these wetland areas, in addition to supporting internationally important levels of biodiversity, are critical to the health and livelihoods of communities living within and adjacent to them.

The main objective of this study is to recommend river flow levels necessary to preserve the aquatic and riparian ecological condition of rivers in the Kilombero valley and main channel of the Lower Rufiji Basin, with special attention devoted to protecting ecological functions that also provide services to neighboring human communities. Under Tanzanian water law, instream flows to protect aquatic ecosystems and meet basic human needs have the highest priority in water allocation and are referred to as the "reserve". It is essential that the reserve be quantified prior to implementing major water-dependent development plans such as those in SAGCOT. Internationally, instream flows to meet social-ecological objectives are known as environmental flows. Our study was designed to meet both the requirements of Tanzanian water law and international best practices in setting environmental flow recommendations. These national and international approaches were harmonized in the recent "Framework and Guidelines for the Assessment and Monitoring of Environmental Flows in Tanzania" (Florida International

University/Tanzania Integrated Water, Sanitation and Hygiene Program [FIU/iWASH] 2013), as provided in full in **Annex E**, commissioned by the Government of Tanzania (GoT), and under consideration for application nationwide. The guidelines are intended for use in developing regulations for determining the reserve and the classification of water resources. This study conforms with these guidelines and serves as a first piloting of their application.

Figure 1.1: Map of Project Geographic Focus from Kilombero River Valley to Lower Rufiji Sub-Basin



Notes: Planned irrigation (IRR) schemes, existing and planned dams, and Ramsar sites are highlighted. See Figure 1.3 for proposed irrigation schemes evaluated for development under USAID/Tanzania's FTF Program.
EPSG Projection: 4210 - Arc 1960.
Data sources: Kapetsky (1981) and WREM International (2015i).

1.2 Tanzanian Policy Context

The institutional and legal framework for the sustainable management and development of water resources in Tanzania is provided by the Water Resources Management Act of 2009. In the Act, Basin Water Boards are empowered to prepare basin water resources management plans, which are to include, among other things, a water balance for each basin, a classification of water resources, requirements for the reserve for each water resource, and measures for implementation of the plan. In the 2009 Water Act, the reserve is "the quantity and quality of water required for:

1. Satisfying basic human needs by securing a basic water supply for people who are now or shall in the reasonably near future be:

    a. relying upon
    b. taking water from
    c. being supplied from the relevant water resources

2. Protecting aquatic ecosystems in order to secure ecologically sustainable development and the use of relevant water resources

The component of the reserve protecting aquatic ecosystems is equivalent to an environmental flow, which is defined internationally as “the quantity, timing, and quality of water flows required to sustain freshwater and estuarine ecosystems and the human livelihoods and well-being that depend on these ecosystems” (Brisbane Declaration 2007).

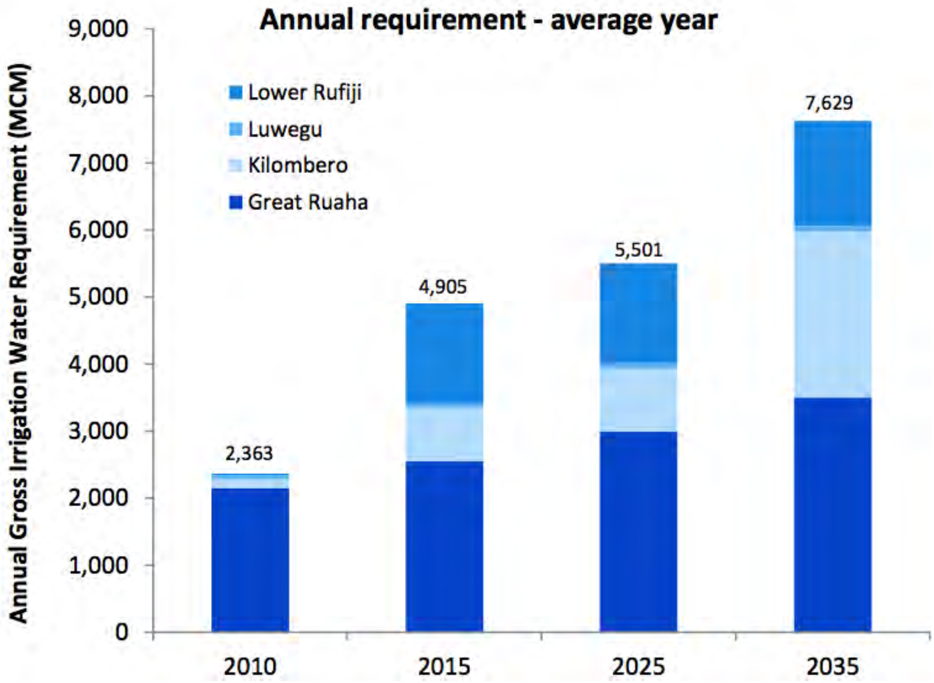
The policy of prioritizing water for basic human needs and the environment as first and second priorities in water extends back to the National Water Policy of July 2002. Authority to issue environmental conservation orders protecting environmental flows was also granted in the Tanzanian Environmental Management Act of 2004. Following these actions, environmental flow assessments (EFAs) were carried out at sites in the Pangani, Mara, Great Ruaha, Wami, and Ruvu River basins. A major review of experiences from these EFAs was undertaken for the Ministry of Water (funded by USAID/Tanzania) in 2013, resulting in a framework and guidelines for the assessment and monitoring of environmental flows in Tanzania (FIU/iWASH 2013). The framework and guidelines document includes recommendations for the future of EFA implementation in Tanzania, synthesized from the comments and suggestions of more than 40 local and international managers, policy-makers, and scientists who were interviewed and/or invited to review the report.

1.3 Water Resources Planning Context for Rufiji Basin

In May of 2015, the Ministry of Water released the final draft report of the Rufiji Basin IWRMD Plan (WREM International 2015a). While notably still in draft form and thus potentially subject to further amendments pre-finalization, the IWRMD Plan provides the most current information available on major trends and future plans for basin water resources. It includes a strategic action plan for 2015-2035, considering five areas: (1) water for social development, (2) water for economic development, (3) disaster risk management, (4) environmental protection and conservation, and (5) water governance. Water for social development addresses the provision of safe water and improved sanitation. Water for economic development addresses the uses of water in energy, agriculture, livestock, fisheries, forestry, and industrial sectors. Disaster risk management addresses structural and non-structural measures to prevent or mitigate impacts of natural and manmade water-related disasters. Environmental conservation and protection addresses water needs for the preservation of conservation areas and riverine and estuarine ecosystems. Water governance addresses issues of institutional capacity building, cross-sectoral coordination, water resources monitoring, water information, and knowledge systems, with resources regulation, stakeholder participation, and gender mainstreaming.

Recommendations in the plan seek to harmonize goals and water use in each of these strategic areas, and as in so many river basins around the world, a major challenge lies in the balance of water use for agriculture and environmental protection. Economic development plans through 2035 in the Rufiji Basin rely heavily on the expansion of irrigated agriculture and associated consumptive water use. In total, water consumption is projected to increase by nearly 6 bcm, or a factor of 3, in comparison with consumption rates in 2010 (**Figure 1.2**). The majority of this increase will be in the Kilombero and Lower Rufiji sub-basins. Increased consumptive water use in Kilombero will be concentrated during the dry season, while increased consumption in the Lower Rufiji will be concentrated during the wet season. No significant development is planned in the Luwegu Sub-Basin during the next two decades (WREM International 2015i).

Figure 1.2: Baseline (2010) and Projected Growth in Irrigation Water Requirement in an Average Year



Note: See WREM International (2015i) for further explanation.

Recommendations for the reserve are presented in the area of environmental protection and conservation. The draft Rufiji IWRMD Plan adopts the precautionary long-term goal of maintaining consumptive water use at a level less than 20 percent of unimpaired river flow during each season, thereby, maintaining 80 percent of flow in rivers for purposes of the reserve. The plan highlights that current consumptive water use in the Usangu area of the Great Ruaha Sub-Basin seriously exceeds sustainable levels. It calls for reductions of between 25 and 33 percent in consumptive water use, more conjunctive use of groundwater, and construction of a dam and storage reservoir at Ndembera to restore sufficient reserve flows to the river at Msembe and meet other water management objectives. Management recommendations in this critical portion of the Great Ruaha Sub-Basin are guided by the environmental flow assessment carried out in the Usangu area between 2008 and 2010 (World Wildlife Fund [WWF]-Tanzania Country Office [TCO] 2010).

In the Kilombero and Lower Rufiji sub-basins, current water consumption does not exceed the precautionary threshold set in the draft Rufiji IWRMD Plan, but planned irrigation schemes and associated consumptive water use are projected to exceed the established reserve threshold for the mainstem Kilombero River during the dry season in the next decade. Moreover, combined upstream uses in the Kilombero and Great Ruaha sub-basins are projected to result in dry season flow deficits in the Lower Rufiji Sub-Basin by 2035. These projected water shortfalls are exacerbated by climate change, which is also projected to modify natural flow levels in the basin's rivers. In response to these projections, the draft Rufiji IWRMD Plan calls for efficiency measures in agriculture; more conjunctive use of groundwater; and the construction of storage reservoirs, in combination with the planned Ruhudji and

Mpanga hydropower projects in the Kilombero Sub-Basin, and construction of storage in the Lower Rufiji Sub-Basin, in combination with the Stiegler's Gorge hydropower projects. The Rufiji IWRMD Plan also emphasizes the urgency of conducting detailed environmental flow assessments in the Kilombero and Lower Rufiji sub-basins, with emphasis placed on the need in the Kilombero Sub-Basin.

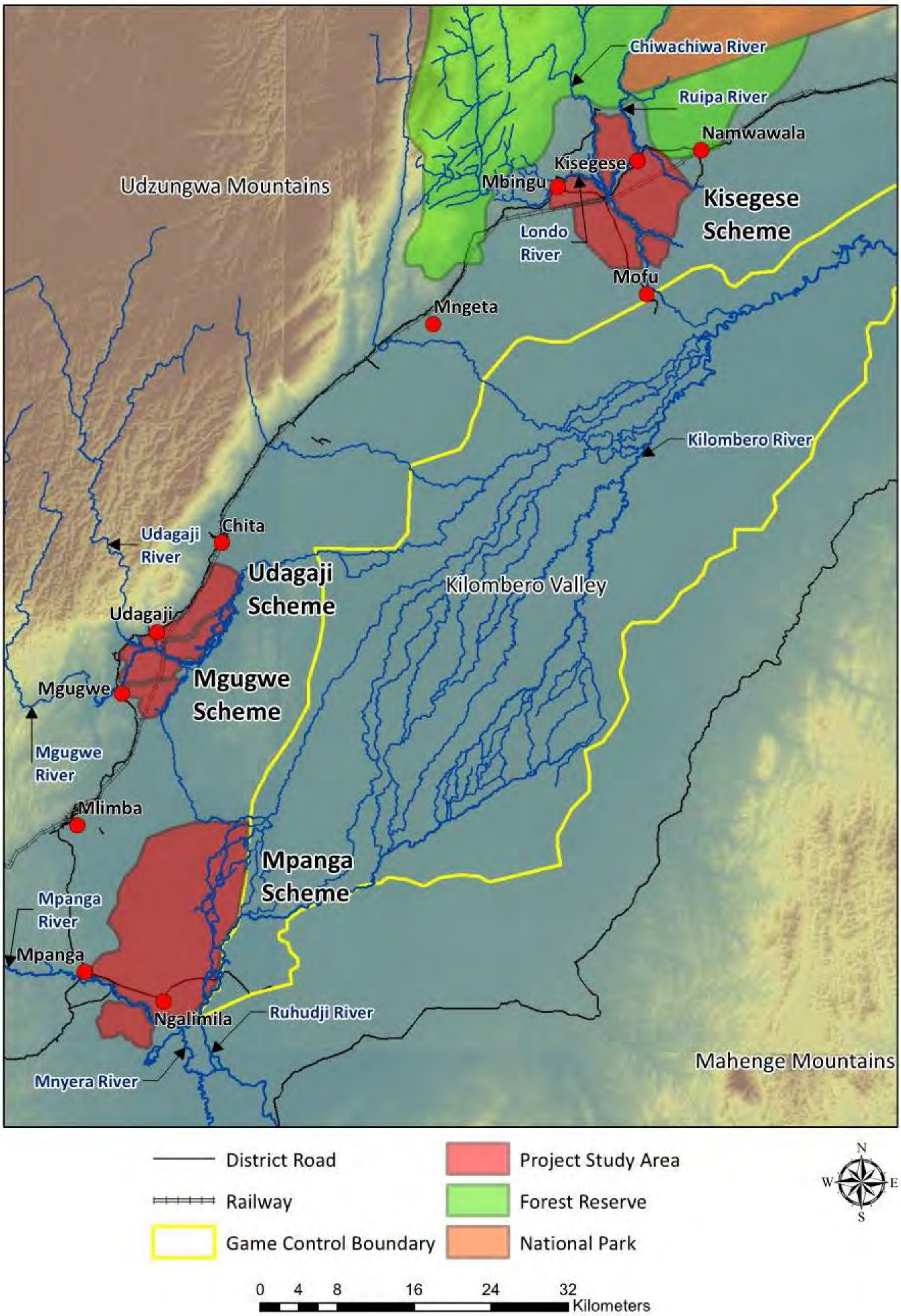
1.4 USAID/Tanzania's Irrigation Activities in Kilombero

As mentioned in Section 1.1, the GoT and USAID/Tanzania have prioritized the potential of expanded irrigation to deliver increased productivity of staple crops in Kilombero Valley as a key contributor to economic growth for Tanzania. The "Technical Assistance to Support the Development of Irrigation and Rural Roads Infrastructure Project" (IRRIP2), implemented by CDM International Inc. (CDM Smith) and funded by USAID/Tanzania under the FTF initiative, prepared comprehensive feasibility studies to evaluate the development of four potential irrigation schemes (Kisegese, Udagaji, Mgugwe, and Mpanga-Ngalimila) in Kilombero Valley (**Figure 1.3**). Water for the proposed irrigation schemes is expected to be abstracted from northern tributaries of the Kilombero River: Lwipa River[1] (for Kisegese scheme), Udagaji River (for Udagaji scheme), Mgugwe River (for Mgugwe scheme) and Mpanga River (for Mpanga-Ngalimila scheme). The feasibility study objective was to derive irrigation scenarios that sustainably use available resources to provide increased irrigated areas for appropriate crops such that production of staple crops (i.e., rice and maize) is increased and the projects are economically attractive.

As part of the feasibility process to ensure that these irrigation projects meet the required environmental standards, USAID/Tanzania requested that an EFA of the broader basin in which the proposed schemes lie be conducted as a parallel but independent activity under IRRIP2. The statement of work (SOW) for the irrigation feasibility studies and EFA is included in **Annex A**.

[1] The Lwipa River is interchangeable with the Ruipa River. These are alternate spellings for the same river. The EFA study adopted the Lwipa spelling, whereas the irrigation feasibility studies standardized on the Ruipa spelling.

Figure 1.3: Proposed Irrigation Schemes in Kilombero Valley Assessed under IRRIP2



1.5 Correspondence with the Task Order Statement of Work

While the original request from USAID/Tanzania called for the EFA to provide recommended flow regimes for all the tributaries and main stem of the Rufiji system, the SOW recognized that the immediate purpose of this EFA was to support the development of irrigation schemes in the Kilombero. Therefore, this particular catchment and the downstream reaches of the Rufiji became the focus of the EFA (**Figure 1.1**). The EFA was expected to add site specificity to the earlier Rapid EFA completed for the Kilombero Valley (Kashaigili 2013) and extend the analysis downstream to lower reaches of the river, delta, and coastal zone.

The EFA was contracted to be conducted over a 2-year period, extending from 9 April 2014 until 30 March 2016. We organized the EFA as a two-phase process. Phase 1 consisted of a detailed, field-based analysis of environmental flow requirements by a team of Tanzanian and international specialists in the northern tributaries and main stem of the Kilombero. This phase was completed successfully and forms the bulk of this report. Phase 2 consisted of rapid literature review of the social-ecological system in the Lower Rufiji Sub-Basin and discussion of the implications for environmental flow recommendations made using the Desktop Reserve Model as part of the Rufiji IWRMD planning process.

Time and resources in the project did not allow for the determination of environmental flow recommendations in the Great Ruaha or Luwegu sub-basins. Flow recommendations are available for the middle reaches of the Great Ruaha River, extending between Ng'iriama and the Mtera Dam. These recommendations were based on studies carried out by WWF from 2008 until 2010, applying a methodology similar to ours though rapid and single-reach focused. The WWF recommendations focused on the most heavily impacted reaches of the Great Ruaha where dry season flows have ceased, degrading environmental conditions in Ruaha National Park. These recommendations are incorporated into the Rufiji IWRMD Plan (WREM International Inc. 2015i). Specific environmental flow recommendations are currently impossible for the Luwegu Sub-Basin because of an absolute lack of available hydrological data.

1.6 Report Layout

Following this introduction (Section 1), we describe the basic characteristics of the Rufiji Basin as the overall study area in Section 2, focusing on those features of particular relevance in setting the context for the environmental flow assessment. Some attention is given to characterizing the four primary sub-basins of the Rufiji, with biophysical and socioeconomic profiles provided for each. More detailed information on the Kilombero Sub-Basin is provided in a series of Annexes (**Annex G** through **Annex Q**) generated during the Kilombero EFA.

While many EFAs to date worldwide have focused almost entirely on the flows needed for ecological purposes (including geomorphology, water quality, and others), we explicitly recognized the direct and indirect social values, ecosystem services, and other benefits the Rufiji River system provides for people. Importantly, therefore, the assessment was designed from the outset to capture the river's environmental flow needs as an integrated social-ecological system, using a holistic methodology known to perform well in such situations. Section 3 outlines the conceptual basis and main stages of the environmental flow methodology used, the Building Block Methodology (BBM), and the ways in which it was tailored to meet local needs for the detailed, field-based EFA for the Kilombero River and tributaries. In **Annex B** and **Annex C**, we provide additional context by describing the conceptual basis of environmental flows and their assessment, including an overall explanation of an

EFA, and details each of the tasks typically undertaken in a holistic environmental flow methodology such as the BBM.

The results of the Kilombero EFA are presented in Section 4 in terms of the environmental flows recommended to meet the needs of the communities that directly depend on the river-floodplain system for their livelihoods and well-being (also referred to as the population at risk, or PAR) alongside the flow-related needs of the ecosystem and its various components and biota. Summary tables and hydrographs describing the recommended environment flow regimes are provided as are the supporting ecological and social motivations. Drawing from an understanding of the present condition of the system, recommendations are provided for a target flow regime (Sections 4.7 and 4.8) and an additional increased use scenario (Section 4.9). Supporting annexes (**Annex G** through **Annex P**) provide all the information and field data collected by the specialist team and the detailed rationale and objectives underpinning recommended flows for the target flow scenario. Post-workshop refinement of the environmental flow recommendations and their implications for system physical state form the final part of this section. Section 4 concludes with a description of flow dependencies identified in the Lower Rufiji river-floodplains and coastal delta.

In Section 5, the environmental flow results are discussed in relation to present understanding of the environmental flow requirements of the river system within other parts of the Rufiji Basin. The implications of implementing the environmental flows relative to current water resource management and development scenarios for the basin are also examined here.

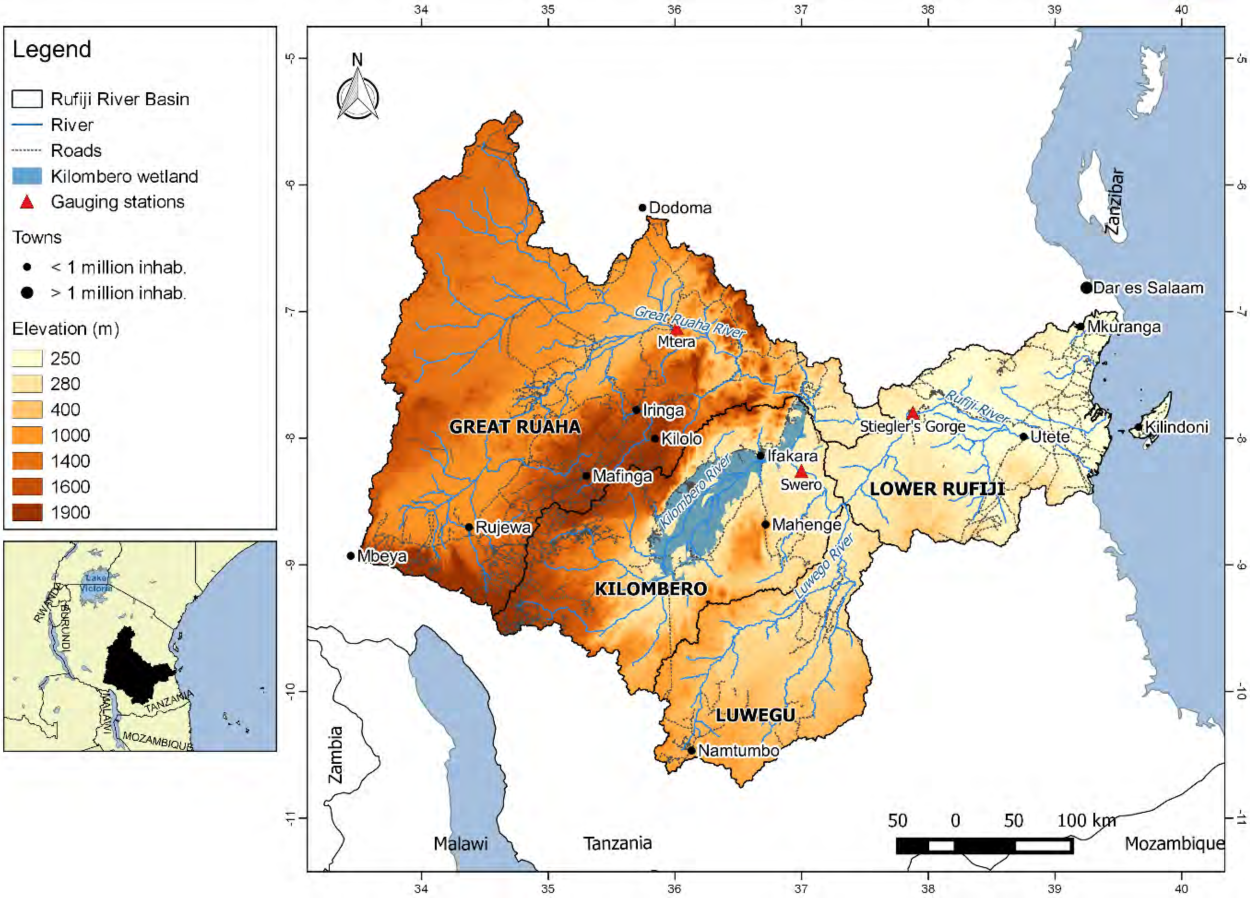
Section 6 presents a synopsis of our main environmental flow recommendations and highlights potential next steps for advancing future environmental water management in the Rufiji Basin as a whole.

A bibliography of references used in the study is provided in Section 7, while supporting data and models are available in digital format.

2 OVERVIEW OF RUFIJI BASIN STUDY AREA

The Rufiji Basin is Tanzania's largest river basin (of a total of nine), occupying approximately 20 percent of the national territory and supplying about 25 percent of the country's renewable water resources (**Figure 2.1** and **Table 2.1**). Environmental flow studies seek to understand the linkages between hydrological, geomorphological, and social-ecological processes, with the goal of recommending components of the hydrological flow regime that must be preserved to meet specific geomorphological and social-ecological objectives. This section presents a broad overview of these characteristics across the four sub-basins of the Rufiji Basin.

Figure 2.1: Rufiji Basin and Four Main Sub-Basins, with River Drainage Network and Principal Rivers



Note: The flow regime at each hydrological gauging station is shown in Figure 2.4.
EPSG Projection: 4210 - Arc 1960.
Data source: Global Multi-Resolution Terrain Elevation Data (GMTED) 2010 (estimated 200 meters of horizontal resolution and 30 meters of vertical accuracy), retrieved from https://lta.cr.usgs.gov/GMTED2010.

Table 2.1: Characteristics of Rufiji Sub-Basins

Sub-Basin	Catchment Area (km^2)	% of Drainage Area	Mean Annual Precipitation ($mm\ y^{-1}$)	Mean Annual Runoff ($bcm\ y^{-1}$)	% of Annual Runoff
Great Ruaha	85,554	47	400-1,200	3.3	15
Kilombero	40,330	22	1,000-2,000	13.8	62
Luwegu	25,288	14	800-1,000	4	18
Lower Rufiji	32,619	18	650-110	1.1	5
Rufiji Total	183,791	100		22.2	100
Tanzania	**945,203**			**89**	

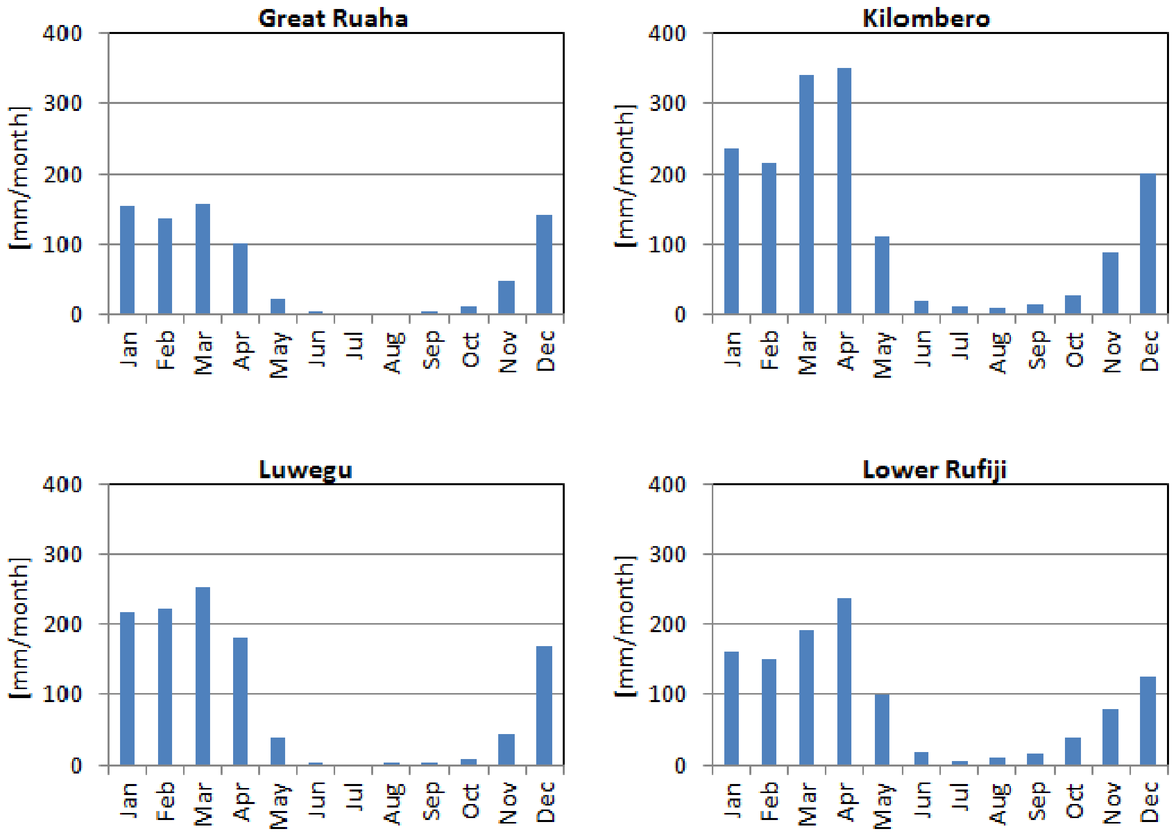
Note: as provided in WREM (2012)

2.1 Climate and Hydrology

Estimated mean annual precipitation over the entire Rufiji Basin is 1,070 mm y^{-1}, but varies significantly over the four sub-basins, from 790 mm y^{-1} over the Great Ruaha to 1,620 mm y^{-1} over the Kilombero Sub-Basin (Food and Agriculture Organization [FAO] 2005). Mean annual precipitation over the Luwegu and Lower Rufiji sub-basins are estimated to be 1,140 mm y^{-1} and 1,130 mm y^{-1}, respectively. The seasonal variability of precipitation in each sub-basin is shown in **Figure 2.2**. Rains begin in October/November when the Intertropical Convergence Zone (ITCZ) passes over the region on its southward track. Rains continue through January/February and then intensify in March/April as the ITCZ passes over the basin again on its way back into the northern hemisphere. These two rainfall periods are referred to as the short and long rains, respectively. Rainfall is also spatially variable in each sub-basin, with higher rainfall amounts in mountainous areas due to orographic effects.

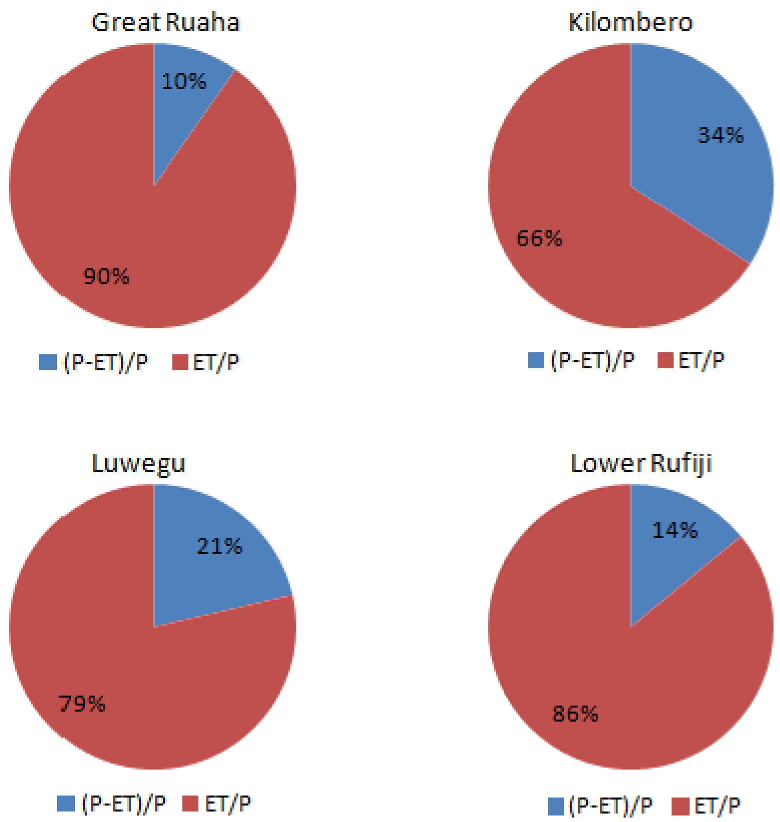
A majority of rainfall on all sub-basins returns to the atmosphere via evaporation and plant transpiration (World Evapotranspiration Web Viewer 2015). This proportion is highest in the Great Ruaha Sub-Basin where only 10 percent of rainfall is estimated to enter the river as surface water and recharge groundwater aquifers (**Figure 2.3**). The proportion of runoff is highest in the Kilombero Sub-Basin (34 percent). The Luwegu and Lower Rufiji are again intermediate, with runoff ratios of 21 and 14 percent, respectively. These figures confirm that the Kilombero Sub-Basin has the highest potential of water resources followed by the Luwegu. These figures are within the same range as recently reported in WREM International (2015b).

Figure 2.2: Mean Monthly Precipitation over Rufiji Sub-Basins



Note: Derived from FAO Local Climate Estimator (FAO 2005)

Figure 2.3: Annual Average Runoff (P-ET) and Actual Evaporation (ET) as Percentages of Total Precipitation (P) in the Four Sub-Basins of Rufiji

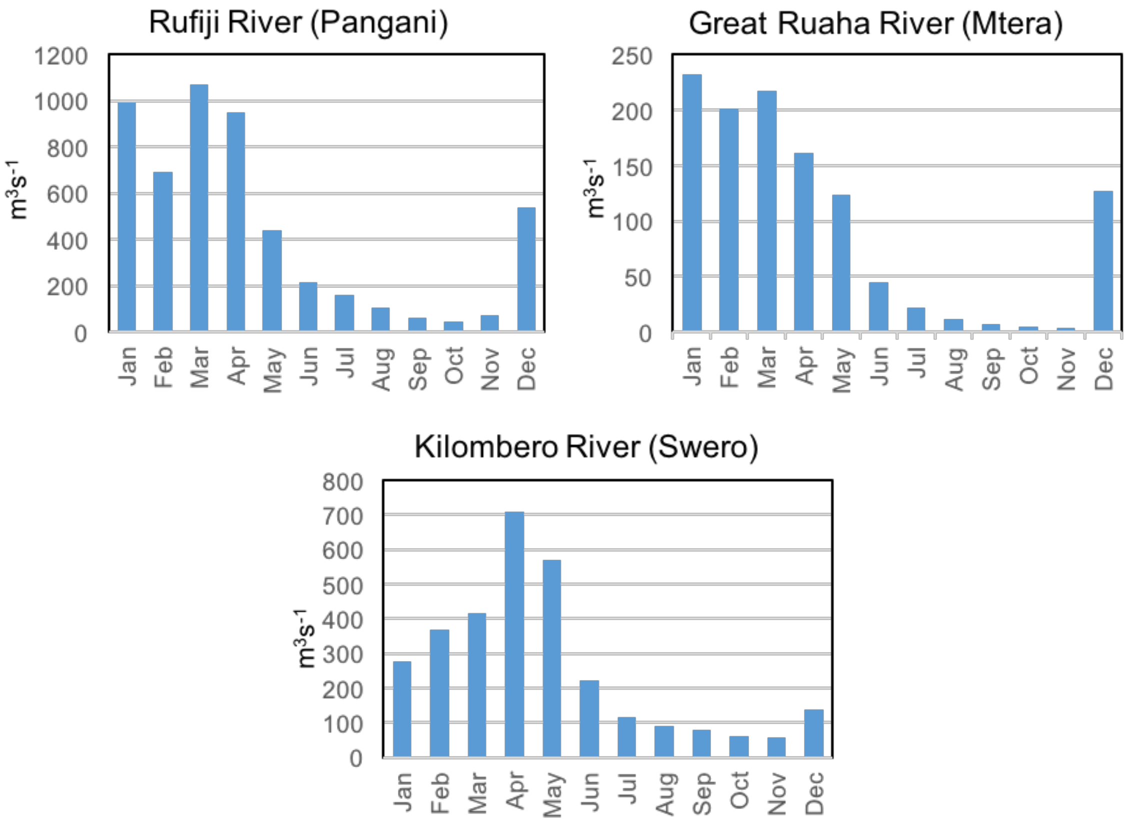


Note: Extracted from World Evapotranspiration Web Viewer (2015).

River discharge patterns across the Rufiji River Basin match those of precipitation, with an approximate 1-month lag in the onset and end to the high flow season (**Figure 2.4**). Discharge values also reflect a more extreme range of seasonal variability in the Great Ruaha, compared to the Kilombero and downstream reaches. This is to be expected from the smaller proportions of runoff registered in the Great Ruaha Sub-Basin. Average monthly flow during the dry season of the Great Ruaha is less than 10 percent of wet season monthly averages, while the comparable value in the Kilombero River is 25 percent. Using the estimated runoff proportions in **Figure 2.3** as a guide, average monthly dry season flows in the Luwegu should lie between those of the Great Ruaha and Kilombero. Values in the Lower Rufiji are in fact intermediate, reflecting the mixing of these sources in downstream reaches.

Hydrological characteristics described here are based mainly on historical data, including satellite-derived data reflecting recent years. Future hydrological behavior in the basin is made more uncertain by climate change. El Niño and La Niña episodes add another layer of variability. El Niño episodes are associated with greater than average rainfall years, especially from October through December. Conversely, years of La Niña episodes are associated with drier than average conditions. Since 1960, temperatures in Tanzania have been increasing at an average rate of 0.23 ˚C per decade. Over the same period, annual rainfall has decreased at an average rate of 3.3 percent per decade. Projections for future change, however, call for increased levels of annual rainfall although the distribution is variable during the year and more is expected to fall during short-term, heavy rainfall events (McSweeney et al. 2010).

Figure 2.4: Average Monthly Discharges for Lower Rufiji, Great Ruaha, and Kilombero Rivers



Notes: Station names are indicated in parentheses. Station locations are shown in Figure 2.1, where the Pangani station is adjacent to Stiegler's Gorge.
Source: Global Runoff Data Center 2015

2.2 Basin Physiography and Geomorphology

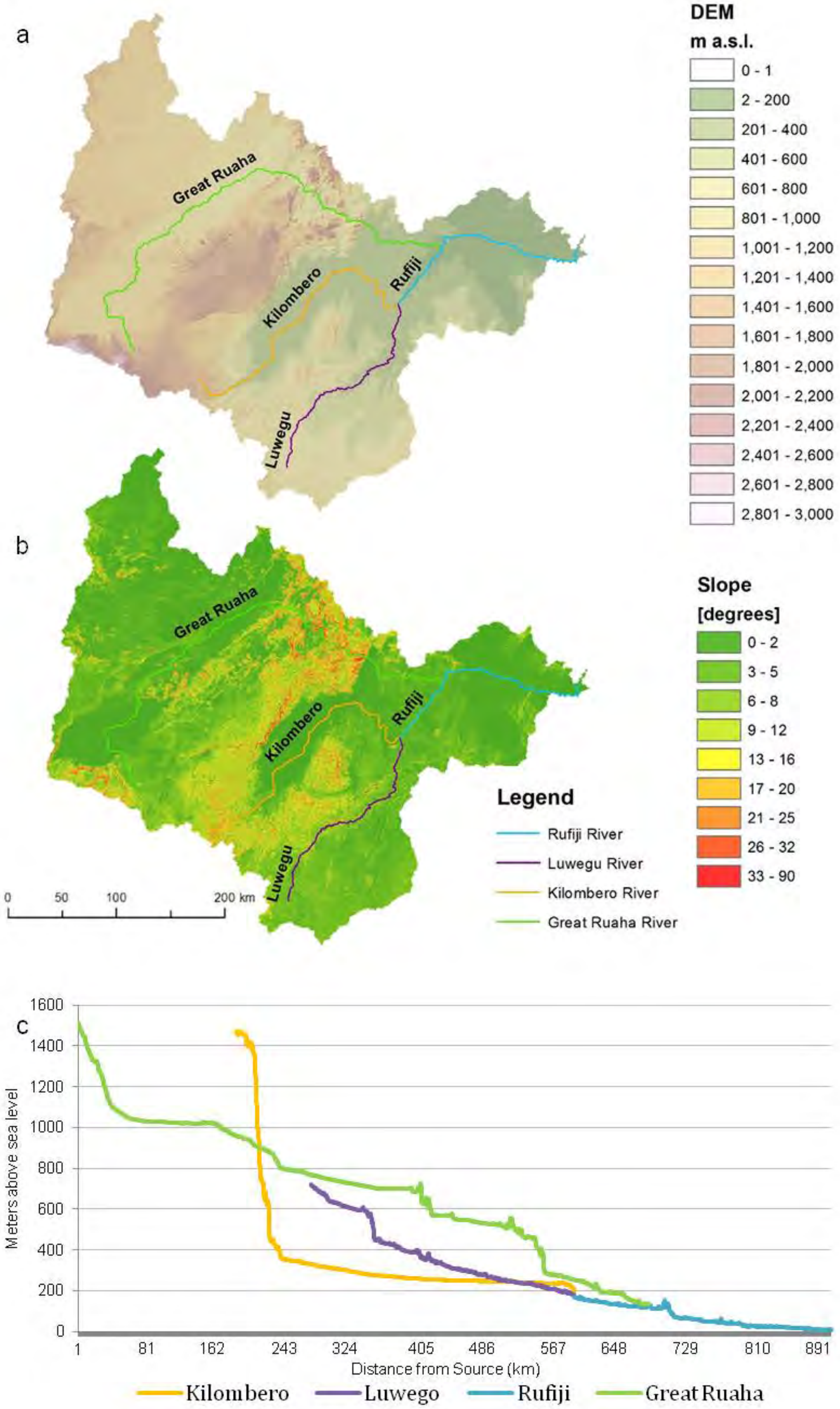
The Rufiji Basin varies in elevation from sea level to greater than 1,500 meters above sea level (masl). About 60 percent of the basin sits at an elevation between 500 and 1,500 masl, including the greater part of the Great Ruaha Sub-Basin. Elevations above 1,500 masl are concentrated in the divide between the Kilombero and Great Ruaha sub-basins and the Rufiji Basin and Lake Nyasa and Lake Rukwa basins. About 20 percent is in the range of 200 to 500 masl, mainly in flat terrains encompassing all of the Kilombero floodplain and about half of the Luwegu Basin, as well as a small portion of the Great Ruaha between Kidatu and the confluence with the Rufiji River. Only about 9 percent of the basin area lies at elevations below 200 masl, all confined to the Lower Rufiji Sub-Basin. The longitudinal profiles of the four sub-basins (**Table 2.2** and **Figure 2.5**) reflect the distribution of slope and elevations described above. The steepest river overall is the Luwegu, with an average slope of 2.4° and a maximum slope of 48°, while the flattest is the Lower Rufiji, with 1.4° and 34° as average and maximum slope, respectively. The steepest longest portion of a river is found in the Kilombero River above the elevation of 350 masl. The Great Ruaha River has three major floodplains laying at about 1,025 masl (100 km along the main axis of the Great Ruaha River), 700 masl (also about 100 km along the river's main axis) and 575 masl (some 70 km along the main axis of the river), as well as a smaller floodplain at about 500 masl just downstream of Kidatu Dam (extending for about 30 km). The Kilombero has a wide and long floodplain at around 200 to 300 masl, extending for about 250 km to the junction with the Luwegu and Great Ruaha. The Lower Rufiji has an extensive floodplain downstream of Stiegler's Gorge, extending for about half of its length to the river mouth.

Table 2.2: Length, Slope, and Elevation Parameters of the Four Rivers Comprising the Rufiji River System

Sub-Basin	Length (km)	Average Slope (degrees)	Maximum Slope (degrees)	Average Elevation (masl)	Maximum Elevation (masl)	Minimum Elevation (masl)
Great Ruaha	713	1.9°	66°	703	1,528	119
Kilombero	422	1.9°	62°	364	1,535	168
Luwegu	329	2.4°	48°	377	727	166
Lower Rufiji	325	1.4°	34°	73	772	0

Parameters such as elevation pertain to the rivers themselves and not their basins. In addition, values may differ from those on topographic maps, due to the different data sources used for calculations.

Figure 2.5: Elevation and Slope of Rufiji Basin, with Longitudinal Profiles for Rivers within Four Main Sub-Basins



Notes: (a) = elevation; (b) = slope; (c) = longitudinal profiles for rivers within four main sub-basins: Great Ruaha (green), Kilombero (orange), Luwegu (violet) and Lower Rufiji (blue). Drainage derived from Shuttle Radar Topography Mission (SRTM) 90 m. Digital Elevation Model (DEM) data - SRTM v4.1 at 90 m pixel size.

Eight landscape element classes may be distinguished throughout the Rufiji Basin (**Table 2.3** and **Figure 2.6**). From a morphometric point of view, the eight classes are a combination of the following three attributes of the slopes: (1) slope gradient or steepness, that is the slope angle in degrees; (2) local convexity or positive surface curvature (equivalent to the longitudinal curvature of slopes); and (3) surface texture or roughness (or frequency of ridges and valleys), represented by measures of spatial intricacy such as drainage density, and changes in sign of slope aspect or curvature per unit area. After classifying the terrain into eight classes, using the algorithm of Iwahashi and Pike (2007), we combined them with additional information on study area morphology and geology to produce the following eight geomorphological classes (see also **Table 2.3**). These classes are:

1. dissected plateau or mountain tops - elevated terrain with a dense drainage pattern that dissects them
2. high plateau, not dissected plateau or mountain tops - elevated landforms without dense drainage networks
3. mountain slopes, and isolated basins, that are the slopes connecting the mountain tops to the lower landforms as well as intramountain basins
4. confined valleys and confined alluvial fans - steep sided valleys with the drainage only in the main valley floor and steep alluvial fans
5. lower slopes - the lower parts of the mountain slopes connecting the mountain front with the lower terrains, usually dissected by many drainage lines
6. alluvial fans and piedmonts - alluvial fans are fans of deposited fluvial sediment at the steep change in topographic gradient where a valley enters a plain and are the place for avulsion of the main rivers, and piedmonts are belts of coalescent alluvial fans
7. confined valleys, smooth hills - not steep, but still confined valleys and smooth hills
8. floodplains and river valleys - the flattest landforms, where the drainage can take a braided pattern with frequent avulsions

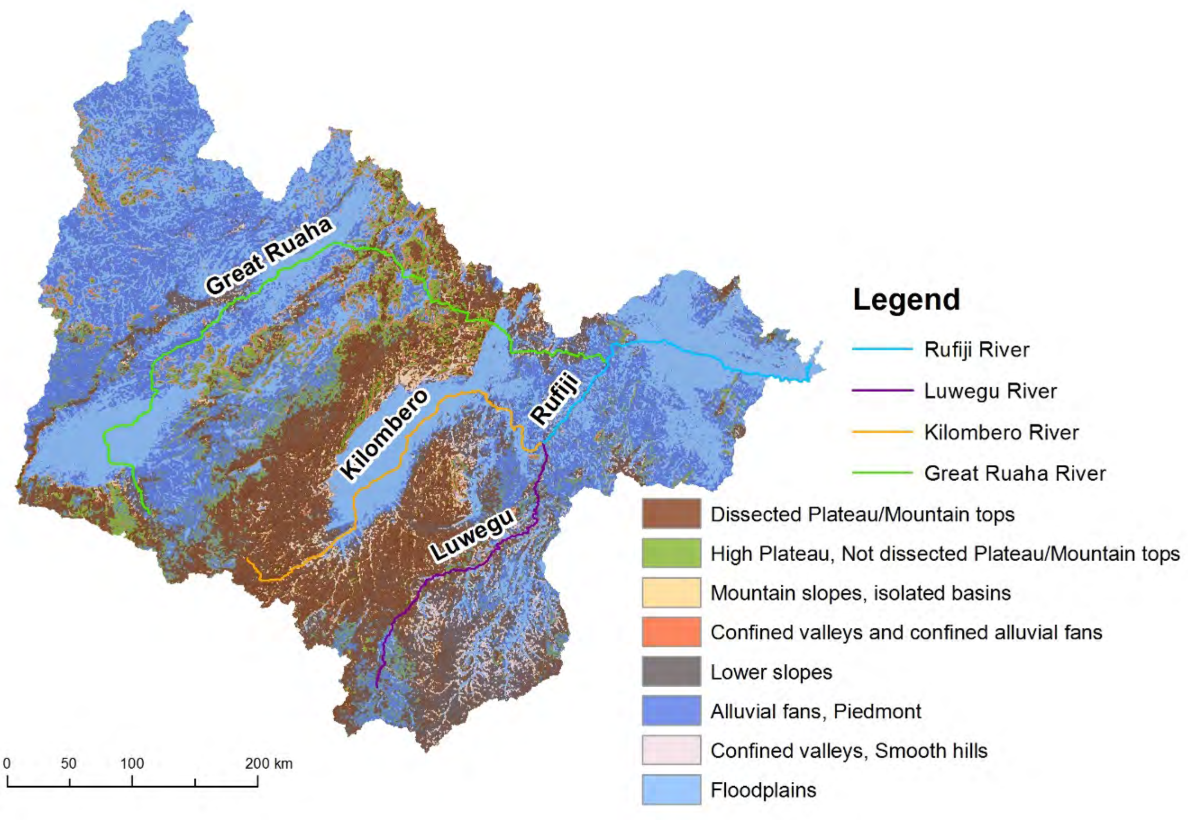
Dissected plateau/mountain tops are concentrated in the central part of the basin and reflect the geological and tectonic structure of the basin. These dissected plateaus are dominated by gneiss. Floodplains occupy, as expected, central depressions of the main sub-basins. Floodplains occupy large proportions of valley bottoms of the Great Ruaha, Kilombero, and Lower Rufiji sub-basins, while the steeper Luwegu Sub-Basin has only a narrow floodplain. A great proportion of the basin is also occupied by alluvial fans and piedmont and hills at various elevations, including the highlands of the Great Ruaha Sub-Basin.

Table 2.3: Landform Classes of Rufiji Basin

Class	Geomorphologically Meaningful Description
1.	Dissected plateau/mountain tops (steep, concave, and rough terrain)
2.	High plateau, not dissected plateau/mountain tops (steep, concave, and not rough terrain)
3.	Mountain slopes, isolated basins (steep, convex, and rough terrain)
4.	Confined valleys and confined alluvial fans (steep, convex, and not rough terrain)
5.	Lower slopes (not steep, concave, and rough terrain)
6.	Alluvial fans, piedmont (not steep, concave, and not rough terrain)
7.	Confined valleys, smooth hills (not steep, convex, and rough terrain)
8.	Floodplains and river valleys (not steep, convex, and not rough terrain)

Note: Based on the approach of Iwahashi and Pike (2007)

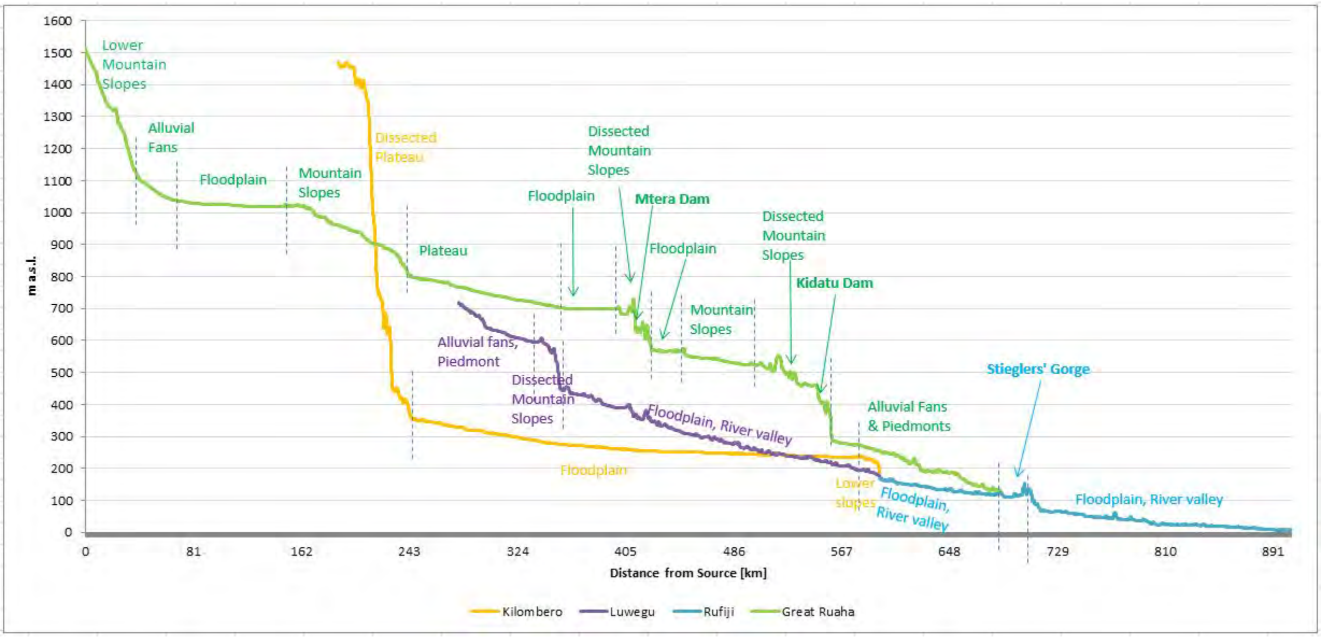
Figure 2.6: Distribution of Eight Landscape Elements in Rufiji Basin According to the Eight Classes



Note: See Table 2.3 for description of landform classes.

River geomorphic characteristics are strongly associated with slope and landscape characteristics, so merging information in **Figure 2.5** and **Figure 2.6** yields a zonation of rivers from upstream to downstream (**Figure 2.7**).

Figure 2.7: Zonation of River Longitudinal Profiles According to the Eight Landscape Element Classes



2.3 Socio-Economic Context and Basin Communities

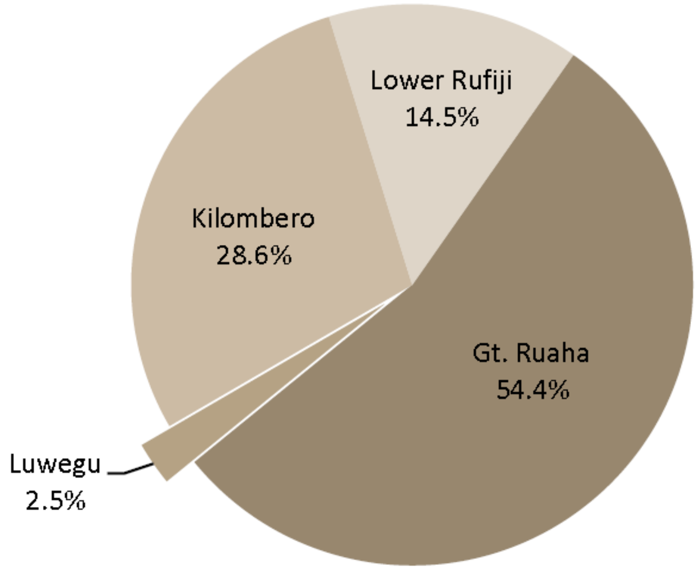
This section gives an overview of the socio-economic characteristics of the basin and sub-basins and describes the social use and dependency of the population on the riverine resources.

2.3.1 Population and Ethnicity

Based on the 2012 census, the population in the Rufiji Basin is estimated at 3.6 million, which is about 8.3 percent of the population of mainland Tanzania. About 54 percent of this population resides in the Great Ruaha Sub-Basin, 29 percent in the Kilombero, and 15 percent in the Lower Rufiji (**Figure 1.1** and **Figure 2.8**). The Luwegu Sub-Basin, while occupying 14 percent of the Rufiji Basin, is home to only 2.5 percent of its population, because a majority of the sub-basin lies in the Selous Game Reserve created in 1922. The basin population has been growing at a moderately low rate compared to the rest of the country. The basin average annual population growth rate estimated in 2012 was 1.95 percent. The sub-basins have differential growth rates due to differences in, for example, rural-urban migration, outmigration of adults and/or creation of protected areas (e.g., Kitulo National Park). Due to these differential growth rates, shares of the total basin population of the Great Ruaha and Kilombero sub-basins are expected to increase in the future, while shares of the total population for the Luwegu and Lower Rufiji sub-basins will decline (WREM International 2015i).

Census results showed that about 50 percent of the population in 2012 was below 20 years of age, while 75 percent was below 40 years old. The proportion of females to males is roughly equal. The average basin household has four to five members. Only a small proportion of the population (28 percent in 2012) resides in urban areas; the rest live in rural areas.

Figure 2.8: Sub-Basin Share of Total Basin Population of 3.6 Million in 2012



Source: WREM International 2015i

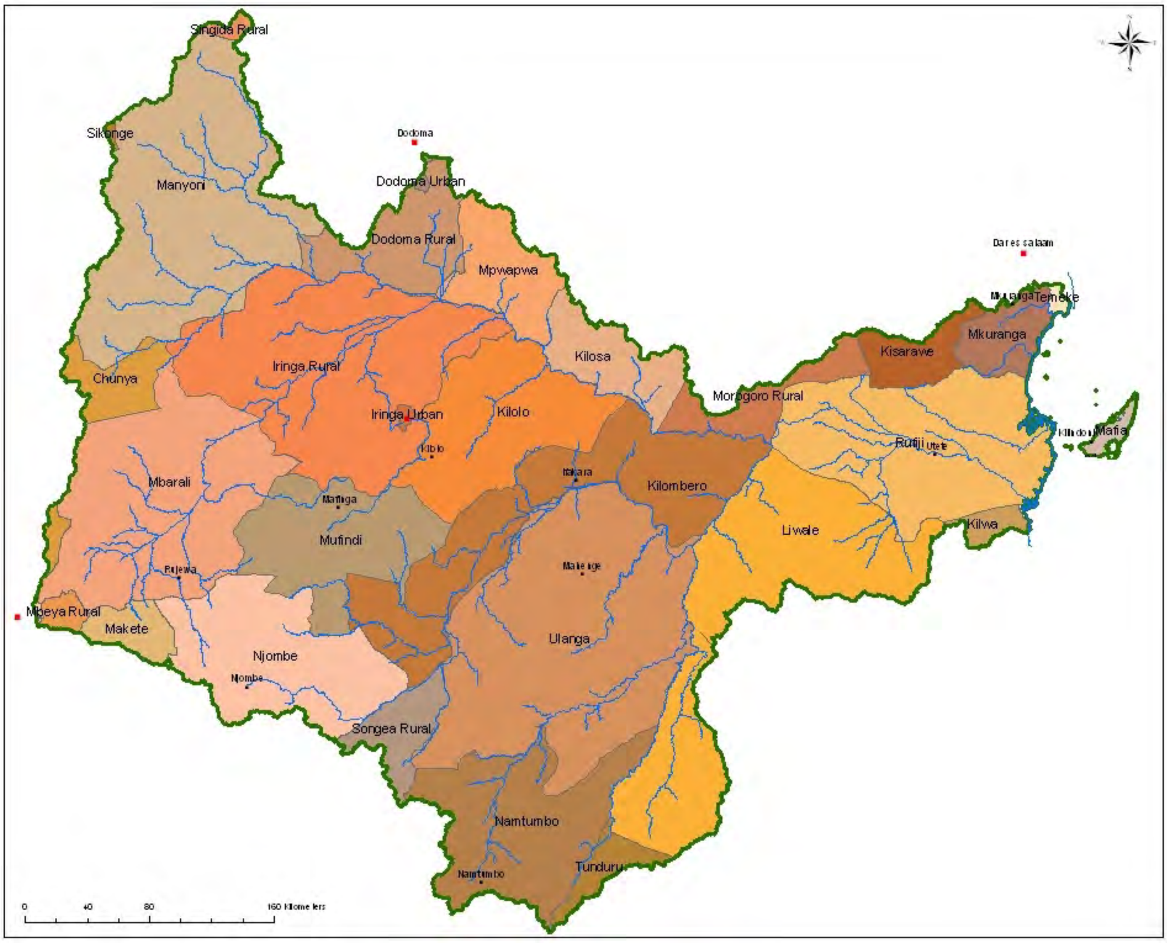
The upper Rufiji sub-basins have a high level of ethnic diversity, including Hehe, Nyakyusa, Gogo, Pogoro, Wasangu, Wanji, Ndamba, Bena, and other groups. These groups bring traditions and worldviews that strongly influence their relationship with rivers and the natural resources associated with them. These communities make maximal use of resources in their immediate environment, focusing on land resources but also exploiting, where available, aquatic resources, including fish and assorted materials for other productive uses. In the Lower Rufiji Sub-Basin, ethnic groups are more closely tied to Swahili culture and more tightly linked to delta and coastal resources. The specific ties found between all Rufiji cultures and the river system in 2015 are featured in the EFA presented here (see Section 4).

2.3.2 Social Use of Riverine Resources

Water Supply and Sanitation

Coverage in terms of a safe and reliable household water supply is generally low in most parts of the basin, averaging about 55 percent for rural populations and 41 percent for urban populations. Coverage disaggregated by district is highly variable, ranging from 17 percent in Sikonge to 79 percent in Ulanga district (**Figure 2.9**). Some of the districts are among the 20 least served districts in Tanzania in terms of safe water coverage. Sanitation coverage within the basin, which is almost exclusively through traditional pit latrines, stood at 92.7 percent in 2002, but in some districts, it is as low as 56 percent. Less than 25 percent of the population uses improved sanitation facilities.

Figure 2.9: Administrative Districts that Intersect with Rufiji Basin



Source: Rufiji Basin Water Board

Fuel

Nearly all households use either firewood or charcoal for cooking, heating, and other basic needs. Access to the electricity grid is very low, especially in rural areas.

Fishing, Crop Cultivation, and Livestock Keeping

Fishing is an important economic activity, especially in the Kilombero Valley, the lower Rufiji freshwater floodplains, and the estuarine-marine systems of the Rufiji Delta. In the Great Ruaha Sub-Basin, fishing is done in Mtera Reservoir. Fishing is mostly dominated by small-scale fishermen who tend to use poor fishing gear and/or poisoning in some instances. Annual fish production in the basin is estimated at 21,000 metric tons, which is 8 percent of the annual fish production in Tanzania. The Rufiji mangrove-estuarine system supports a vibrant fishing industry for shrimp, prawns, finfish, crabs, and gastropods. More than 80 percent of the prawns caught in Tanzania come from the Rufiji Delta, and a large proportion are exported. Sea grass farming is also practiced in the estuarine areas.

The basin is a regional food basket for agricultural products and produces surpluses sold to nearby cities such as Dar es Salaam, Morogoro, and Dodoma. Major crops grown include rice, maize, round potatoes, sunflower, beans, groundnuts, sesame, soya beans, cowpeas, pigeon peas, sorghum, millet, wheat, cassava, sweet potatoes, cashew, tomatoes, onions, and other vegetables. Agriculture is characterized by low inputs and low productivity and dominated by smallholder farmers.

Upstream of the Mtera and Kidatu hydropower plants (**Figure 1.1**) the Great Ruaha River is heavily utilized for irrigation. Agriculture in the Great Ruaha Sub-Basin is concentrated in the Usangu Plains. The crops that are cultivated include maize, beans, rice, and vegetables; with the first two crops grown mostly under rain-fed conditions, whereas the latter two are grown under irrigation. Paddy rice is the predominant irrigated crop; a core area of 15,000 to 20,000 ha can be irrigated every year, which can expand to a maximum of about 40,000 to 55,000 ha, depending on water availability (Mtahiko et al. 2006; Mwakalila 2011b; SAGCOT 2013).

Farming in the Kilombero Sub-Basin is practiced mainly in the lower and some of the higher parts of the floodplain that inundate annually. The main crops cultivated are rice and maize, but many other crops are cultivated, including sesame, potatoes, cassava, and fruits such as banana, mango, and oranges. Crop cultivation is both for food (subsistence) and cash (to pay for basic needs, i.e., school fees, medication, and transportation) (see **Annex N** for additional information).

The Lower Rufiji Sub-Basin supports significant agricultural activities, mostly in the Rufiji floodplains and delta. Recent estimates show that about 10 percent (58,500 ha) of the terrestrial area has been converted to agricultural land. Rice (staple food) is the most important crop and is grown by about 76 percent of households. Most agricultural activity is for subsistence, but some proportion is sold. Seasonal floods control agricultural activities in the area (see **Annex N**). People who live and farm in some floodplains move to higher lands during the floods and return to the valleys during the cultivation season also enabling farmers to cultivate two types of crops. Some crops are planted when the water level is falling and the areas are still wet (flood recession agriculture). The use of such seasonal floodplains allows the planting of a range of crops; paddy rice is planted in standing water as the water level falls, while quick growing crops, such as cucumber and tomato, are planted later in damp soil.

The Rufiji Basin is not traditionally a high livestock production area. The income generated from livestock is only 10% of the total for the average household. While not historically a high production area for livestock since the 1970s, livestock keeping (particularly nomadic pastoralism) has been one of the major challenges of natural resources management in the Rufiji Basin. Nowadays, there are pockets with relatively high stocking rates, mostly in the dry central belt, parts of Kilombero, and increasingly, in the coastal region. A significant proportion of the livestock in the basin is reared by traditional pastoralist tribes who have emigrated from other parts of Tanzania. The basin has an estimated 1.4 million indigenous cattle, 670,000 indigenous goats, and 420,000 indigenous sheep. Livestock production is characterized by a dominance of indigenous breeds (the Tanzanian short-horn zebu is the main livestock breed kept), and a high occurrence of livestock disease, high mortality rates, low productivity, and low value addition.

The Usangu Plains in the Great Ruaha Sub-Basin are an important livestock pastoral area, with cattle numbers in the hundreds of thousands and goats, sheep, and donkeys in the tens of thousands. During the dry season, water is scarce on the central Usangu Plains, and pastoralists migrate to graze their herds at the only permanent water source, the Utengule-Ihefu wetland, compounding local water resources depletion (SAGCOT 2013).

Since the 1990s, Barabaig pastoralists who are culturally close to the Maasai in social and political organization, have been moving into the Lower Rufiji floodplains in search of grazing lands, as they are no longer able to graze their animals in northern regions and have, like the Maasai of the Pangani River Basin, been pushed farther away from their original territories throughout the colonial and postcolonial periods (Haller et al. 2013). More recently, an estimated 2,630 pastoralists from Iringa and Morogoro regions, accompanied by 272,800 cows, 51,160 goats and 20,120 sheep, are reported to have arrived in the Pwani (Coast) Region's Rufiji Delta since April 2010. This has impacted some 4,500 ha of arable farmland and escalated existing conflicts between local settled farmers and livestock keepers (Rufiji District Commission 2012). The situation was exacerbated by prolonged drought over the preceding 5 years, which detrimentally affected traditional pastoralist grazing lands and water supplies and triggered migration to the Rufiji Delta.

Wild Vegetables and Fruits

Forests within Great Ruaha Sub-Basin provide different types of wild fruits for harvest. The most common are the fruits of *Uapaca kirkiana* (sugarplum, locally known as Mikusu, Phyllanthaceae). Their distribution is wide in the sub-basin and mostly occurring in the southern highlands (Iringa and Mbeya). However, the extent of harvest and contribution of these products to the rural economy is not understood. The common wild vegetables used in the basin include *Solanum nigrum, Sesamum angolense, Bidens schimperi, Bidens pilosa, Caylusea abyssinica, Conchurus tridens, Amaranthus spinosus, Celosia trigyna, Cucurmis figarrei,* and *Rumex usambarensis*.

Communities living in the Kilombero River valley, within and along the margins of the Ramsar site, make great use of wild (non-cultivated) vegetables. Over 75 percent of households collect wild vegetables, primarily for their own consumption, approximately 7 days out of every month. *Barleria submollis* (Mwidu), *Aeschynomene uniflora* (Linyala), and mushrooms are the common, preferred vegetables. Wild fruits are also collected and consumed. Preferred fruits include *Uapaca kirkiana* (Mikusu), *Vitex doniana* (Mfuru/Mafulu), *Strychnos innocua* (Madongadonga), *Parinari curatellifolia* (Misaula), and *Tamarindus indica* (Ukwaju). There is no substantial revenue from selling of wild vegetables, but they are sold and/or traded at village markets. Vegetables can be found year round in the valleys, during the rainy season in maize farmlands, and during the dry season in the forest and around ponds. Most of the fruits are found in the uplands and valleys, and the highest availability is during the dry season.

The Lower Rufiji Basin has various forest vegetation types that provide wild vegetables and fruits. The common vegetables from those forests, especially Kichi Forest Reserve (FR) and Ngumburuni FR, include *Sesamum* spp, *Zanthoxylum chalybeum*, and *Bidens pilosa*. Fruits are used as food, beverages, and sources of cooking oils, and they include *Adansonia digitata*, *Allanblackia* spp, *Parinari exelsa*, *Parinari curatelifolia*, *Azanza garckeana*, *Uapaca kirkiana, Vitex* spp*,* and *Tamarindus indica*. Wild fruits from tree species, like *Vitex doniana, Manilkara sansibarensis, Syzygium guineense, Tamarindus indica,* and *Suregada zanzibariensis,* are plentiful in Ngumburuni FR in the Lower Rufiji Sub-Basin.

Construction Materials

Most materials used for construction come from the natural forest areas. For example, the mangrove ecosystem of the Lower Rufiji Sub-Basin has a high extraction of trees for timber, furniture, and boat-building though this extraction is mostly done illegally. The same situation is reported from Ngumburuni FR, where illegal tree extraction has occurred at scales from a few building poles for individual house construction to massive cutting of large diameter trees for commercial export. In the Kilombero Sub-Basin, thatching grasses (*Cymbopogon nardus,* Mbasa, *Imperata cylindrical*, Lusanu) are widely used and found in higher parts of the floodplain. Also, construction materials from *Pennisetum pedicellatum* (Matete) and *Oxytenanthera abyssinica* (Mianzi) are used. These trees can be found in the forest area or further away in the floodplain but not in the riparian zone.

Weaving Materials

Within the basin, different plant species are used for weaving mats, hats, and baskets. Though not well documented, there is an increasing harvest of *Phoenix reclinata* (Ukindu), *Borassus aethiopum,* and *Hyphaene petersiana* (Malala), which are mostly found in wetlands. The majority of mats produced are for use in individual households, not for sale.

Traditional Medicine

People in the basin use different plant species as traditional medicines for curing injuries and diseases. Extracted honey was reported to be used in curing burns and blisters and can also be is used to treat malaria and coughs, mainly in children. Commonly used plants include the roots of Mduma (*Garcinia burchananii*), which is used as an aphrodisiac; leaves and stems of Lipembapemba (*Rumex abyssinicus*) to treat pneumonia, cough, and in dressing wounds; leaves of Linyimbili (*Rumex usambarensis*) for stomachaches and to reduce constipation; and Mikusu (*Uapaca kirkiana*) for treating intestinal problems.

Hydropower Generation

In the Rufiji Basin, power generation currently contributes 464 megawatts (MW) from three hydropower stations: Kidatu (204 MW), Kihansi (180 MW), and Mtera (80 MW). The installed capacity in these three power plants represents 83 percent of the total national hydropower capacity (561.75 MW) and 49 percent of the total national hydrothermal power capacity (953.75 MW). There is potential to develop an additional 2,435 MW of installed capacity at Ruhudji (358 MW), Mpanga (144 MW), Upper Kihansi (248 MW), Stiegler's Gorge (1,200 MW), Ikondo (340 MW), and Taveta (145 MW). The planned Rufiji hydro-stations would nearly triple the current national energy generation (from all stations, hydro and thermal) and eliminate energy shortages (for some time), even during dry years. There are numerous minor and micro hydropower plants in the Rufiji Basin, and the potential for developing such schemes is considered very high (M. Mwaruvanda, pers. comm. 2015).

Tourism

The many national parks and game reserves and the wide biodiversity that they harbor make the basin an important tourist attraction with a high revenue generation potential.

Water-associated Health Problems

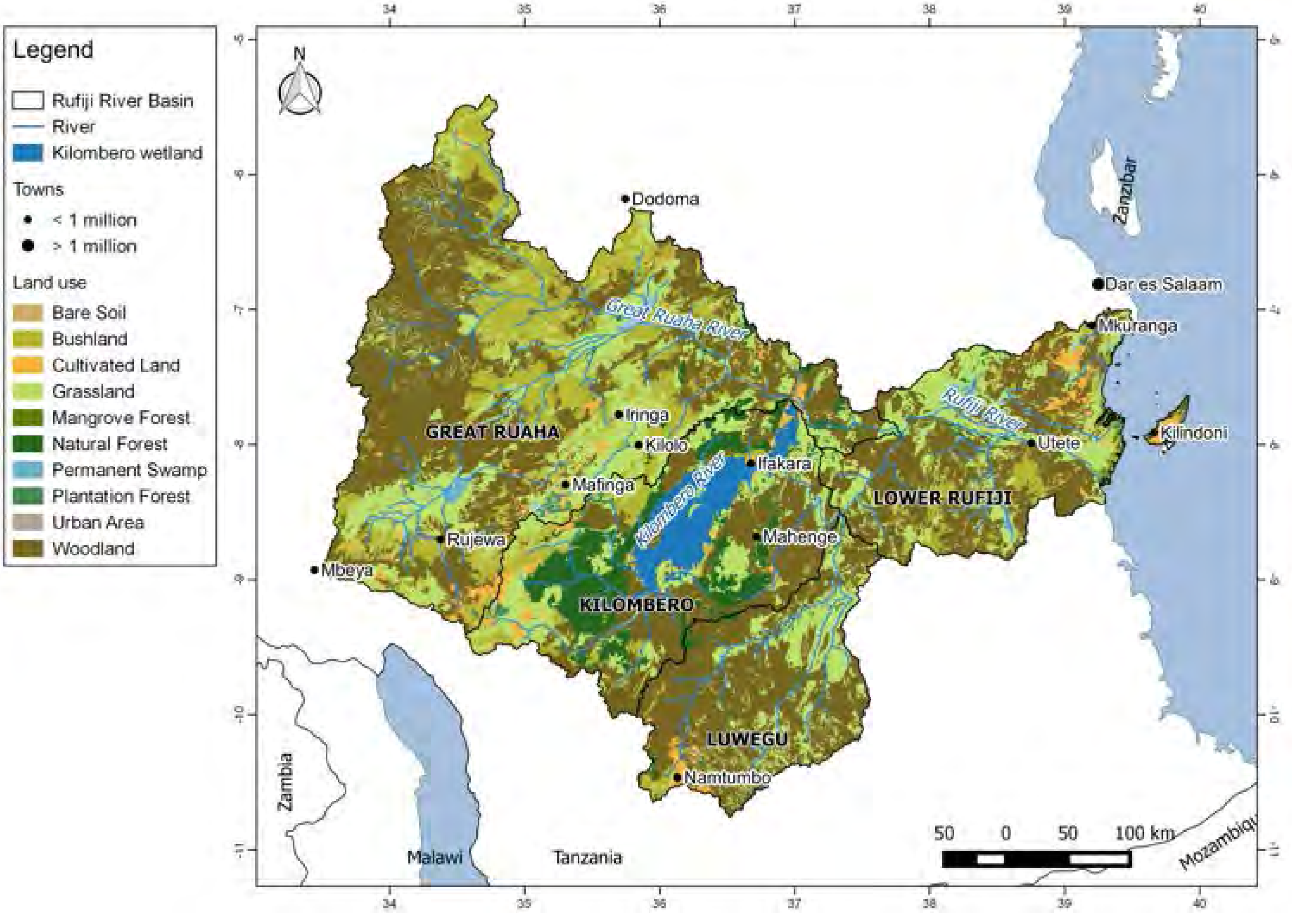
The water-associated disease, malaria, is the leading cause of morbidity and mortality both in under five and over five age groups. Malaria causes three times more illnesses and two times more deaths than any other disease. Other important causes of morbidity include acute respiratory infections, pneumonia, diarrhea, anemia, intestinal worms, tuberculosis and clinical AIDS.

The following water-related diseases were reported in the Kilombero Sub-Basin, based on the field surveys: malaria, fungus, diarrhea, typhoid fever, amoebic dysentery, cholera, bilharziasis (or schistosomiasis), and urinary tract infections.

2.4 Basin Protected Areas, Biodiversity and Aquatic Ecosystems

The Rufiji River Basin supports a diverse range of land covers and ecosystems, including woodlands, grasslands, forests, and swamps (**Figure 2.10**). These serve as home to a diversity of plant and animal species that benefit from the numerous ecological niches (Caras 2001).

Figure 2.10: Land Use and Land Cover in Rufiji Basin in 2002

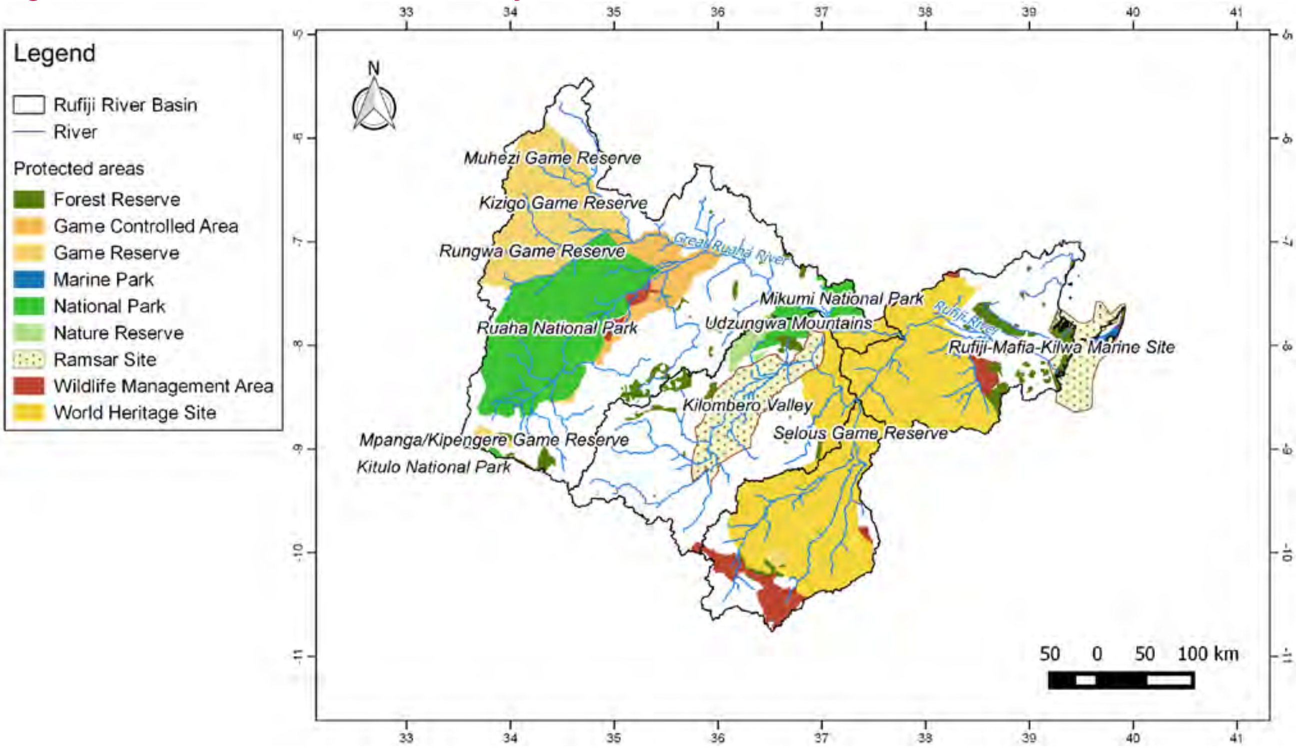


Notes: International Livestock Research Institute (ILRI) geographic information system (GIS) Services. EPSG Projection: 4210 - Arc 1960. Data source: Land-use patterns in Tanzania as of the year 2002, ILRI, retrieved from http://data.ilri.org.

Approximately 57 percent of the basin land surface is currently under environmental protection in a system that includes national parks, game reserves, forest reserves, nature reserves, game control areas, wildlife management areas, marine parks, Ramsar sites, and a United Nations Educational, Scientific and Cultural Organization (UNESCO) World Heritage Site (**Figure 2.11**). The Selous Game Reserve is a dominant feature of the Luwegu Sub-Basin and western half of the Lower Rufiji Sub-Basin. It is amongst the largest and oldest protected areas in Africa (United Nations Environment Programme [UNEP] and World Conservation Monitoring Centre [WCMC] 2011), with protection status since the late 1800s and UNESCO World Heritage status since 1982. People largely have been excluded from the area over the past 100 years, which contributes to its high degree of ecological integrity, especially in the Luwegu Sub-Basin, but this has also led to some conflict. The reserve includes large wildlife populations, including the rare black rhinoceros (*Diceros bicornis*), the Nile crocodile (*Crocodilus niloticus*), and the endemic Udzungwa forest partridge (*Xenoperdix udzungwensis*) (UNEP and WCMC 2011).

There are also smaller forest reserves and wildlife management areas bordering it, which extends the available wildlife habitat. Understanding of the ecology of the Luwegu River, which flows through the southern extent of Selous Game Reserve, is limited although some scattered studies exist, especially for the river lowland parts of the sub-basin. A high level of system ecological integrity is expected, however, due to the free-flowing condition of the river and low human pressure in the catchment.

Figure 2.11: Protected Areas in Rufiji River Basin



Notes: EPSG Projection: 4210 - Arc 1960.
Data source: International Union for Conservation of Nature (IUCN) and UNEP-WCMC (2015) The World Database on Protected Areas (WDPA) [online, 08/2015], Cambridge, UK: UNEP-WCMC; www.protectedplanet.net.

To the northwest of Selous Game Reserve lies the Kilombero Valley Floodplain, which was listed as a Ramsar Wetland of International Importance in 2002. The floodplain is a vast (7,967 km^2) and complex network of intersecting river channels interspersed with seasonally flooded islands and plains. It is the largest such complex in East Africa and thus a unique habitat for wetland vegetation, mammals, water birds, and fish. Unique wildlife in the floodplain includes East Africa's largest Puku antelope (*Kobus vardonii*) and more than 300 bird species, including three endemics. Large animals migrating between the Selous Game Reserve and Udzungwa Mountains National Park use the wetland as important dry season habitat (Semesi 1989), while fish migrate into the wetland from surrounding rivers to access important spawning and nursery areas (Ramsar 2002). People living in and adjacent to the wetland rely on up to 30 different species of fish, at least two of which (*Citharinus congicus* and *Alestes stuhlmanni*) are endemic to the Kilombero River Valley (Ramsar 2002).

The Great Ruaha Sub-Basin is home to Ruaha National Park and adjoining game reserves and control areas. Ruaha National Park is the second largest wildlife conservation area in Tanzania after the Selous Game Reserve (Kashaigili et al. 2007). It is rich in rare plants, and in animals such as the Greater Kudu (*Tragelaphus strepsiceros*) and the African wild dog (*Lycaon pictus*), amongst many other species.

The park is an important habitat for bird species, some of them migrating from Europe, Asia, Australia, and Madagascar (Baker and Baker 2001).

The Rufiji River terminates in a large delta, which is partially covered by the largest area of estuarine mangroves in East Africa (Ochieng 2002). The mangrove and neighboring coral reefs and sea grass beds are highly productive and also rich in biodiversity, as multiple species find refugia, breeding grounds, and nurseries in these habitats (Rufiji Environmental Management Project (REMP) 2001; Ochieng 2002). The whole channel along the Rufiji coast was listed as a wetland of international importance, the Rufiji-Mafia-Kilwa Marine Ramsar Site. The Rufiji Delta and adjoining coastal ecosystems support abundant shrimp and prawn fisheries, which are dependent on the flows of freshwater and nutrients from the Rufiji River.

3 ENVIRONMENTAL FLOW ASSESSMENT PROCESS

3.1 Selection of Environmental Flow Methodology and Specialist Team

Environmental flow assessment has been practiced in Tanzania for a decade, with assessments of the Mara, Great Ruaha, Pangani, Wami, and Ruvu having been undertaken, using a variety of available assessment methodologies. Dickens (2011) provides a critical analysis of the environmental flow assessments undertaken for several rivers in Tanzania (and Kenya). A major review of environmental flow practice and experience in Tanzania was undertaken for the Ministry of Water (funded by USAID) in 2013 (FIU/iWASH 2013). The full report is provided in **Annex E**. It includes recommendations for the future of EFA and implementation in Tanzania, synthesized from the comments and suggestions of more than 40 local and international managers, policy-makers, and scientists who were interviewed and/or invited to review the report. The results of the review served as the framework for the design of the Rufiji EFA and methodology used. In particular, a mix of international and local scientists were contracted to undertake the study (Section 3.1.2). The experience gained from previous environmental flow assessments on Tanzanian rivers was exploited to optimize the engagement of stakeholders (see also **Annex F**), the process of establishing the environmental flow objectives and scenarios for assessment, and the utility and clarity of the results.

3.1.1 Building Block Methodology as Selected Holistic Methodology

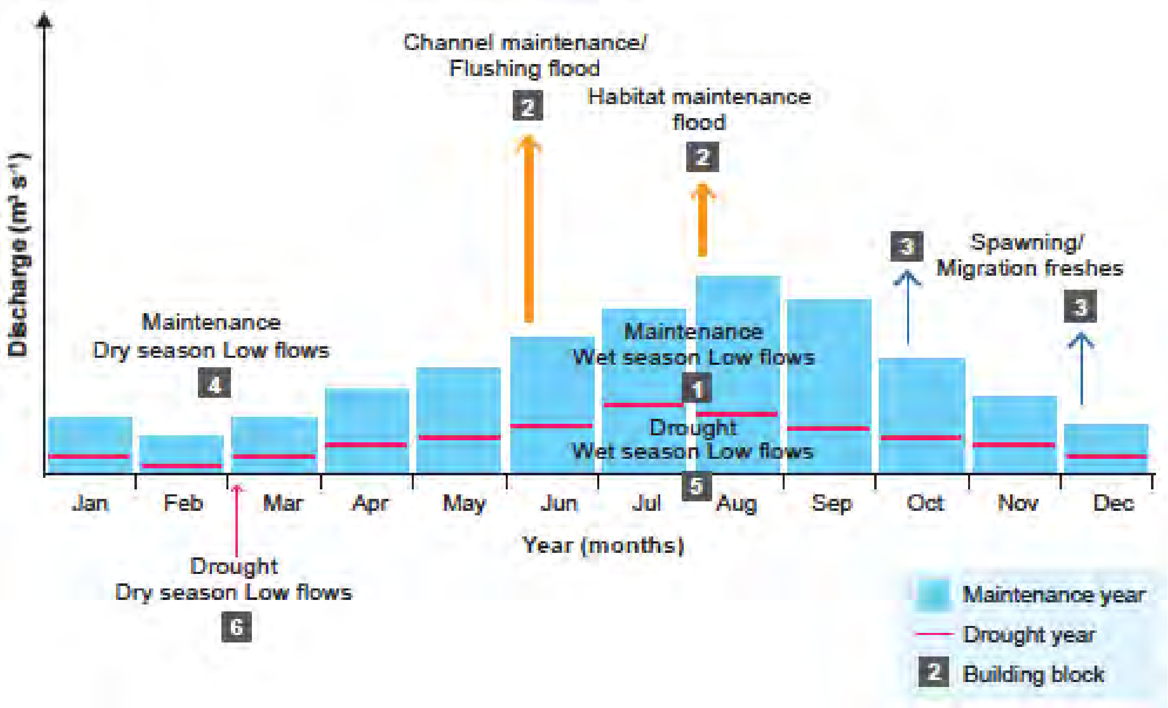
There are a large number of effective and useful environmental flow methodologies available globally (as reviewed in, among others, Tharme 2003; Annear et al. 2004; Arthington 2012; Adams 2014). A general introduction to environmental flow assessment, including the conceptual basis and some of the lessons derived from applications of these different types of approaches, is provided in **Annex B**. Many of the Rufiji Basin EFA study specialists have experience in a variety of the methods currently available. In this instance, the Rufiji EFA team decided to use a holistic methodology (see Tharme 2003 for discussion), the modified BBM (King et al. 2008) to provide a high-confidence assessment of flow needs. The reasons for this choice were:

- It has been widely used and accepted in Tanzania.
- Many of the Rufiji specialists are familiar with the BBM and have helped to modify it for the Tanzanian context (see Section 3.1.3).
- It is a whole-ecosystem oriented methodology that addresses different aspects of the entire riverine-floodplain ecosystem and incorporates both ecological and social data and information (including traditional ecological knowledge).
- It follows closely the phases and tasks detailed in the SOW (**Annex A**).
- It is robust in the face of data shortages and usable with a blend of low- and high-resolution data sets.
- It is readily understandable not only to specialists but also to stakeholders who can usually see how the process leads to the recommended flows and why these are felt to be necessary.

The holistic group of methodologies has become widely used over the past decade, since they are robust, can be used with different objectives and levels of data available, have the credibility of the joint expertise of a number of specialists in different scientific disciplines, and can provide alternative flow scenarios that predict the successive effects of successive reductions in flows. Like other holistic methodologies, the BBM is based on the inputs of multiple specialists (or working groups) from different disciplines who aim to reach a consensus regarding the setting of appropriate flows to meet a stakeholder-defined set of environmental objectives and to describe the consequences of different levels of modifications to the flow regime. The multi-disciplinary team includes a hydrologist and a hydraulics engineer to provide the baseline data on flows and hydraulic conditions; a geomorphologist to predict the changes in sediment transport and channel maintenance at different flows and describe the physical habitat template; freshwater biologists (typically for fish, invertebrates, and riparian vegetation) to characterize the requirements of the biotic communities; a water quality specialist; and a socio-economist.

The flow 'building blocks' that comprise the environmental flow recommendation are basically those elements of the flow regime that are considered to have particular ecological and geomorphological functions (see Bunn and Arthington 2002 for a full explanation and illustrative case examples). As illustrated in **Figure 3.1**, they describe the specific flow requirements of the system for the following main flow components of the hydrograph: extreme low flows, low flows, high flow pulses (freshes), and small and large floods. They are also used to characterize, in this event-based way, the specific magnitude, timing, duration, frequency, and rate of change of each key flow event, as well as any other aspects of flow regime variability and predictability of known importance.

Figure 3.1: Schematic Illustration of Main Components of a Generic Flow Regime (Comprised of Individual Flow Building Blocks) Considered in the BBM

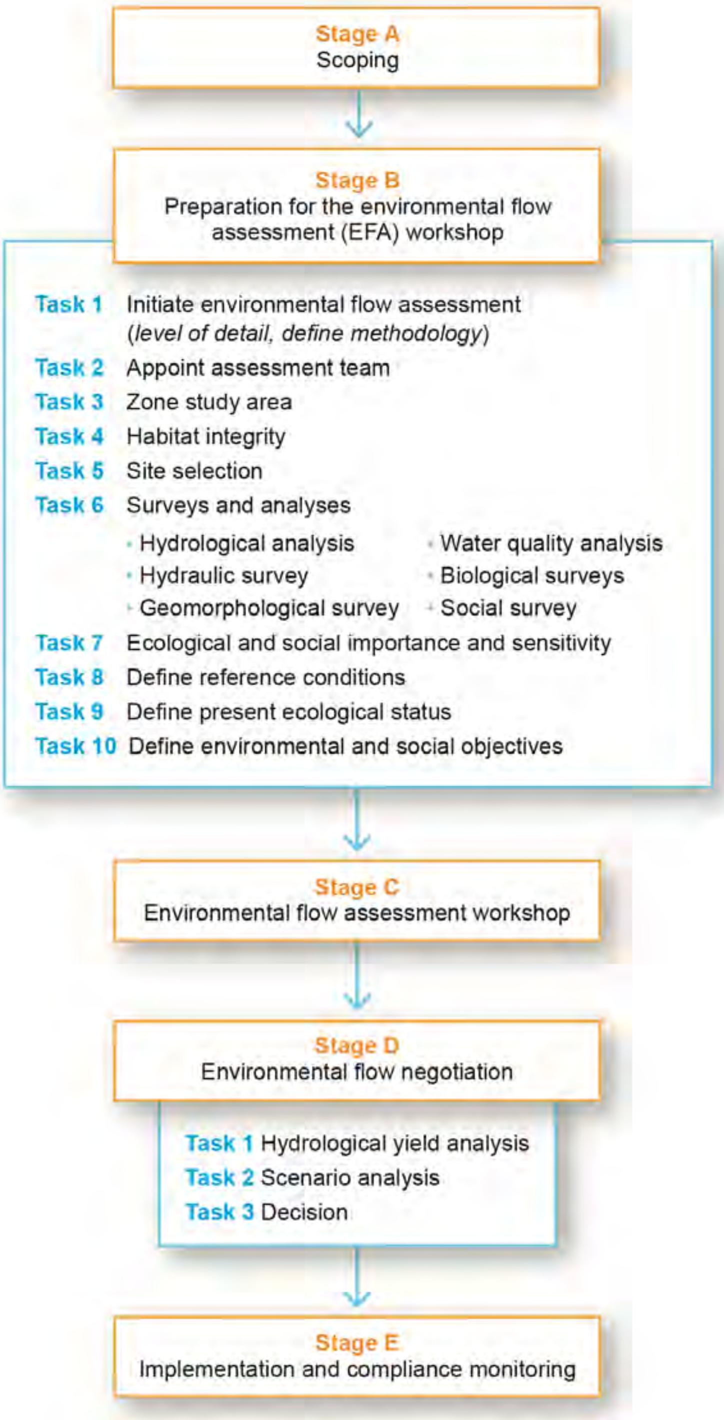


The main stages and associated tasks in an EFA that are normally required using a holistic methodology, such as the modified BBM used in the present study, are described in **Annex C**, as a general guide for detailed assessment methods. These tasks may vary depending on the methodology used; the size and type of river being assessed; and the time, resources, and information available for the assessment.

Figure 3.2 outlines the EFA process, with each stage and task described in more detail below. It is important to note that although the social survey is indicated as only one part of Stage B (i.e., part of Task 6) it includes the stakeholder process, which ideally should provide an overall framework for the whole assessment within the context of Integrated Water Resources Management (IWRM).

In Section 3.1.3, we describe how and why this general template was tailored for the Kilombero EFA and explain the modified tasks that were undertaken.

Figure 3.2: Main Stages and Tasks in Building Block Methodology for Environmental Flow Assessment



3.1.2 Assembling Specialist Team

In assembling the specialist team for the EFA, the aims were to:

- Engage qualified professionals in each of the required areas of expertise for holistic EFA
- Promote local expertise and experience where possible
- Build new national technical and institutional capacity for environmental flow assessment in Tanzania
- Engage with the local context both in terms of Tanzanian water policy and community requirements and understanding
- Ensure that the team was capable of producing a robust and internationally respected and defensible outcome

The result was a team with a strong core of local and international experience in EFA, both globally and on local rivers (some of the local specialists had contributed to four of the EFAs previously undertaken on Tanzanian rivers). The team was also comprised of local specialists with excellent credentials in their own fields, but new to EFA, who brought new ideas and thinking to the process while benefitting from the wealth of experience and expertise provided by the other team members. **Table 3.1** lists the details of the specialist project team as well as of key stakeholders for the EFA (final two in the table). They attended all the EFA workshops and meetings and contributed significantly to the practicality of the outcomes of the process.

Table 3.1: Multi-Disciplinary Specialist Team for Environmental Flow Assessment

Name	Specialty/Project Role	EFA Experience (years)
Prof. Japhet Kashaigili	Hydrologist	8 years
Dr. Rashid Tamatamah	Fish and macroinvertebrate ecologist	10 years
Prof. Preksedis Ndomba	Hydraulic engineer	10 years
Dr. Samora Macrice Andrew	Riparian and instream vegetation ecologist	New
Mr. Leodgard Haule	Social-economist	2 years
Prof. Karoli Njau	Water quality specialist	2 years
Dr. Felister Mombo	Social-economist	New
Ms. Susan Graas	Social-economist	5 years
Dr. Paolo Paron	Geomorphologist	5 years
Dr. Francisco Martinez Capel	Fish ecologist and hydraulic habitat modeler	5 years
Mr. Rafael Muñoz Mas	Hydraulic habitat modeler	1 year
Prof. Michael McClain	EFA team leader	10 years
Prof. Jay O'Keeffe	EFA facilitator/environmental flows specialist	30 years
Dr. Rebecca Tharme	Aquatic ecologist/senior EFA advisor	24 years
Mr. William Kasanga	EFA coordinator	3 years
Mr. Charles Mengo	Environmental engineer	2 years
Mr. Stephen Kamugisha	Irrigation engineer	New

3.1.3 Expert Review Panel

There is a need for the EFA to maintain impartiality and independence with respect to the irrigation feasibility studies conducted under IRRIP2 so that the conclusions and recommendations reached from the EFA can be seen to stand on their own, without a predetermined "answer", influenced by the objectives of the irrigation component. It is with this in mind that an Expert Review Panel was assembled to independently review the findings of the EFA.

The Expert Review Panel provided a rigorous review of the methodology and results of the EFA from an independent scientific perspective. The Panel provided recommendations on improvements to the final report, as well as improvements to the EFA process that will increase its usefulness in Tanzanian integrated water resources management.

At USAID/Tanzania's request, the Panel consisted of one internationally-recognized EFA expert (Prof. Graham Jewitt, University of KwaZulu-Natal, South Africa), as well as two Tanzanian experts (Prof. Yunus Mgaya, University of Dar es Salaam, Tanzania and Mr. Willie Mwaruvanda, Water Resources Specialist) to check that the EFA conforms with Tanzanian policies and regulations.

3.2 Procedure Used to Establish Environmental Flow Recommendations in Kilombero System

In the Kilombero EFA, the BBM process followed the main stages and sequence of tasks described in **Annex C** and illustrated in **Figure 3.2** above, but with some tailoring of tasks dictated by the nature and scope of the project. The specific tasks that were modified are described below. Where no additional information is provided below, the task closely followed standard procedures.

Task 1: Initiate the EFA

Task 2: Appoint specialists

This was undertaken as described in Section 3.1.2, for the reasons outlined there.

Task 3: Zone the study area

The area and river sections to be assessed in detail were defined in large part by the effects of the proposed irrigation schemes, and the zonation of this detailed study area is described in the results (Section 4.1).

Task 4: Habitat integrity

As the detailed study area was pre-defined, it was decided that this task would not be necessary for the Kilombero EFA. The habitat integrity assessment is a general broad-scale survey of a river system, designed to highlight areas for detailed study and identify any issues of particular concern.

Task 5: Sample site selection

Five sample sites were selected within the study area for detailed analysis. Sites consisted of approximately 100 meters (m) of river – a scale sufficient to provide a diversity of conditions and habitats suitable for habitat modeling but manageable for the time and resources available. The general approach was to locate one sample site per zone that characterizes the conditions throughout that zone where the EFA-related detailed specialist studies were to be undertaken.

The criteria for selecting sites suitable for the assessment of environmental flows included:

- Ease of accessibility: This was a major criterion for the Kilombero EFA where roads are few and of uncertain condition. In the wet season, most of the study area is inaccessible by road, and roads are frequently washed away. Therefore, it was important that sites could be accessed by main roads and distances were not too great since driving speeds are very slow, and time for fieldwork was limited.

- Habitat diversity: It is important for the ecological teams that sites include a range of diverse habitats to maximize the opportunities for sampling all available species and characterizing their habitat requirements.

- Sensitivity of habitats to flow changes: Sites containing only deep pools are usually unsuitable since water depths, widths, and current velocities will only tend to change at extremes of floods or no-flow. Sites with shallow fast flow and with diverse riparian vegetation provide flow-related habitat changes that allow predictions of species changes at different flows.

- Suitability for measuring a rated hydraulic cross-section and for modeling discharges, velocities, and wetted perimeter at different water depths: The accuracy and range of hydraulic modeling at sites is a critical limitation for environmental flow prediction since it provides the link between habitat parameters (depth, width, current velocity) and required discharge (i.e., flow rate) in $m^3 s^{-1}$ (the ultimate aim of an EFA). The problem here is that accurate hydraulic modeling ideally requires regular homogeneous straight river reaches in direct contradiction to the requirements of the ecologists for habitat diversity (see above).

- Proximity to a flow gauging site: Useful in order to check the accuracy of flow measurements at the site and provide a record of flows over time. Fortunately, in the Kilombero study area, gauging sites were situated near or at four of the five sites: Lwipa, Udagaji, Mpanga, and Ifakara Ferry although some of these were of uncertain accuracy throughout their period of record.

- Representation of conditions in the river zone and critical flow site (i.e., where flow will stop first if discharges are reduced): Since the study sites would be used to characterize flow requirements for the whole river zone, the chosen sites must include conditions typical of the whole zone. However, in keeping with the requirement for flow sensitivity (above), the site should include a hydraulic break such as a local change in gradient where flow changes will be most marked.

For the Kilombero EFA, the choice of sites was in large part dictated by the proposed irrigation areas so that site selection had to take account of the river reaches from which the irrigation water would be withdrawn. As is typical for most EFAs, the choice of sites seldom met all the requirements and was a compromise between the requirements of the ecology and the hydraulics and the ease of access. For the Kilombero, the range of river sizes and floodplains in the study area provided the opportunity to assess a wide variety of sites, with differing geomorphological and biodiversity characteristics, and thus a diversity of flow requirements that could be checked for upstream-downstream hydrological coherence.

Task 6: Specialist surveys and measurements

Most of the specialist surveys followed the standard BBM procedures, with the following adjustments:

Hydraulic survey and analysis

Habitat modeling, based on multiple surveyed cross-sections, was undertaken at all the detailed study sites, to maximize the usefulness of the hydraulic surveys and to begin to build up a database on hydraulic habitat requirements of some of the key Tanzanian riverine biota.

Water quality analysis

This had to depend on a limited set of measurements taken by the water quality specialist during the Kilombero EFA as well as a patchy but nonetheless usable series of historical water chemistry records compared against available water quality standards (**Annex J**). Because such short-term and/or irregular measurements are of somewhat limited use in predicting changes in water quality over time, or in response to modified flows, the specialist also made use of anecdotal information on water quality problems discussed by local residents during interviews carried out by the socio-cultural team.

Biological surveys

These focused on the fish, riverine invertebrates, and instream, riparian, and floodplain vegetation, with some attention paid to human responses to specific water-dependent mammals (hippopotamuses) and herpetofauna (crocodiles). This was to concentrate information gathering on biotic groups, which were important to local communities and on which there was sufficient knowledge and expertise to provide useful data.

Social survey

Extensive use of the river and floodplain resources is made by local communities within the study area, enabling the socio-cultural team to obtain a considerable amount of primary data, secondary information, and traditional ecological knowledge about the importance of a healthy riverine ecosystem for local livelihoods, recreation, and cultural events. The team coupled extensive (more than 700) interviews of riparian and floodplain communities linked to each of the sites with interrogation of institutional stakeholders who were able to express the wider importance of the basin for national and provincial priorities.

The other specialist teams, particularly the fish, water quality, and riparian specialists, were able to link their information on key indicator species and processes to the livelihood priorities of the local communities, providing strong, highly integrated motivations for the recommended environmental flows.

Full details of all the various methods used to collect, analyze, and model the data for each component of the river social-ecological system for use in the EFA are provided in the individual specialist starter documents (**Annex G** to **Annex N**).

Task 7: Ecological and social importance and sensitivity

Assessed by each specialist group as very high, high, moderate, or low for each site, these importance and sensitivity ratings are typically used to add motivation for the improvement of conditions in sites that are rated as high or very high. For the Kilombero, where flows are still near natural, the ratings were used as part of the motivations for maintaining the present high flow-related ecological conditions.

Ecological importance and sensitivity (EIS) is used to quantify, as far as possible, the relative importance of environmental issues in a river. It can be quantified in different ways but is a measure of the priority of the study area from an ecological perspective. Typical measures (or indicators) include the number of sensitive and rare species, the resilience of the system to human disturbance, biodiversity, habitat diversity, importance as a migration route, and presence of conservation areas.

Social importance and sensitivity (SIS) provides an index of social importance, which takes into account the number of people directly dependent on a healthy riverine ecosystem, for example, using it as a direct source for drinking and washing, stock watering, subsistence fishing and farming, recreation, as well as for cultural and religious purposes. The development of such indices should be specific to particular regions and cultures rather than a "one size fits all" approach.

Task 8: Define reference conditions

Because the present flows in the rivers of the Kilombero Sub-Basin are not considered to be significantly modified by human use, it was possible to define the reference flow conditions as the present state. This had a number of advantages: the team could assume that any degradation of ecological conditions was due to factors other than flow modification or water abstraction. The initial flow scenario considered was the natural/present day flow regime, and two other scenarios could be considered:

1. A flow regime that would meet the objectives defined through the stakeholder process
2. An increased use regime that would result in the reduction of the ecological condition by one environmental management class (EMC)

Therefore, the implementation of the environmental flows in the Kilombero River and tributaries is a matter of maintaining some of the present flows rather than having to reduce water uses and abstractions, as is usually the case.

Task 9: Define present ecological status (PES)

The specialists used the general definitions below to define the PES for each component for each site. **Annex I** to **Annex N** provide examples of the specific descriptions of PES for each component for each site.

Table 3.2: General Definitions of Classes for Present Ecological Status (PES A to F) and for Ecological Management Classes (EMC A to D)

A	Unmodified/Natural	Reaches that are minimally affected by human interference
		- Even the most sensitive species are present in natural abundances. - All biophysical processes are operational. - Minimal artificial erosion and sedimentation. - Largely unmodified channel morphology with natural riparian vegetation cover. - Floodplains natural, with no or insignificant agriculture, unmodified wetlands, and flooding regime. - High water quality.

B	**Largely natural with few modifications**	**Reaches that have some evidence of human interference but are still functionally intact**
		- There may be some reduction in the abundance of sensitive species, but they are not at risk of extinction even during drought periods. - Some artificial erosion and sedimentation may be evident but with slight or negligible effects on biodiversity and biophysical processes. - Slight or insignificant modifications to channel morphology, with largely natural riparian vegetation. - There may be some introduced or exotic riparian plant species, but natural species are still dominant. - Floodplains largely natural, possibly with some agriculture, but most wetlands largely unmodified and natural flooding regime. - Water quality clean or only slightly modified, with zero industrial waste, possibly some agricultural runoff, but insignificant, and insignificant domestic waste.
C	**Moderately modified**	**Reaches that have clear evidence of human interference but are still largely functionally intact**
		- Reduction in the abundance of sensitive species and possible risk of local temporary extinction for the most sensitive during stressful periods (e.g., drought or pollution events). - Significant artificial erosion and sedimentation may be evident, with observable effects on biodiversity and biophysical processes, but natural biodiversity and processes are still largely intact. - Significant modifications to channel morphology may be present, possibly with introduced or exotic riparian plant species, which may be common. - Floodplains often used mainly for agriculture but with some wetlands, which may be modified, flooding regime mostly natural. - Water quality may be moderately modified, with the possibility of industrial waste, agricultural runoff, and/or domestic waste, which may affect the natural biodiversity in terms of relative abundance of and risk to sensitive species.
D	**Largely modified**	**Reaches that have major evidence of human interference and are marginally functionally intact**
		- Large reduction in the abundance of sensitive species and local extinction of the most sensitive. - Extensive artificial erosion and sedimentation may be evident, with significant effects on biodiversity and biophysical processes, but most species still present and processes are marginally intact. - Extensive modifications to channel morphology may be present, often with introduced or exotic riparian plant species, which may be common. - Floodplains mostly drained and used mainly for agriculture or urban settlement. Occasional modified wetlands still existing; flooding regime may be modified. - Water quality may be significantly modified, with the probability of industrial waste, agricultural runoff, and/or domestic waste, which significantly affects the natural biodiversity in terms of relative abundance, and disappearance, of sensitive species.
Note: Only the four categories above may be applied as environmental objectives. For reaches presently in a Seriously or Critically modified category (see below), the minimum objective will be to improve them to at least a D (Largely Modified) category over the long term.		

E	Seriously modified.	Reaches that have serious evidence of human interference and are at most only partially functionally intact
		- Sensitive species will be absent (except during rare improved flow and/or water quality conditions). Biodiversity dominated by common/generalist species, with many hardy species. - Serious artificial erosion and sedimentation may be evident, with significant loss of biodiversity and biophysical processes, which will at most be partially intact. - Serious modifications to channel morphology may be present, with extensive introduced or exotic riparian plant species, which may be invasive and dominant. - Floodplains usually completely modified for agriculture and/or urban development, possibly isolated surviving modified wetlands, and flooding regime may have been significantly reduced. - Water quality may be seriously modified, with one or more of industrial waste, agricultural runoff, and/or domestic waste, which will have seriously reduced the natural biodiversity in terms of the absence of sensitive species, and increased abundance of hardy species.
F.	**Critically/Extremely modified**	**Reaches that are dominated by human interference, with little or no natural functionality**
		- Sensitive species will be permanently absent, and communities will be dominated by hardy species, some of which may be pests or disease vectors. - Very little natural biodiversity will be apparent (except for hardy species). - Serious artificial erosion and sedimentation may be evident to the extent that channel morphology will have been permanently altered (possibly channelized). - Riparian vegetation, if present, will be dominated by introduced or exotic invasive species. - Floodplains may have been drained and disconnected from the river but will be completely modified for agriculture or industrial uses; no surviving wetlands and flooding regime may have been significantly reduced, diverted, or intercepted. - Water quality will probably be completely modified, with flow usually dominated by industrial, agricultural, and/or domestic effluents.

Sites and individual components were also assigned a trajectory of change, indicating whether each EFA component is improving or degrading in condition under the current river management regime. They allowed the specialist team to gain an improved understanding of where on the path of change between the present class of condition and either of the adjacent ones a particular component was likely positioned and, thus, of the risk of an overall change in EMC in the near- to longer-term (see below). Trajectories were defined as follows:

- Positive (+): Situation will improve
- Neutral (no change, 0): Situation will remain as current
- Negative (-): Situation will further deteriorate

Task 10: Define environmental objectives

For the Kilombero EFA, the specialists used an objectives hierarchy to describe their environmental objectives at four levels from a general overall objective (an environmental [ecological] management class from A to D (see Task 9 above for definitions) to more detailed levels. These levels are comprised of general flow objectives; component objectives (e.g., for fish, water quality, geomorphology); and specific indicator objectives, which might be a defined density of a flow-sensitive fish species or the presence of seedlings of a flood sensitive riparian tree. The general level (EMC) is intended to be clearly understandable to all stakeholders but may not be directly measurable. In contrast, the indicator level might appear obscure to non-specialists but is specific and measurable and, when monitored, will indicate whether the environmental flow objectives are being achieved.

At the flow assessment workshop (Stage C, Section 3.4), these objectives are used to guide the assessment of flows for each site in different seasons that will result in the attainment or maintenance of the objectives. See **Annex K** to **Annex N** for examples of the objectives hierarchies for each component and **Annex O** for the objectives used in the EFA.

3.3 Methods for Choosing an EMC

Choosing environmental objectives for an EFA is not a scientific process; it is a societal judgement reflecting national and local values and aspirations. As a result, it is necessary to underpin these values with valid information, and it is possible to adopt a formal process for choosing an EMC. For the Kilombero EFA, the specialist teams, with extensive guidance from stakeholder participation, recommended EMCs for each specialty at each site. At the EFA meeting in June 2015, the specialists arrived at a consensus EMC for each site, and flows were then assessed that would achieve or maintain that EMC. These high-level objectives are described as “pre-defined EMCs” in the report, not because they were defined prior to the EFA project but because they were decided on prior to the flow setting process for each site rather than the alternative process, which is to develop a number of scenarios and then to assess which would provide optimal benefits for the least cost.

The BBM basically follows a 5-step process:

1. Define the reference (usually natural) conditions. This describes the category A EMC. In the Kilombero EFA, the specialists were mostly dealing with river sites, which were considered only slightly impacted by human activities, making it easier to infer what natural unmodified conditions would have been. The difficulty was that these activities were largely undocumented before the EFA. The EFA, with time and resource constraints, could not conduct the sorts of holistic investigations that might have revealed more about the effects of non-flow-related activities such as poor land use, vegetation clearance, and the use of fertilizers, pesticides, and poisons for fishing. This is not uncommon for most EFAs; therefore, it requires a measure of professional judgement to describe the natural unmodified conditions.

2. Measure the PES and compare it to the reference conditions. This was done through fieldwork by each specialist team using the limited historical information that was available. The specialists were able to predict which species and processes were missing or modified from expected at each site and to define these as slight, moderate, large, serious, or critical modifications.

3. Assess the ecological and social importance and sensitivity. Very high or high ratings would provide motivation for improving the PES (recommending a higher EMC), while moderate or low ratings would support a recommendation to maintain PES.

4. Assess the trajectory of change. A negative trajectory of change would imply that under present management conditions, the PES would be likely to deteriorate, at least in the long term, and that improved management would be necessary simply to maintain the PES.

5. Ensure the recommended EMC reflects the needs and priorities of as many stakeholders as possible. In this regard, the Kilombero EFA provided a two-part stakeholder process to investigate national and local stakeholder opinions:

    - An institutional stakeholders' workshop was held in Morogoro in February 2015 and attended by 41 delegates; the report is provided in **Annex F**. Participants were from the major national ministries involved, the Rufiji Basin Water Board (RBWB), interested non-governmental organizations (NGOs) and private companies, the local district council, and universities, as well as the project team members. Amongst other activities, the stakeholders were provided with a list of ecosystem services and asked to prioritize them. These priorities were then factored into the objective setting process by the specialist teams.
    - Involvement of local stakeholders: The socio-cultural specialist team interviewed and questioned over 700 local stakeholders, predominantly riparian village and floodplain dwellers (see the social starter document, **Annex N**). Importantly, the social starter document was prepared in advance of those of the other teams so that they could factor in the stakeholder uses of riverine resources into their assessments of priority objectives and, therefore, into the recommended EMC.

3.4 Stage C: Environmental Flow Assessment Workshop

The flow setting process was accomplished as a series of tasks, as set out above, with modifications to suit the local context and specific project aims. The tasks were punctuated by a series of workshops and meetings (**Annex D**) where the specialist team, project management, and key stakeholders planned the progress of the project, reviewed progress, and gathered and integrated information for the flow setting.

The process culminated in the flow-setting meeting (Morogoro, Tanzania, 15-20 June 2015), for which the specialists prepared starter documents (**Annex G** to **Annex N**). These technical reports detailed the information and data gathered by the specialists, the environmental objectives for their specialist component, and the types of flows that would be required to meet or maintain those objectives. The purpose of the flow setting workshop was to allow the specialists to share their findings and to come to a consensus on the flows required to meet the objectives of all the specialist components with motivations. The steps used to guide and structure the EFA workshop process are given in **Table 3.3**.

One of the major strengths of the process is that the results are based on the integrated motivations of an inter-disciplinary team of ecologists; geomorphologists; water quality, hydraulics, and hydrology specialists; and social, cultural, economics, and livelihoods specialists. The outcome is that, rather than relying on one or a few indicators to guide the flow recommendations, the results are motivated by a closely interlinked web of information, analysis, and conclusions from different perspectives but aiming at a common goal – the maintenance of a set of environmental conditions characterized by a particular management class. For example, the geomorphological flow requirements and motivations might seem obscure (to non-specialists) on their own but are linked to the necessity to maintain channel characteristics that provide the particular habitat features for particularly flow-sensitive fish species. That species may not itself be of commercial or community value but may be the indicator species for flow conditions, which, if maintained, will ensure the healthy survival and propagation of those fish communities that support subsistence and livelihoods among the riparian and floodplain villages. Similarly, water quality requirements and riparian vegetation underpin the ecosystem structure and conditions that support the river and floodplain biodiversity, which in turn provide the ecosystem services on which people depend.

Table 3.3: Description of Steps Taken during Kilombero EFA Flow Setting Workshop

1. Hydrologist summarizes flow characteristics for the site and defines wettest and driest months for maintenance conditions versus drought conditions.
2. Hydraulic engineer displays rated cross-sections, describes hydraulic characteristics and possible uncertainties, and points out significant channel and floodplain features/processes.
3. Specialists describe present state for each component (hydrology, socio-economics, water quality, fish, insects, vegetation, and geomorphology), its trajectory of change, its ecological importance and sensitivity, social importance and sensitivity, and target environmental management class.
4. Specialists discuss and assess mean monthly low flows for the following conditions:
    a. Driest month in a maintenance year
    b. Wettest month in a maintenance year
    c. Driest month in a dry year
    d. Wettest month in a dry year
5. Specialists provide written motivations for the target low flows and express consequences of not providing target flows.
6. Hydrologist presents flood characteristics: Within year floods - size and frequency, 1:3 year flood size, and 1:5 year flood size.
7. Specialists assess within-year and between-year flood requirements for maintenance and drought years and provide written motivations for the target flows.
8. Specialists discuss and assess low flows for an increased use EMC: Low flow for driest month in maintenance year, low flow for wettest month in maintenance year, low flow for driest month in drought year, low flow for wettest month in drought year and write one set of motivations for all these flows.
9. Specialists consider the requirements for within-year and between-year flood requirements for maintenance and drought years for the increased use EMC and provide written motivations.
10. Specialists discuss results for the site and assign confidence ratings (with written reasons) from 1 (very low confidence) to 5 (absolute certainty) for the effects of the flows. They also list the areas of uncertainty, with recommended further work to reduce uncertainty.

The specialists rated their confidence in their flow predictions for each site on a scale of 1 to 5, as described in **Table 3.4**, reflecting the amount of available data, information, and knowledge of flow-ecology and flow-social relationships. They also were asked to describe the additional research effort that would need to be done to most effectively increase their confidence in their flow recommendations in the near-term.

Table 3.4: Confidence Rating Scale and Interpretation Used by Individual Specialists to Assign Confidence Levels to Site Flow Predictions

Confidence Rating	Interpretation
1	Very low. Almost no reliable supporting information available.
2	Low. Available information indicates support but requires extensive further research to confirm.
3	Moderate. Some further research and information necessary.
4	High. Some issues may need confirming by further research.
5	Absolute certainty. No further information necessary.

In all EFAs, specialists demonstrate a variety of opinions about their level of confidence in the amount and accuracy of information and data that they have and in their own ability to predict the consequences of modified flow regimes. Some will back their experience and ability even in the face of minimal supporting information, while others will be dissatisfied even with many years of data, always striving to reduce uncertainty. Therefore, for example, the generally moderate to high confidence in the results of this EFA (see Section 4.7 for discussion) are probably a reflection of the general level of knowledge about Tanzanian rivers where many remain largely unstudied and unmonitored. Somewhat counterintuitively, a similar level of data and information in a European, American, or Australian context, where comprehensive monitoring programs have been in place for many years, likely would be considered to allow for much lower confidence results. Therefore, this inherent subjectivity makes it inadvisable to take confidence ratings too literally. They are used in the BBM process to provide a general impression of the usability of the recommended flows rather than to allow statistical analysis of the remaining uncertainties. The most useful aspect of the confidence ratings is that they provide a framework for the specialists to consider what additional research and monitoring should be done to most effectively improve the confidence ratings and decrease uncertainties.

In the Kilombero EFA, three flow scenarios were described:

1. Present-day condition of largely unmodified natural flows that are currently still in the rivers.
2. Target flow scenario, which would be predicted to maintain the objectives described by the specialists.
3. Increased use flow scenario, which predicted the reduced low and high flows for maintenance and drought years, which would likely degrade river condition in each case into the next lower class (A to D, where A is natural, unmodified, and D is largely modified). In other words, if the target scenario objective for flows were to meet EMC of B, the increased use scenario used an objective of a C class. The purpose of this scenario is not to motivate for such degradation but to provide the range of modifications and the flows that would result in a class change. The Tanzanian Ministry of Water has expressed a requirement that ecological reserve determinations should provide such a range of conditions and flow scenarios for consideration.

Increased use scenarios were considered for EFA sites 1, 3, 4, and 5. Workshop time constraints precluded the generation of environmental flow recommendations for this scenario for the Udagaji River (Site 2).

In the Kilombero, ‘maintenance years’ were hydrologically defined using all years of record with the historical time series that were ‘normal flow’ years, i.e., neither classed as wet or dry years (Section 4.3). They represent years with sufficient flow to support all the flow-related biophysical processes (e.g., fish migration and breeding, riparian vegetation growth and seeding, sediment transport) that are required to meet the environmental objectives. For the Kilombero, as a general guide, a flow expected to achieve maintenance conditions was taken to be around 60 percent of the annual daily flow duration curve (FDC), so that over a long period, it would be expected that flows for 60 out of 100 years would be at or higher than the maintenance recommendations. Forty years would be between maintenance and dry flow recommendations, and once every 5 to 10 years of that 40, flows would be at (but not below) the drought year recommendations. The choice of 60 percent was taken on the advice of the hydrologist as representing more or less ‘normal’ flow conditions in a system that experiences fairly stable seasonal flows rather than one with highly variable seasonal flows. The choice is to some extent arbitrary but enables the specialists to concentrate on the same statistical meaning of ‘maintenance.’

Drought years were determined based on the very driest years of record and considered to occur roughly 1 in every 5 years. The definition of drought was approximate and understood to be limited in this study by the short lengths of the observed historical records at the gauging stations; this explains the assumed high frequency of occurrence of such years. The drought year is equivalent to a significant drought event, in which the flows are insufficient to support all the flow-related biophysical processes (e.g., flow-sensitive species might miss a breeding season but would survive, likely in reduced numbers). There is ample evidence that biodiversity in rivers is intimately linked to the natural flow variability such that natural floods and droughts (not droughts due to human overexploitation of water resources), which may seem destructive to the ecology, are inevitable and necessary to maintaining the diversity of habitats and conditions that result in natural biodiversity.

The outcomes of the flow-setting meeting are a series of flows, for different seasons, during normal and drought years, for each study site. Each of the flows is carefully motivated in terms of the benefits for specific features of the river and its floodplain and in terms of the consequences if that flow is not maintained. The different flows are illustrated over an annual hydrograph (in much the same way as illustrated in **Figure 3.1**). The recommended flows are then extrapolated to the other months of the year, using the natural annual flow patterns, to provide modified yearly hydrographs of low flows and floods for each site during a normal and a dry year. These can then also be summarized in terms of the percent of natural and present day mean annual flow (MAF) required for environmental flows to achieve different objectives.

Once the hydrologist has produced the annual hydrographs, the next step is to check that the flows recommended for each site are coherent and consistent in terms of the hydrological connections down the river. It is not sensible to require a small proportion of the flow for environmental purposes in the upstream tributaries if that will not result in a sufficiently large volume of water in the lower reaches to achieve objectives. Some adjustment in recommended flows may be necessary to make sure that the flows will result in this hydrological consistency.

The resulting hydrographs are not intended to be implemented year-on-year in the river. They are meant to guide the eventual range of flows that will be matched to climate-related flow triggers in different parts of the river (e.g., rainfall or flow gauges). For example, although specialists may have recommended a 1,200 $m^3 s^{-1}$ flood in April during normal (maintenance) years, implementation during any specific year would only be expected if a rainfall event occurred that would justify such a flood, and this might occur in March or May.

Ideally, with unlimited time and resources, it would be possible to measure and verify all conditions and the effects of different flows in all sections of a river. However, this is not possible, so the limited field data that can be collected during the project have to be augmented and extended by modeling as well as by the application of any previous documentation about the river. The EFA is essentially a series of predictions about the effects of modifying the flow regime, and therefore, verification can only come when a modified flow regime is implemented and monitored. In the case of some components (e.g., geomorphology), the full consequences of flow modification can only be seen many years (even decades) after the flow changes are made.

The result is that the lead-up to the flow-setting meeting consists of a series of carefully directed field trips to survey and rate hydraulic cross-sections; measure hydrology; and collect ecological, water quality, geomorphological, and socio-economic data. For the Rufiji EFA, in excess of 100 person-days of fieldwork were undertaken in total, but confined to two seasons during one hydrological year, at particular study sites on the main river and tributaries of the Kilombero River. This provides a partial view, at a restricted time/space scale, of a system stretching over thousands of square kilometers that has evolved over geological time. To better understand, the picture requires the extrapolation of the collected data via models, and this section summarizes the relationships between the field data collection and the modeling that resulted in the understanding of flow relationships throughout the system.

3.5 Capacity Building

A major aim of EFA projects in Tanzania, since the process was started in 2005 by UNESCO-IHE, WWF East Africa, and the Global Water for Sustainability Program (GLOWS), has been to develop local capacity and expertise – to expose Tanzanian scientists, managers, and policy makers to the EFA process so that they can take ownership. The key issue in developing capacity for environmental flow assessment is that the scientists are already expert in their own disciplines (e.g., hydrology, hydraulics, ecology, geomorphology, sociology), and the managers and policy makers are already experienced in their own fields, so there is no requirement for basic skills training. The aim must simply be to show what the EFA process is, how it works, how the individual skills and expertise can be used in the EFA process, and how the different disciplines need to be integrated to achieve the desired outcome. Since environmental flow assessment has a clear set of desired outcomes and the steps in the assessment process are well defined (see **Figure 3.2**), the best way to build capacity is training-by-doing.

As explained in Section 3.1.2, the decision for the Kilombero EFA was to assemble a mix of experienced local and international specialists while adding some specialists new to the EFA process. This had the value that the established specialists would ensure a credible well-supported outcome while gaining additional experience in another river basin and wider expertise in the methodology from the international participants. At the same time, the first-time specialists would learn the process and contribute their own fresh insights.

It was important that the RBWB should understand and support the process and take ownership of the resulting flow recommendations and motivations; thus, RBWB staff were invited to all the EFA meetings and workshops. In the event, Charles Mengo, Environmental Engineer, was the designated representative, and he participated in all aspects of the EFA, offering a useful sounding board about the process and providing local knowledge about the catchment. Other stakeholders were engaged at different levels in the project. Because the assessment centered around the proposed irrigation schemes, it was important to involve the Ministry of Agriculture, Food Security and Cooperatives, and their representative, Stephen S. Kamugisha (irrigation engineer), attended a number of the EFA meetings.

As explained in Section 3.1.3 under Task 10, the main stakeholder engagement operated in two phases – institutional stakeholders attended a workshop in Morogoro in February 2015, and the socio-cultural team visited and interviewed more than 700 local stakeholders living next to the rivers and on the floodplains. The institutional stakeholder workshop was attended by delegates from the Ministry of Water, Ministry of Natural Resources and Tourism, Vice President's Office, Kilombero District Council, RBWB, National Irrigation Commission, Morogoro Zonal Irrigation Office, USAID/Tanzania, and a number of local and international NGOs and companies. Presentations by the Director of Water Resources and a member of the RBWB explained the policy and implementation of the reserve in Tanzania and were followed by presentations from the EFA specialist teams' facilitator and project leader, explaining the purpose and process of the EFA. The delegates were invited to discuss and question the process and prioritize a list of ecosystem services in terms of their importance for the Rufiji Basin. These discussions and priorities are recorded in the stakeholder workshop proceedings (**Annex F**).

Detailed results of the meetings and interviews of the socio-cultural specialist team are contained in **Annex N**. These provided an exhaustive analysis of the uses and importance of natural resources in the rivers, riparian zones, and floodplains, which were used to help define objectives for the EFA (see Section 3.1.3, Task 10). At the same time, the EFA process was explained to stakeholders. The final element of stakeholder engagement in this project will be the presentation of the final report to stakeholders.

4 ENVIRONMENTAL FLOW RESULTS

4.1 Conceptual Model of Study Area

4.1.1 Zonation of Kilombero System

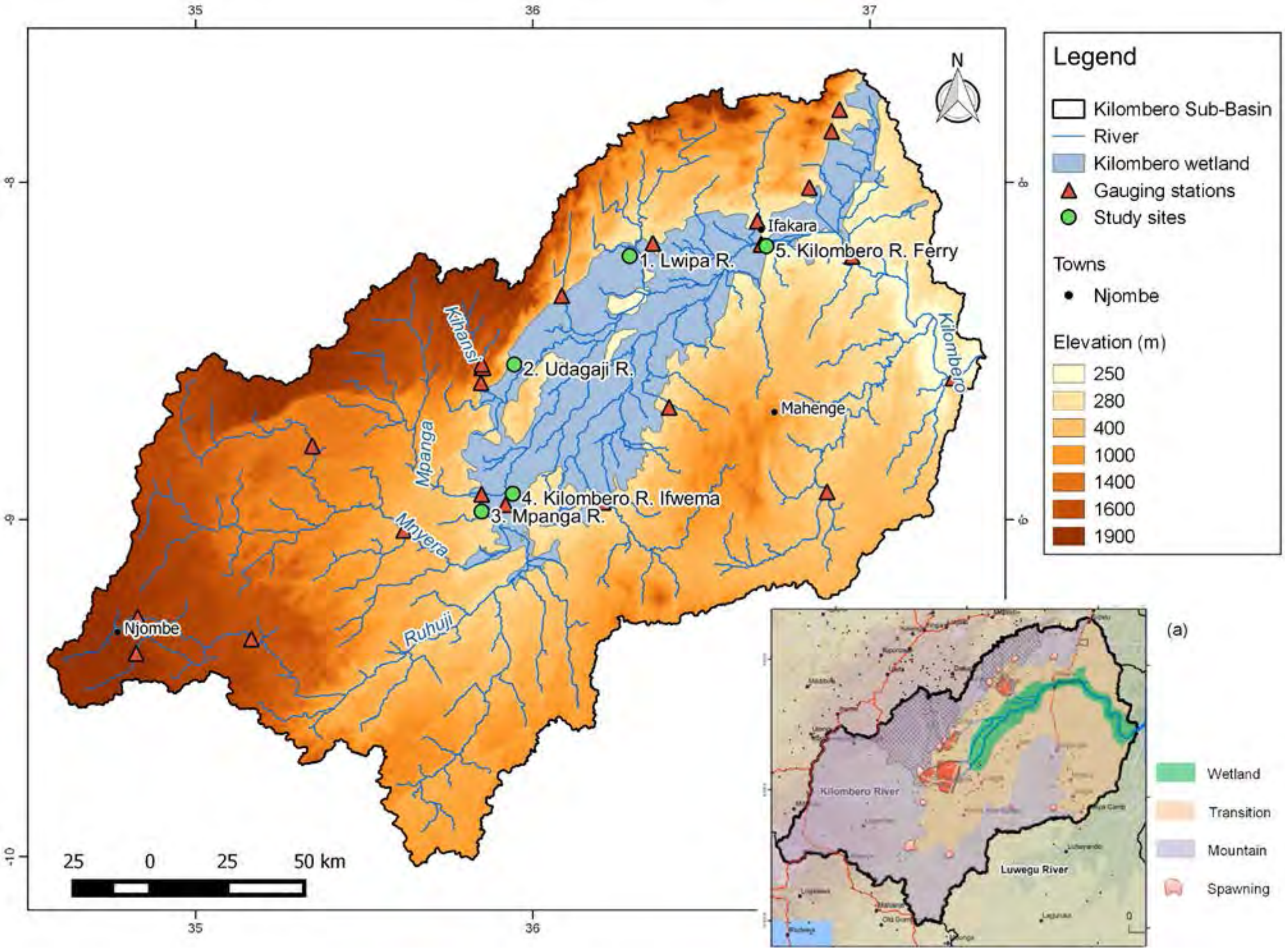
We formulated an initial conceptual model of the spatial and temporal dynamics of flow-related controls on the geomorphology, ecology, and socio-economics of the Kilombero River system (**Figure 4.1**), including the areas of proposed irrigation schemes (see Section 1), based on available data, field observations, and specialist experience. This simple model helped guide the zonation of the study area and selection of representative reaches, i.e., the study sites. It also directed the working hypotheses of the different specialists and associated field sampling, analysis, and modeling activities.

At its center are four spatially distinct zones of the Kilombero system that present different combinations of geomorphological dynamics, ecological processes and importance, and socio-economic values and significance (see also **Figure 4.1**, inset (a)):

1. Mountain zone. Steep gradient lower order streams and small rivers characterized the mountain slopes surrounding the Kilombero valley floor.
2. Spawning zone. A number of these zones, which typically occur at the foot of the mountain zone (i.e., piedmont area), occur across the sub-basin tributary network. They are ecologically recognizable as key spawning grounds for fish species (see **Annex L**).
3. Transition zone. Transitional areas of the basin between the higher elevation mountain streams and foothill spawning areas and the wetland zone, which are not subjected to regular flooding. River reaches in this zone are considered to represent dry season refugia for riverine biota.
4. Wetland zone. This zone comprises the river floodplain and various associated wetland habitats characterized by the flooding regime of a number of rivers and the Kilombero mainstem within the valley.

The main representative reaches and their study sites for the EFA (as well as additional sites used during some expert field surveys) were located within each of these zones, except in (1) the mountain zone. The spawning zone is represented by the Udagaji River (Site 2), which also effectively represents several other spawning areas located within the sub-basin on various other Kilombero tributaries. Sites 1 and 3 are located on different tributaries of the Kilombero River, the Lwipa (also known as Ruipa) and Mpanga rivers, respectively, but both represent a range of features characteristic of the transition zone. The Kilombero River and floodplain wetland zone are represented by sites at the upper, Site 4 at Ifwema (also referred to as Ifuema), and downstream, Site 5 at Ifakara Ferry, ends of the Kilombero wetland.

Figure 4.1: Location of Main Study Sites for Environmental Flow Assessment of Kilombero River and Tributaries



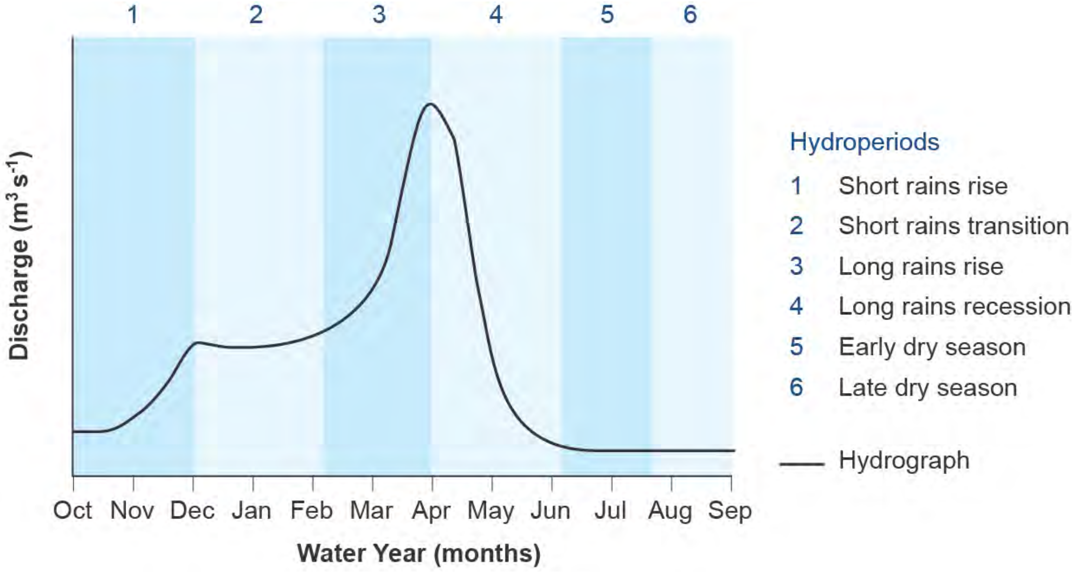
Note: Inset (a): Schematic of the four spatial zones distinguished in the conceptual model of flow-related dynamics in the Kilombero Sub-Basin
Source: EPSG Projection: 4210 - Arc 1960.
Data source: Global Multi-resolution Terrain Elevation Data 2010, GMTED2010 (estimated 200 meters of horizontal resolution and 30 meters of vertical accuracy), retrieved from https://lta.cr.usgs.gov/GMTED2010.

4.1.2 Working Hypotheses on Social and Ecological Relationships with Hydro-Periods

The conceptual model also distinguished six hydro-periods during the year, each with characteristic geomorphological, ecological, water quality, and socio-economic features (**Figure 4.2**). The sub-basin may be subdivided climatically into two zones, a unimodal-rainfall upper Kilombero and a bimodal-rainfall lower Kilombero. The model described here reflects the more bimodal pattern:

1. Short rains rise - November and December
2. Short rains transition - January and February
3. Long rains rise - March and April
4. Long rains recession - May and June
5. Early dry season - July and August
6. Late dry season - September and October

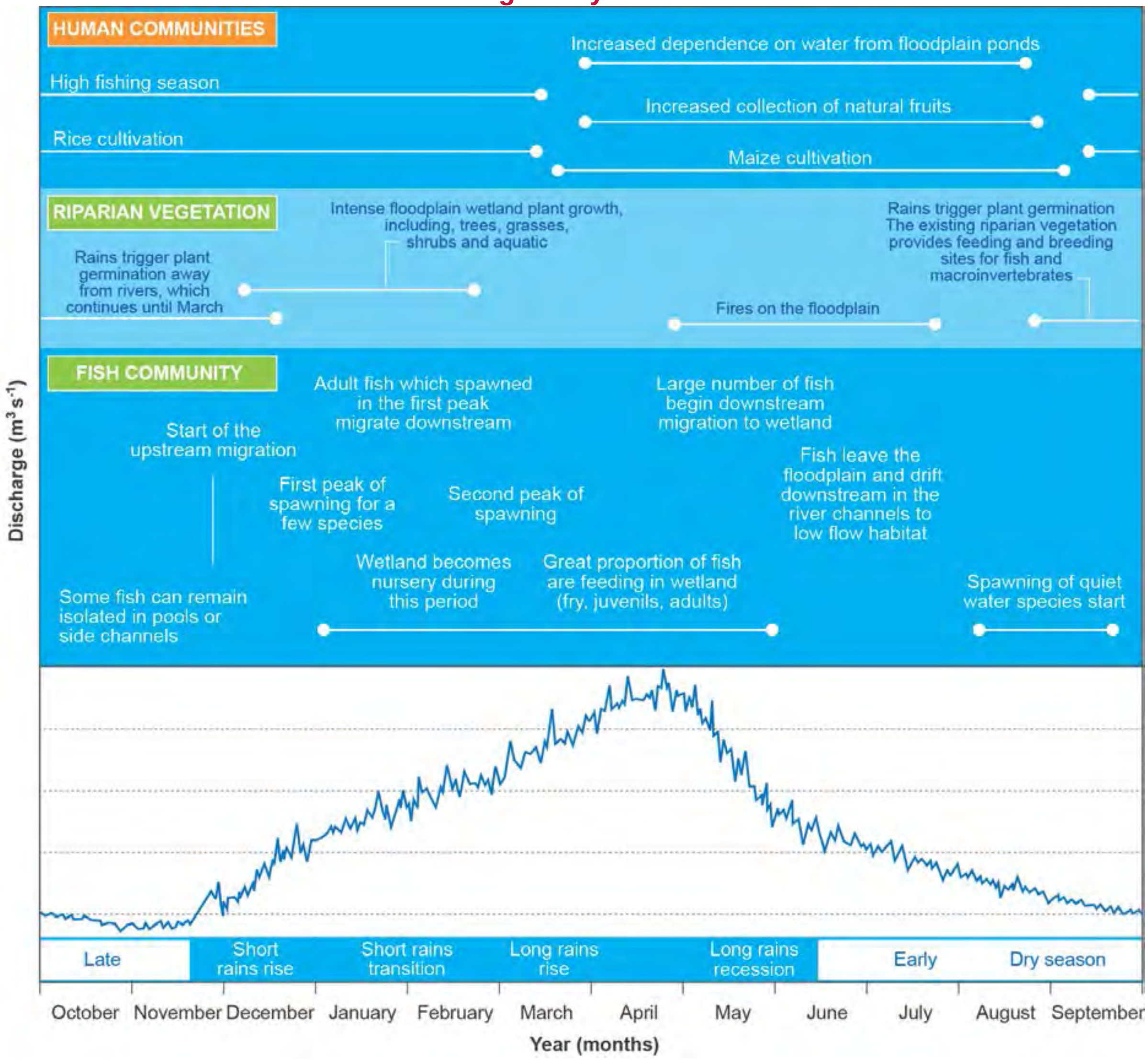
Figure 4.2: Schematic of Six Hydro-Periods Distinguished for Kilombero River Sub-Basin



Note: Hydro-periods are in relation to the hydrological year beginning 1 October (averaged from the hydrographs of several flow gauging stations).

Using the zonation and hydro-periods as a guide, the specialist team developed working hypotheses for the various relationships between flow regime and the social-ecological system around which field data collection and modeling were orientated. **Figure 4.3** illustrates the outcomes of this process for select components. The methods used and the full set of baseline results obtained for each of the specialists for the different components of the Kilombero system assessed for study reach are given in **Annex G** to **Annex N**).

Figure 4.3: Schematic Illustration of Types of Working Hypotheses Developed for Relationships between Flow Regime and Different Elements of Kilombero Social-Ecological System



4.2 Location and General Description of Study Sites

The location and general description of each of the main study sites is provided in **Table 4.1**. Further details of each site are available in **Annex G** to **Annex N** as are descriptions of additional river reaches for which surveys were made or data examined. Corresponding photographs and aerial and plan views of each site representative reach are provided below (**Figure 4.4** to **Figure 4.8**). The locations of field-surveyed hydraulic cross-sections used within the EFA workshop are indicated on the plan view figures (see also **Annex H**).

As laid out in **Table 4.1**, the subsequent discussion of the environmental flow requirements of the river reaches represented by each of these sites is according to zone and then site number.

Table 4.1: Locations and Descriptions of Five Main Study Sites of Kilombero Sub-Basin

Site Name	Zone Represented by Reach and Site Number	Coordinates (Arc 1960)	Locality	Physical Description	Ecological Description	Social Description (Key Ecosystem Services)
Udagaji River	Spawning EFA Site 2	E 0816580 N 9047210 Universal Transverse Mercator (UTM) Zone: 36	Upstream and downstream of Udagaji Bridge, downstream of the proposed Udagaji Irrigation scheme water offtake weir.	Boulders, rocks, and gravels form the channel bed; short straight reach with narrow channel width and shallow flow depth; moderately steep vegetated stable banks.	Presence of all common and highly flow sensitive fish species; largest number of flow sensitive macroinvertebrates; riparian plant species cover is 75%.	Flood recession agriculture = 93%; domestic water supply = 95%; malaria and bilharzia control = 36%
Lwipa River	Transition EFA Site 1	E 0202906 N 9093070 UTM Zone: 37	Lwipa at Mbingu gauging station (1KB 27A) located at upstream and downstream of Lwipa bridge; downstream of the confluence of Lwipa and Londo tributary.	Deep and fast turbulent flowing river with short straight reach; elevated vegetated stable banks with isolated collapsing banks; runs, pools, and sand bars are present.	Few common fish species; no flow sensitive macroinvertebrate species; riparian vegetation cover > 60% and plant species diversity index *H'* = 3.20.	Flood recession agriculture = 99%; domestic water supply = 89%; malaria and bilharzia control = 62%
Mpanga River	Transition EFA Site 3	E 0809887 N 9010738 UTM Zone: 36	Mpanga at Mpanga Mission gauging station (1KB 8), upstream and downstream Mpanga Bridge.	Deep, fast, and turbulent river with long straight reach and wide channel width; elevated vegetated stable banks with isolated collapsing banks; runs and pools are present.	Occurrence of 75% of the common fish species; macroinvertebrates dominated by pollution tolerant groups; riparian vegetation species cover > 60%, vegetation species diversity index *H'* = 3.15 and presence of exotic species.	Flood recession agriculture = 94%; domestic water supply = 97%; malaria and bilharzia control = 48%
Kilombero River at Ifwema	Wetland EFA Site 4	E 0821691 N 9007263 UTM Zone: 36	At the inlet of the Kilombero floodplain wetland, downstream of Mnyera/Mpanga and Ruhudji rivers confluence.	Relatively straight, mild bed slope, wide and deep river channel with extensive vegetated floodplains on both overbanks.	Riparian and floodplain vegetation species cover of >75% and vegetation species diversity index *H'* = 2.70.	Flood recession agriculture = 95%; domestic water supply = 95%; malaria and bilharzia control = 48%
Kilombero River at Ifakara Ferry	Wetland EFA Site 5.	E 0246770 N 9094015 UTM Zone: 36	Upstream and downstream of the Ifakara Ferry point; downstream of the Lumemo River confluence at the outlet of the Kilombero Valley wetland.	Meandering, mild bed slope, large channel width and deep river channel with extensive vegetated floodplains especially on the right overbank.	Occurrence of 90% of the common fish species; macroinvertebrate community dominated by pollution tolerant groups; riparian and floodplain vegetation cover >75%; vegetation diversity index values *H'* = 2.04 and presence of exotic species.	Flood recession agriculture = 100%; domestic water supply = 79%; malaria and bilharzia control = 65%

Figure 4.4: Udagaji River (EFA Site 2): Aerial View, Photo, and Plan View of Hydraulic Cross Sections

(a) (b) (c)

Notes: (a) aerial view; (b) photo; and (c) plan view of hydraulic cross sections. Blue arrow indicates the direction of flow, with river left and right banks in a downstream direction.

Figure 4.5: Lwipa River (EFA Site 1): Aerial View, Photo, and Plan View of Hydraulic Cross Sections

(a) (b) (c)

Notes: (a) aerial view; (b) photo; and (c) plan view of hydraulic cross sections. Blue arrow indicates the direction of flow, with river left and right banks in a downstream direction.

Figure 4.6: Mpanga River (EFA Site 3): Aerial View, Photo, and Plan View of Hydraulic Cross Sections

(a) (b) (c)

Notes: (a) aerial view; (b) photo; and (c) plan view of hydraulic cross sections. Blue arrow indicates the direction of flow, with river left and right banks in a downstream direction.

Figure 4.7: Kilombero River - Ifwema (EFA Site 4): Aerial View, Photo, and Plan View of Hydraulic Cross Sections

(a) (b) (c)

Notes: (a) aerial view; (b) photo; and (c) plan view of hydraulic cross sections. Blue arrow indicates the direction of flow, with river left and right banks in a downstream direction.

Figure 4.8: Kilombero River - Ifakara Ferry (EFA Site 5): Aerial View, Photo, and Plan View of Hydraulic Cross Sections

(a) (b) (c)

Notes: (a) aerial view; (b) photo; and (c) plan view of hydraulic cross sections. Blue arrow indicates the direction of flow, with river left and right banks in a downstream direction.

4.3 Characterization of Hydrological Regime and Hydraulic Habitat

4.3.1 Hydrological Regime

General climatic and hydrological features of the Rufiji Basin and Kilombero Sub-Basin are covered in Section 2.2. Detailed results of the analysis of hydrological regimes of the Kilombero River and tributary sites for the EFA are in **Annex G** as are the various methods used.

The survey data and information on water abstractions in the Kilombero catchments (e.g., Ruhudji, Mnyera, Mpanga, and Kihansi) were sourced from the RBWB for use in the hydrological analysis. The data did not reveal large water withdrawals from the rivers for agricultural activities, with this sector being the main water user. The database of legal water abstractions showed limited large-scale irrigation and industry water abstractions and diversions in the Kilombero Sub-Basin (though some occur, for example, Kilombero Plantation Limited (KPL) and Kilombero Sugar Co./Illovo sugar plantations, and Mufindi Paper Mill) and a high reliance on groundwater for domestic water supply.

Major agricultural activities in the area include tree plantations, tea plantations (which mostly source water from small reservoirs or *charco*), and valley bottom cultivation. The cultivation of valley bottom wetlands is responsible for significantly increased rates of sedimentation in river runoff, especially during the rainy seasons following wetland cover removal. Tree plantations are largely rainfed except for the nurseries. There are small patches of deforestation within the catchments. The Udagaji Catchment, which is adjacent to the Kihansi Catchment, is a steeply sloped forested catchment. The Kihansi Catchment, on the other hand, while also forested, has a larger part of the basin on the plateau without dense forests and is under rainfed farming, tree plantations, and valley bottom/wetland agriculture. Hydrologically, cover removal may be associated with increased runoff in the event of rain but with skewed peaks and less sustained baseflows. Despite this effect, the available data did not show statistically significant reductions in low flows.

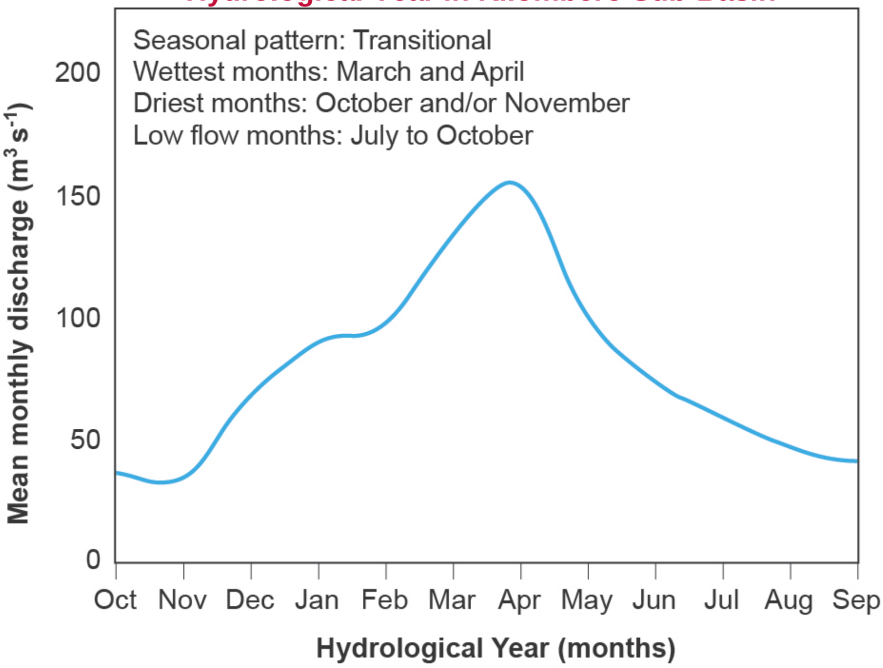
Notably, most of the Kilombero Sub-Basin is ungauged, including several tributary inflows to the Kilombero River and floodplain wetland. Most streamflow gauging data for the few stations with observed records fall within the period from the 1950s/1960s until the late 1970s/early 1990s. There are no reliable more recent data to characterize the present-day flow situation, so such flows had to be entirely modeled. Moreover, the quality of the existing hydrological record is considered poor for all of the river flow gauging stations used in the analysis due to the limited spatial distribution of gauging stations, poor quality and short length of observed time series, inaccuracies in rating curve equations, and known under-representation of actual surface water and groundwater abstractions. As a result, considerable reliance was placed on filling and reconstruction of discharge records using regression analyses from existing stations and rainfall-runoff modeling (using the Soil and Water Assessment Tool (SWAT) Model). The discharge data for the Udagaji River (Site 2) are generated from the Lwipa (Site 1) flow record, and the discharge records for the Mpanga River (Site 3) and Kilombero River at Ifakara Ferry (Site 5) were extended using the SWAT Model.

It is important to note that these data constraints affected the degree of confidence that could be placed in the environmental flow results at all of the sites. Data limitations were particularly challenging for the river-floodplain wetland reaches (mainstem Kilombero Sites 4 and 5).

Trend analysis of annual flows showed negligible positive (or, less commonly, negative) deviations from the natural hydrology. Given the data from the RBWB and hydrological modeling results (**Annex G**), it was concluded that there are limited large-scale water abstractions, and the flows in the rivers are minimally impacted. Therefore, present-day river flow regimes in most of the river catchment, including all of the study sites analyzed, can be considered near natural.

In terms of general flow pattern, a transitional regime of intra-annual flow variation (between a bimodal and unimodal regime) dominates in the Kilombero Sub-Basin, with a well-defined peak during the long rains (highest rainfall occurs in March and April) and a weak peak during the short rains (more evident at higher catchment elevations; **Figure 4.9**). The high flow period during the peak of the wet season is generally March to April. April was generally the focal month for specialist recommendations for wet season low flows and large flood events. The only exception was Site 5 where peak flows tend to occur in May. The low flows in rivers in the Kilombero Sub-Basin are experienced during the dry period, July to November, with October being the lowest flow month for sites 1 to 3 and November being the lowest flow month for sites 4 and 5. Hence, these months were the focus for specialist recommendations for dry season low flows.

Figure 4.9: Typical Average Seasonal Flow Pattern for a Hydrological Year in Kilombero Sub-Basin



Specialists made use of a wide range of hydrological results in their assessment of site environmental flow needs, including daily flow time series over the period of record, average daily and monthly discharge distributions, 1-day flow duration curves, and high flow frequency analyses (see **Annex G**). The annual average monthly discharge distributions for each of the rivers for which environmental flows were determined are shown in **Figure 4.10**; note the differences in scale, reflecting the different sizes and magnitude flows of the various sites. The hydrographs used as reference by the specialists for the general pattern and timing of flows for each site are given below (**Figure 4.11**).

Daily (1-day) FDCs at the five sites (see **Annex G**) showed a generally gradual slope. This indicated stable (non-flashy), river flow regimes, with river discharge magnitudes around the mean for 30 to 70 percent of the time and a comparatively high proportion of the flow regime represented by baseflow contributions from groundwater; groundwater conditions remain poorly understood (this study; WREM 2015j). The FDCs were used to calculate the exceedance percentiles recommended environmental flows represented at each site (see below).

A summary of site flood quantiles (derived from site distributions of annual maxima from observed daily discharge records fitted to a Log-Pearson Type III probability distribution; see **Annex G**), used to help characterize the different magnitude and return period flood events of particular social, ecological, and geomorphological importance, is provided in **Table 4.2**. It is noteworthy that the values carry a high degree of uncertainty due to the known unreliability of gauging station high flow estimates as well as record length and the lack of recent (post 1990s) flood observations.

Figure 4.10: Average Monthly Discharges for Study Rivers

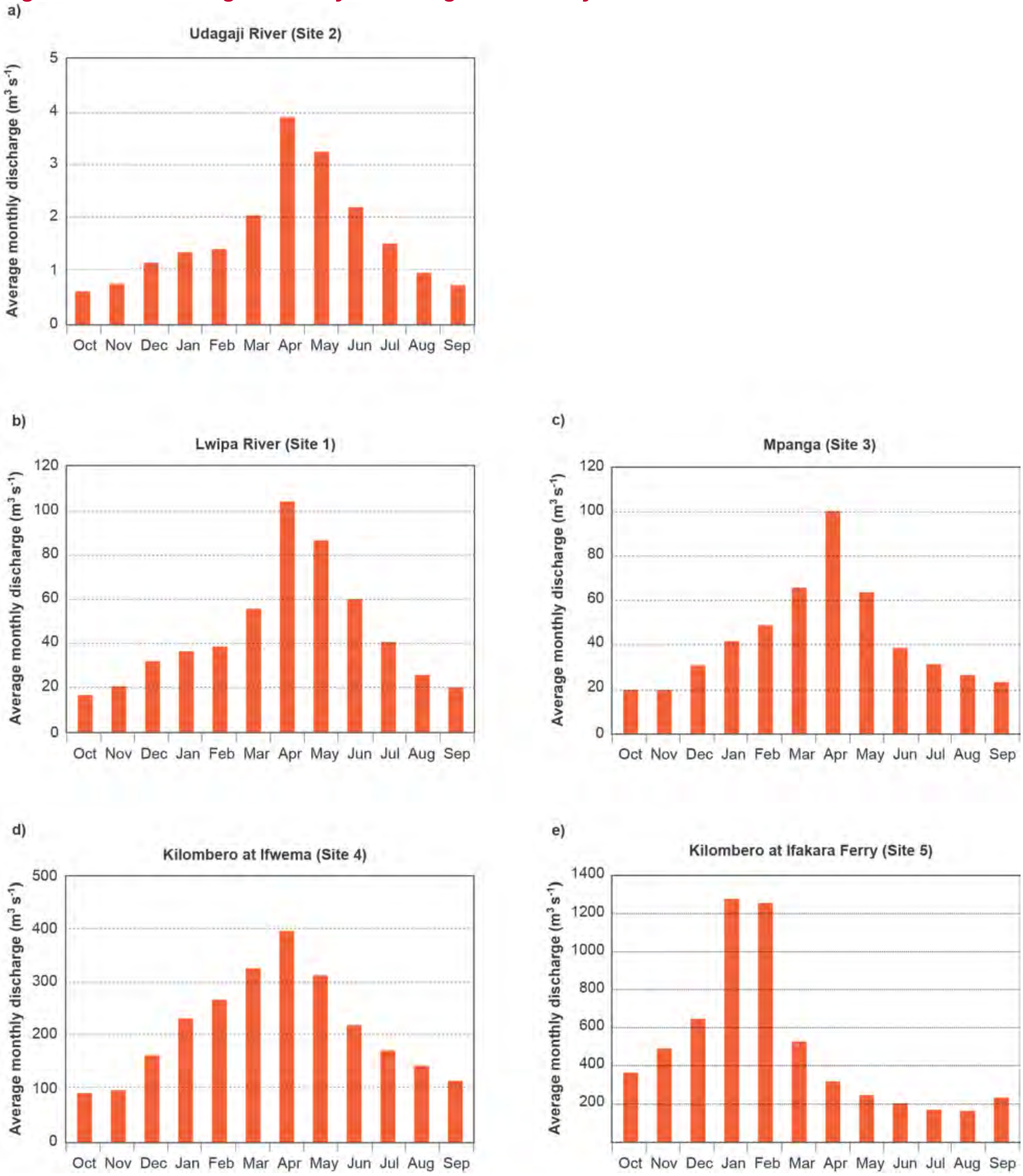


Figure 4.11: Annual Hydrograph of Average Daily Discharge for Study Rivers in a Characteristic Wet, Average/Normal, and Dry Year

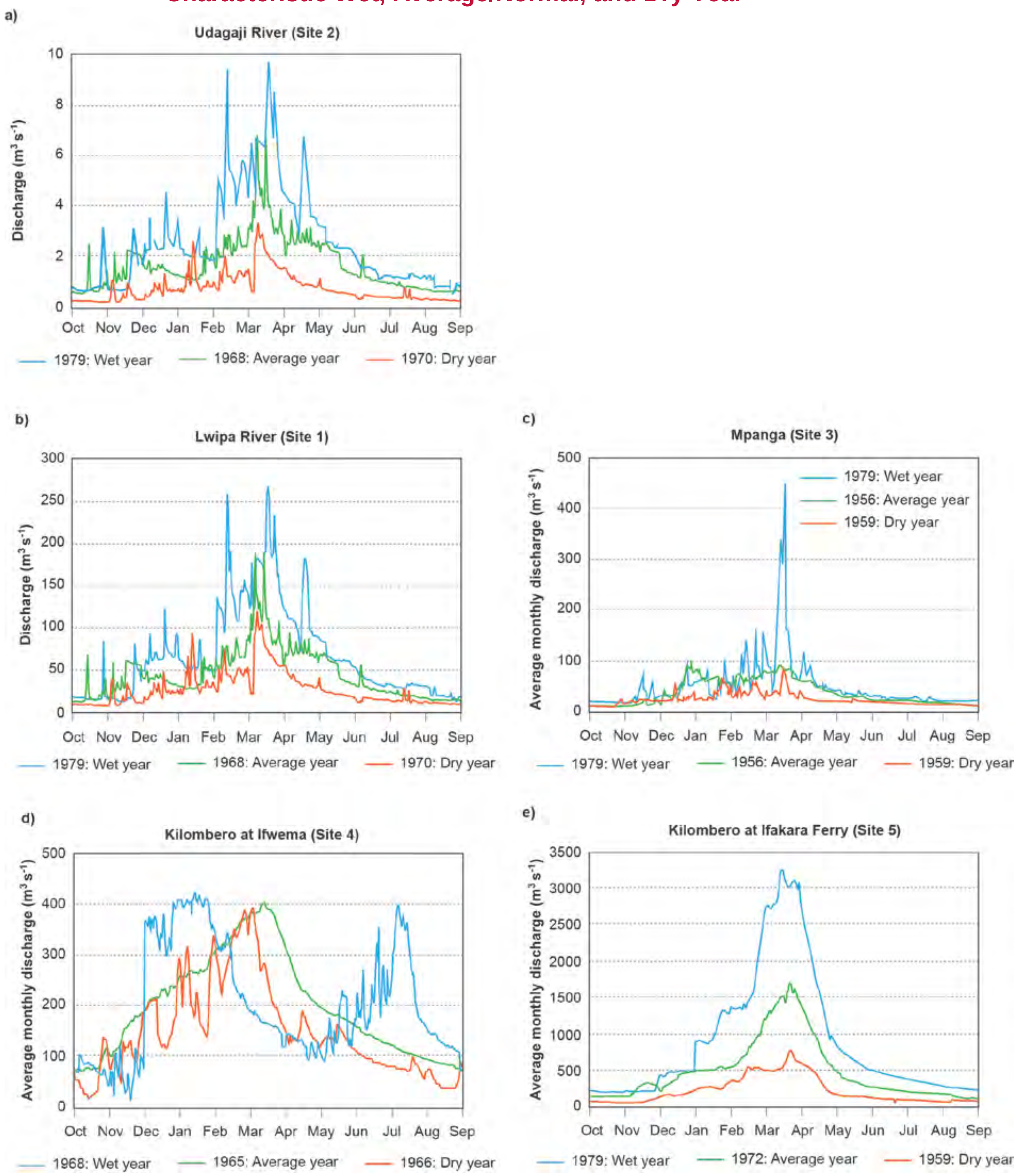


Table 4.2: Summary of Maximum Discharges (m^3/s) for Study Rivers in Kilombero Sub-Basin

River Name	Return Interval (years)							
	1	2	5	10	25	50	100	200
Lwipa	112	195	222	235	247	254	260	265
Udagaji	4.2	7.3	8.3	8.8	9.2	9.5	9.7	10.0
Mpanga	81	199	269	312	365	403	440	476
Kilombero at Ifwema	303	458	539	590	650	693	735	777
Kilombero at Ifakara Ferry	715	1,702	2,366	2,819	3,406	3,854	4,311	4,780

4.3.2 Hydraulics of River-Floodplain System

Details of the hydraulic features of the various sites are presented in **Annex H**. A summary of the field survey methods used is also provided in the annex. Hydraulic habitat modeling was predominantly focused on the main channel and neighboring riparian zones and did not extend the full breadth of the floodplain. Additional floodplain modeling after the flow assessment workshop was used to add greater understanding of flooding dynamics (Section 4.10.2).

4.4 Ecological and Social Importance and Sensitivity

The importance of the different Kilombero sites for the maintenance of ecological diversity and system functioning and their sensitivity to human-induced change (i.e., EIS; Section 3.1.3) are strongly apparent. The overall scores, as well as the assessments made for all individual ecological and social components, are presented in **Table 4.3**. The overall EIS scores ranged between moderate (the transition sites of the Lwipa (Site 1) and Mpanga (Site 3) rivers), to very high for the Udagaji River (Site 2), the smallest, highest elevation site. The ecologically critical role played by the assessed reach of the Udagaji River as a spawning ground for fish species of high biodiversity and social value (for own consumption and market), including several migratory species from the mainstem Kilombero River, as well as its high degree of naturalness (e.g., presence of sensitive macroinvertebrate taxa), were primary reasons for its scores (see also **Annex I** to **Annex N** for complete explanations). Both the Kilombero River floodplain sites studied are considered of high ecological importance. Site 5 is located within the internationally recognized Kilombero Ramsar wetland site (as is the Lwipa River reach).

All of the Kilombero sites are highly or very highly important from a social perspective, taking into account the number of people directly dependent on the riverine ecosystem for ecosystem services and other natural resource benefits. This is reflected in their SIS scores, which lend additional support to the EIS results obtained. Significantly, there were no sites of low to moderate social importance. Again, as for EIS, the Udagaji River (Site 2) was rated very highly, as was the upper part of the Kilombero wetland (Site 4). The Kilombero River floodplain reaches provide multiple ecosystem services and other benefits to local communities, from wild vegetables and fruits for domestic consumption to additional income at market from the fishery. The provision of valuable high-quality water supplies for direct human consumption from the main channel and ponds and other floodplain wetlands, as well as nutrient-rich soils for floodplain and river bank flood recession agriculture, are also central contributing factors to the importance of this river.

4.5 Reference Conditions and Present Ecological Status

The reference conditions for the Kilombero sites provide a baseline against which to determine how much the river system has already been anthropogenically modified from its natural state (Section 3.1.3). While changes in catchment condition and in natural resource use were evident, the vast majority of these changes were not directly or indirectly attributable to flow alteration (e.g., fishing using poison, removal of riparian vegetation). The hydrological regimes of the mainstem Kilombero and tributaries were considered minimally altered from their natural flow patterns at present, though with a negative trajectory of change in the longer term in all cases (see Section 4.3). Therefore, we identified present-day condition as an appropriate reference condition for all of the sites for the EFA.

The current state of the river social-ecological system at each site, for each component, was determined by the individual specialists and expressed in terms of PES, rated from A (unmodified/natural) to F (critical/extremely modified) (**Table 3.2** explains the PES and EMC classes; Section 3.1.3). Consensus was reached among the specialists on an overall EIS, SIS, PES (Section 4.4), trajectory of change, and EMC for each site (**Table 4.3**). Specific reasons for the assigned PES (and EMC) classes are summarized in **Table 4.4** for each site and component.

Table 4.3: Importance and Sensitivity, Present Status, and Proposed Environmental Management Classes for Kilombero Study Sites

Site Name (Site Number)	Component	EIS	SIS	PES	Trajectory	EMC
Udagaji River (EFA Site 2)						
	Hydrology	Medium/High	N/A	A/B	Negative	B
	Geomorphology	N/A	N/A	D	Negative	C
	Water Quality	Very High	High	A/B	0	A/B
	Vegetation	Very High	Moderate	A	0	A
	Fish	Very High	Moderate	A/B	0	A/B
	Macroinvertebrates	Very High	Moderate	A/B	0	A/B
	Social	N/A	Very High	D	Negative	B
	Overall	Very High	Very High	B	Negative	A/B
Lwipa River (EFA Site 1)						
	Hydrology	Medium	N/A	A/B	Negative	B
	Geomorphology	N/A	N/A	B/C	Negative	B
	Water Quality	High	High	A/B	Negative	A/B
	Vegetation	Moderate	High	B	Negative	B
	Fish	High	High	B	Negative	B
	Macroinvertebrates	High	High	C	Negative	B
	Social	N/A	Very High	C	Negative	B
	Overall	Moderate	High	B	Negative	B

Site Name (Site Number)	Component	EIS	SIS	PES	Trajectory	EMC
Mpanga River (EFA Site 3)						
	Hydrology	Medium/High	N/A	A/B	Negative	B
	Geomorphology	N/A	N/A	B/C	Negative	B
	Water Quality	High	High	A/B	0	A/B
	Vegetation	Moderate	High	C	Negative	B
	Fish	Moderate	High	B	Negative	B
	Macroinvertebrates	Moderate	Mod	B	Negative	B
	Social	N/A	Very High	B	0	B
	Overall	Moderate	High	B	Negative	B
Kilombero River at Ifwema (EFA Site 4)						
	Hydrology	Medium/High	N/A	A/B	Negative	B
	Geomorphology	N/A	N/A	B/C	Negative	B/C
	Water Quality	Moderate	High	B	Negative	B
	Vegetation	High	Very High	B	0	B
	Fish	High	High	B	Negative	A/B
	Macroinvertebrates	High	Moderate	B	Negative	A/B
	Social	N/A	Very High	B	Negative	B
	Overall	High	Very High	B	Negative	A/B
Kilombero River at Ifakara Ferry (EFA Site 5)						
	Hydrology	Medium	N/A	B	Negative	B
	Geomorphology	N/A	N/A	B/C	Negative	B/C
	Water Quality	High	High	A/B	0	A/B
	Vegetation	High	High	B	0	B
	Fish	High	High	B	Negative	A/B
	Macroinvertebrates	Moderate	Moderate	B	Negative	B
	Social	N/A	Very High	C	Negative	B
	Overall	High	High	B	Negative	A/B

In terms of PES, across ecosystem components, present geomorphological conditions tended to be worse than for other components, particularly in the Udagaji River (PES = D; **Table 4.3**) due to poor land use practices (agriculture, deforestation) that have increased sediment inputs to the river and altered the physical character of the river bed. The social environment associated with the river was either largely unmodified or moderately modified, except again in the Udagaji River reach, which was considered the most detrimentally impacted (see **Table 4.4** for site-specific reasons). Despite these ranges in PES categories across components and across sites, there was clear consensus that overall all of the river reaches at the sites were in a Class B present condition (**Table 4.3**), indicating they were generally still largely natural with few modifications. This in part reflected the relatively unaltered flow regimes of the sites.

However, trajectories of change were typically negative across the sites and components, strongly pointing to an expected future deterioration in ecological and social conditions under the status quo (**Table 4.3**). There were no components showing any trends of increasing ecological or social health. In the case of the Udagaji River, there was some evidence that the system was comparatively stable in condition, with several components without evidence of any directional change. Importantly, the vast majority of the evidence of negative change was not attributable to changing flow regimes and its knock-on effects but, rather, a result of human induced stressors and inadequate catchment management. Examples include agrochemical inputs from riparian farmland and illegal fishing practices.

Table 4.4: Principal Reasons for the Assigned PES and EMC Classes at Each Site

Component	State	Rank	Reason(s)
Udagaji River (Site 2)			
Hydrology	PES	A/B	• The flow regime is almost natural with very little or no modification.
	EMC	B	• Need to preserve the current state of the river and minimize further likely modifications in flows.
Geomorphology	PES	D	• Presence of disused river structure (weir) that although has no gates is a physical obstacle to sediment and water flows. The widening of the river upstream of the weir has created sedimentation of finer grain size (fine gravel and coarse sand) that away from the structure is only present in the flow shadow of the main boulders. Just downstream of the weir, there are signs of erosion.
	EMC	C	• Restoring the original water and sediment flow (removal of the weir).
Vegetation	PES	A	• There is minimal human disturbance at this site and also no exotic plant species. Occurrence of spp. common in tropical riparian ecosystems like *P. mauritianus*, *Ficus sycomorus,* and *Penissetum purpureum* suggests that conditions are near natural. • There is a good cover and high abundance of typical riparian native plant species (i.e., 75%). • There is also good abundance of sensitive species, including *P. mauritianus*, *Ficus sycomorus,* and *Penissetum purpureum*.
	EMC	A	• EMC for riparian vegetation is set to improve the site's present conditions. Increasing the class requires improvement of practices other than those linked to flow.
Fish	PES	A/B	• Occurrence in the catches of all fish species commonly known to occur in this area, including upstream breeding migrants *Labeo cylindricus* and *Barbus macrolepis,* as well as indicator/highly flow sensitive species of *Amphilius uranoscorpus*, *Chiloglanis deckenii*, and *Parakneria* sp.
	EMC	A/B	• EMC is set at A/B to improve the site's good conditions. Increasing the class requires improvement of practices other than flow regulation.

Component	State	Rank	Reason(s)
Macroinvertebrates	PES	A/B	• The site hosts the highest number of flow sensitive macroinvertebrates, including Prosopistomatidae, Heptageniidae, Teloganodidae, Perlidae, Helodidae, Pyralidae, Psephenidae, Tricorythidae, and Leptophlebiidae. As a result, the site has the highest value of Average Score per Taxon (ASPT = 7.38). • This site has a macroinvertebrate species diversity index *H'* > 2.
	EMC	A/B	• EMC is set at A/B to improve the site's good condition. Increasing the class requires improvement of practices other than flow regulation.
Water Quality	PES	A/B	• The site scored the highest both during the wet season data (score of 4.9/5) and during the dry season (score of 4.4/5). In terms of water quality, this site is relatively natural.
	EMC	A/B	• The EMC should maintain the current status due to the ecological importance and sensitivity of the site confirmed by the water quality results and biology of the site.
Social	PES	D	• A loss of natural habitat, biota, and basic ecosystem functions has occurred.
	EMC	B	• Needed major improvement in the whole biophysical condition of the river to mitigate floods downstream and also restore the degraded biodiversity, including decreased fish varieties. Also, to enhance crop farming, especially in the lower parts of the rivers. Increasing the class requires improvement of practices other than flow regulation.
Lwipa River (Site 1)			
Hydrology	PES	A/B	• The flow regime has very slightly changed due to upstream land use change.
	EMC	B	• Need to maintain the current state of the river and minimize further likely modifications in flows.
Geomorphology	PES	B/C	• Anthropogenic changes of the floodplain at the site and upstream and downstream have occurred, with cropping patterns that most probably induce higher suspended sediment (and likely some bedload) input to the river. Much stronger anthropogenic impacts are present upstream (high deforestation) that most probably have also affected the granulometry and amount of fine sediment input at the site, modifying the substratum of the riverbed.
	EMC	B/C	• Maintain the present status without further modification of the sediment balance.

Component	State	Rank	Reason(s)
Vegetation	PES	B	Largely natural with few modifications because: • Although this site shows some signs of human disturbance and exotic species (e.g., *Tectona grandis* and *Bauhinia variegata*), there are still good representatives of native riparian species (e.g., *Phragmites mauritianus*, *Ficus exasperata,* and *Penissetum purpureum*). • There is a good abundance of sensitive plant species (e.g., *P. mauritianus* and *Penissetum purpureum)*.
	EMC	B	• It is set at the same level as the PES to maintain good condition; although with the negative trajectory, there may have to be improvements in the flow to maintain present conditions.
Fish	PES	B	Largely natural with few modifications due to the following reasons: • A large number of fish species described in the Kilombero Valley were caught at this site, including *Bagrus*, *Barbus*, *Labeo,* and others. • A few of the most common species were not encountered in the catches at this site (e.g., *Alestes*, *Citharinus*), possibly showing that the component has deviated from natural conditions.
	EMC	B	• In order to improve the conditions and maintain the site's high importance rating, as it occurs in the protected area of the Kilombero Ramsar Site. Increasing the class requires improvement of practices other than flow regulation.
Macroinvertebrates	PES	C	Moderately modified, evidenced by the following: • None of the expected flow sensitive species was collected from this site, possibly indicating that moderate modification has occurred at this site. • The site recorded the lowest ASPT value (4.78) in comparison to other sites.
	EMC	B	• Set at B (a higher class than the PES) in order to improve the conditions and maintain the site's high importance rating as it occurs in the Kilombero Ramsar site. Increasing the class requires improvement of practices other than flow regulation.
Water Quality	PES	A/B	• According to the proposed definition of Classes for Water Quality, the site is relatively natural, especially during wet seasons (score of 4.7/5), but shows slight modifications during dry seasons (score of 3.7/5).
	EMC	A/B	• Maintain the current status.
Social	PES	C	• Anthropogenic changes of natural habitat and biota have occurred, but the basic ecosystem functions are still predominantly unchanged.
	EMC	B	• High community dependence on moist and fertile soil for recession agriculture and on fish for consumption.

Component	State	Rank	Reason(s)
Mpanga River (Site 3)			
Hydrology	PES	A/B	• The flow regime is almost natural with very little modification.
	EMC	B	• Need to preserve the current state of the river and minimize further likely modifications in flows.
Geomorphology	PES	B/C	• Anthropogenic changes of the floodplain at the site and upstream and downstream have occurred, with cropping patterns that most probably induce higher suspended sediment (and probably some bedload) input to the river. Much stronger anthropogenic impacts are present upstream (high deforestation) that most likely have also affected the granulometry and amount of fine sediment input at the site, modifying the substratum of the riverbed.
	EMC	B	• To reduce the anthropogenic input of fine sediments to the river by means of sediment management.
Vegetation	PES	C	• Relatively few riparian species were sampled from this site, possibly indicating that moderate modification has occurred, which is confirmed by significant disturbance indicators (e.g., cut stems, grasses, and fire remnants recorded during the survey). • There were also exotic species in this site, including *Acidosasa edulis* (bamboo) and *Euphorbia heterophylla*. As a result, the site recorded relatively low value of species diversity index (*H'* = 3.15).
	EMC	B	• EMC is set at a higher class than PES to improve the conditions and maintain the site's high importance rating. Increasing the class requires improvement of practices other than flow regulation. • *Ophrypetalum odoratum*, one of the tree species recorded at this site, reported as 'vulnerable' in the IUCN Red List of categories, provides strong motivation for improving the present river management regime.
Fish	PES	B	• About 75% of the common fish species harvested in the Kilombero valley were recorded at this site. The fact that few of these common species in the valley were not encountered in the catches recorded possibly indicates that the component has deviated from the natural pristine conditions although deviations not due to flow alterations.
	EMC	B	• Set at the same level as the PES to maintain good conditions although with the negative trajectory there may have to be improvements in the flow just to maintain present conditions.
Macroinvertebrates	PES	B	• Although the community is dominated by pollution tolerant groups, there are still some representatives of flow sensitive taxa. • The site still has moderate ASPT values of 5.69 and species diversity index (*H'* = 1.44).

Component	State	Rank	Reason(s)
	EMC	B	• The EMC is set at the same level as the PES to maintain good conditions although with the negative trajectory there may have to be improvements in the flow and habitat conditions in order to maintain present conditions.
Water Quality	PES	A/B	• In terms of water quality, this was the second best site after Udagaji, with wet season score of 4.5/5 and dry season score of 4.4/5. The site is relatively natural.
	EMC	A/B	• Maintain the current status.
Social	PES	B	• A small change in natural habitat and biota may have taken place, but the ecosystem functions are essentially unchanged.
	EMC	B	• To maintain the current status so as to enhance the ecosystem services provided by River Mpanga to the local communities.
Kilombero River at Ifwema (Site 4)			
Hydrology	PES	A/B	• The flow regime is almost natural with very little modification.
	EMC	B	• Need to preserve the current state of the river and minimize further likely modifications in flows.
Geomorphology	PES	B/C	• The river banks are highly impacted by human activities at the site, reducing their stability and increasing the input of sediment to the river at least locally, but given the large size of the Kilombero River at this site, the influence to the overall geomorphologic dynamics could be limited.
	EMC	B/C	• To preserve the present status without further changes to the river banks and sediment balance.
Vegetation	PES	B	• There are signs of human disturbances and exotic plant species; however, it has good species richness and composition of native grasses, shrubs, and few tree species along the riverbanks. • There is abundance and dominance of native riparian species (i.e., 75%), including species like *Penissetum purpureum, Phragmites mauritianus,* and *Vossia cuspidata*. The site recorded moderate values of species diversity index (*H'* = 2.70).
	EMC	B	• EMC is set at the same level as the PES in order to maintain present good conditions.
Fish	PES	B	Site not covered during data collection due to flooding.
	EMC	A/B	Site not covered during data collection due to flooding.
Macroinvertebrates	PES	B	Site not covered during data collection due to flooding.
	EMC	A/B	Site not covered during data collection due to flooding.
Water Quality	PES	B	• According to water quality classes, the wet season class is B (Score of 4.3/5), and the dry season class is B (Score of 3.5/5). The site definitely shows slight modification.
	EMC	B	• Maintain the site at its present management class and prevent further changes.

Component	State	Rank	Reason(s)
Social	PES	B	• A small change in natural habitat and biota may have taken place, but the ecosystem functions are essentially the same.
	EMC	B	• To maintain the current status to enhance the ecosystem services provided by the Kilombero River to local communities.
Kilombero River at Ifakara Ferry (Site 5)			
Hydrology	PES	B	• The flow regime is almost natural with very little modification. There are some upstream interventions.
	EMC	B	• Need to preserve the current state of the river and minimize further likely modifications in flows.
Geomorphology	PES	B/C	• The river banks are highly impacted by human activities at the site, reducing their stability and increasing the input of sediment to the river at least locally, but given the large size of the Kilombero River at this site, the influence to the overall geomorphologic dynamics could be limited.
	EMC	B/C	• To preserve the present status without further changes to the river banks and sediment balance.
Vegetation	PES	B	• There is evidence of human disturbances although important functions are still maintained. There are exotic species, including invasive non-natives (e.g., *Mimosa pigra* on the site), especially within floodplain areas. • The site has good native species richness and composition of grasses, shrubs, and very few tree species along the banks. The abundance of native riparian species is high (i.e., 75%) with species like *Penissetum purpureum, Phragmites mauritianus,* and *Vossia cuspidata*. These species are sensitive natives. • The site recorded moderate values of community diversity index (*H'* = 2.04).
	EMC	B	• The EMC is set at the same level as the PES to maintain present good conditions.
Fish	PES	B	• Close to 90% of the common fish species harvested in the Kilombero Valley were recorded at this site. The fact that a few of the common species in the valley were not encountered in the catches possibly indicates that the component has deviated from the natural pristine conditions although deviations are not due to flow alterations.
	EMC	A/B	• The EMC for fish is set at A/B (a higher class than PES) in order to improve the conditions and maintain the site's high importance rating as it occurs in the Kilombero Ramsar Site and to continue to maintain the Red List species. Increasing the class requires improvement of practices other than flow regulation.
Macroinvertebrates	PES	B	• Although the macroinvertebrate community is dominated by pollution tolerant groups, there are still some representatives of the flow sensitive taxa. As a result, the site still has moderate ASPT values of 5.78 and macroinvertebrate species diversity index (*H'* = 1.22).

Component	State	Rank	Reason(s)
	EMC	B	• The EMC is set at A/B (a higher class than PES) in order to improve the conditions and maintain the site's high importance rating, as it occurs in the Kilombero Ramsar Site. Increasing the class requires improvement of practices other than flow regulation.
Water Quality	PES	A/B	• According to classes for water quality, the site is slightly changed from natural, with wet season class of A (score of 4.5/5) and dry season class of B (score of 4.1/5).
	EMC	A/B	• Maintain the current status.
Social	PES	C	• A loss and change of natural habitat and biota have occurred, but the basic ecosystem functions are still predominantly unchanged.
	EMC	B	• Major improvement in the whole biophysical condition of the river is needed to mitigate floods and restore the degraded biodiversity, including decreased fish varieties. Increasing the class requires improvement of practices other than flow regulation.

Note: See **Annex G** to **Annex N** for more detailed information for each component.

Some of the more salient features of the sites and system components and their present status are discussed below. While an overview is provided of some of the key social aspects of the community linked to flows and river state, **Annex N** presents an in-depth account of the wider range of considerations.

Changes in catchment condition, and the resultant impacts on PES in terms of geomorphology and water quality appear in large part related to increased settlement and widespread, rapid conversion of land to agriculture (including the destruction of natural forest and wetland habitats), especially with the rapid influx of people. A survey by Harrison (2006) showed that 71 percent of the Kilombero Valley residents are recent immigrants.

While the Udagaji reach was geomorphologically highly modified with signs of sedimentation and erosion (discussed above), the present geomorphological condition of the Lwipa and Mpanga rivers was in the range low to moderate, with elevated instream sediment levels (suspended and on the river bed) due to land use practice changes, and floodplain alteration. The Lwipa and Mpanga sites also showed some influences of upstream deforestation. For the two Kilombero floodplain reaches (Sites 4 and 5), the comparatively large river size likely has helped mitigate human influences on overall geomorphological condition (physical habitat and processes). However, the river channel banks are highly impacted by human activities at the study sites, reducing their stability and increasing local sediment inputs to the river.

Water quality was assessed in terms of a wide range of parameters, from temperature and system variables such as pH through to nutrients; contaminants were indirectly evaluated (e.g., pesticide application). Present water quality conditions were scored independently for the wet and dry seasons, because most water quality parameters tend to be at their worst levels at very low flows (e.g., low oxygen, high ammonia). In some cases, wet season values for some parameters may be high (e.g., high turbidity, nitrates, and organic material) due to entrainment from the riparian and floodplain areas at high flows. Conditions were based on an established Tanzanian water quality classification system, with a focus on dissolved oxygen, ammonia, turbidity, organic matter, nitrate, and orthophosphate (described in full in **Annex J: Table 5.1**; see **Table 4.4** above for site scores).

Despite land use changes, demographic pressures, and cultivation practices, the Udagaji River, followed by the Mpanga River, showed relatively natural water quality, especially during wet seasons. A slight general decline in quality was sometimes evident during dry seasons. The PES for water quality at other sites was similarly slightly modified (A/B) down to a B PES class in the Kilombero River at Ifwema (Site 4), where water quality was poorest overall. This was due to relatively low oxygen saturation, high ammonia, and high biological oxygen demand, probably attributable to a combination of agricultural, industrial, and municipal pollution sources, with agro-industries and Njombe municipality upstream, as well as a paper mill in the Mnyera Catchment (Kigogo Ruaha River). While all other sites fell within the water quality range of the Tanzania Bureau of Standards Category III for dry-season condition (see **Annex J: Table A.2**), the Kilombero did not meet this category.

A total of 306 plant species belonging to 73 families and 219 genera were identified from the study sites. Six main plant communities, characterized by their dominant plant species, were identified based on their flow requirements, across the aquatic, riparian, floodplain, and terrestrial zones (see **Annex K: Section 6** for details): (1) *Pistia-Vossia* aquatic community, (2) *Phragmites-Penissetum* grasslands, (3) *Ficus* spp.-*Cyperus,* (4) *Voacanga-Ficus-Acacia* riparian community, (5) *Panicum-Kigelia* floodplain community, and (6) *Diplorhynchus-Combretum* woodland. *Phragmites mauritianus* and *Penissetum purpureum* (Poaceae), which occur along the channel and on the lower banks and beaches of rivers, were indicator species common to all sites.

Most of the present-day alterations from natural vegetation conditions, in terms of vegetation cover and composition, likely are caused by human disturbances rather than flow change. Riparian vegetation was in relatively good condition, with good cover and abundance (more than 75 percent) of common tropical, native riparian species. The exception was the Mpanga River where there was moderate alteration from natural conditions, with comparatively low diversity, few native riparian species, and a presence of exotic species (e.g., bamboo and *Euphorbia heterophylla*). *Ophrypetalum odoratum*, a vulnerable tree species, was recorded at this site. Human disturbance to vegetation at the Udagaji site was minimal, with good plant cover and high abundances of typical riparian native species (*Phragmites mauritianus*, *Ficus sycomorus,* and *Penissetum purpureum*); exotics were absent. The Lwipa and Kilombero rivers showed signs of human disturbance, and exotic species are present. However, the species richness, composition, and diversity of native grasses, shrubs, and tree species within the Kilombero River-floodplain remain moderate to good. Sensitive native aquatic macrophytes, such as *Vossia cuspidata*, are present. At the Ifakara Ferry site, the invasive, non-native *Mimosa pigra* is evident, and there are fewer tree species along the banks. We found that many of the plant species at the different sites represented valuable natural resources for communities, from thatching grasses to wild fruits, vegetables, and herbs (see **Annex K** for further discussion of the vegetation and its many benefits for people).

Macroinvertebrate communities are important for river trophic structure, as food for fish and other fauna, indicators of general river health and water quality, and for biodiversity value. A few species are also a food source for communities (e.g., *Macrobrachium*). Across all sites surveyed, we recorded a diverse set of 32 macroinvertebrate families from nine orders (see **Annex L: Figure 3.1**, for the full assemblage composition). Assemblages were dominated in terms of abundance (32 percent of the total) by Baetidae (mayflies; Ephemeroptera), followed by net-spinning caddisfly larvae (Hydropsychidae; Trichoptera) at 17 percent. Both flow-hydraulic habitat generalists and specialists were found.

The South African Scoring System Protocol 5 (SASS5) rapid bio-assessment scores, including the Average Score per Taxon (ASPT) and sensitivity score (see **Annex L** for methods and **Figure 3.2** and **Table 3.2** in the annex for results and interpretation of site scores, respectively), indicated that the Udagaji River has a healthy invertebrate assemblage, very good water quality, and near natural conditions, with high instream habitat diversity. SASS5 results provide an index of general river health as well as of physical habitat, water quality, and flow conditions for invertebrate communities. Notably, the SASS5 protocol may require further tailoring to be fully applicable to Tanzanian river systems.

Flow sensitive benthic macroinvertebrate families were present (including Prosopistomatidae, Heptageniidae, Teloganodidae, Perlidae, Helodidae, Pyralidae, Psephenidae, Tricorythidae, and Leptophlebiidae). The greatest number of macroinvertebrate families (24) and of sensitive taxa (8) of all sites was recorded in the Udagaji River. The Mpanga site had a moderate number of macroinvertebrate families (13) followed by the Kilombero (9), with both sites having one sensitive taxon, of the mayfly family, Heptageniidae. The Kilombero and Mpanga river reaches were of lower general health and water quality than the Udagaji River. The Lwipa site had no sensitive macroinvertebrate taxa and the lowest number of families (9). Low invertebrate ASPT scores suggested that moderate pollution likely is already occurring in the Lwipa River (though not as apparent from the water chemistry data). Similarly, SASS5 sensitivity scores were highest for the Udagaji River, lowest for the Lwipa River (which also showed the lowest invertebrate diversity of the sites), and moderate for the other reaches (**Annex L: Figure 3.2**).

Twenty-seven fish species (13 families, 21 genera) were identified from the EFA sites, with several new distribution records for the Kilombero River-floodplain (e.g., *Amphilius*, *Chiloglanis*, *Parakneria*, *Neobola*), bringing the total number of fish spp. in the Kilombero valley to 49 (**Annex L: Table 3.5** provides the species distribution list, conservation status, and Swahili common names). Except for some species caught only in the Udagaji and Mgugwe rivers (see **Annex L** for details of this additional survey site) the remaining fish are common and abundant throughout the entire Kilombero valley, across all sites, and into the Lower Rufiji River. The fish fauna of the Kilombero Basin resembles that of other East African coastal rivers although a proportion of the diversity (e.g., *Citharinus* sp.) reveals an important shared geological history with the Zaire Basin. Only one fish species is listed in the IUCN Red Data Book as vulnerable, *Distichodus petersii*; this species has a wider distribution than the Rufiji Basin, occurring in other systems such as the Ruvu and Ruvuma rivers. One introduced exotic species, the Nile tilapia (*Oreochromis niloticus*) occurs in the study area. Because it is a problem species, hybridizing with native tilapiine spp. leading to reduced genetic distinctness of native species, care needs to be taken to ensure changes in flow regime and other management practices do not promote further spread of this invasive species or the addition of any new ones (International Finance Cooperation Performance Standard 6).

The fish fauna of the Kilombero River system is composed of five major environmental guilds, each with its own characteristic interrelationships between life history cycles and the pattern and timing of flow events, and with physical habitat. Based on Welcomme et al. (2006), guilds include: (1) the main channel guild inhabiting riffles (rhithronic), (2) the main channel guild inhabiting pools, (3) a lotic guild that includes longitudinal migrants, (4) a eurytopic (generalist, extremely adaptable) guild comprising low dissolved oxygen tolerant communities, and (5) a catadromous guild (see **Annex L: Table 3.7** for a summary of representative fish species of the various guilds). A good proportion of the current resident fish species in the Kilombero River System are from flow-sensitive guilds, with fewer species from highly pollution-tolerant guilds. This suggests the river is still in good condition throughout its drainage network.

The rhithronic (fast, mountain stream) communities are represented by species abundant in the Udagaji River such as *Chiloglanis*, *Amphilius,* and *Parakneria*. Longitudinal migrants from the floodplain use this river as a critical reach for spawning. The other river-floodplain reaches include various species from the other guilds and are all in good condition (PES B). Species present include representatives of the lotic (flowing water) guild and longitudinal mainstem migrants such as the cyprinid *Labeo* (especially *Labeo ulangensis*, but also *L. cylindricus*), the large barbel *Barbus macrolepis*, and the tiger fish *Hydrocynus vittatus*, as well as *Alestes, Distochodus*, *Citharinus*, and *Mormyrus.* Several of the long and short distance longitudinal migrants also migrate laterally between the main channel and floodplain. Species dependent on flows for lateral spawning and rearing migrations into floodplain habitats include the catfish *Clarias,* squeaker catfish *Synodontis*, the smaller characin species (e.g., *Brycinus affinis*), and the schilbeid catfish, *Schilbe moebiusii.* The catadromous guild found in the river-floodplain reaches includes *Anguilla mossambica* and *Anguilla bengalensis labiata* (Anguillidae; Mkunga). While various species, including the long-distance river migrants *Labeo* and the tiger fish, bagrids, mormyrids, tilapia, and *Barbus* spp. were present in the Lwipa River, the fact that a few of the commonest species were not encountered (e.g., *Alestes*, *Citharinus*) suggests some change from natural conditions.

Fishing was reported as the second most important economic activity. Traditionally, fishing has been the primary natural resource use in the Kilombero Valley, with 23 to 27 fish species regularly caught, from across the five fish guilds. The annual fish harvest is highly significant for livelihoods and the local economy. It ranges between an estimated 9,500 and 12,000 tons, caught by 5,000 to 10,000 full-time fishers and 15,000 to 25,000 part-time fishers (**Annex L**; Kilombero Valley Ramsar Site Project 2009; KPL 2014). During the peak fishing season (the high flow period, April-May), dominant fish species in the catch include *Bagrus* (Kitoga), *Clarias* (Kambale), *Distichodus* (Ndungu), *Oreochromis* (tilapia, Perege), *Hydrocynus* (tiger fish, Njege), *Citharinus* (Mbala), *Schilbe* (Bula), and *Synodontis* (Ngogo) (information from fisher interviews).

In the Lwipa River, the consumption of fish for subsistence is extremely important to the entire community (100 percent of respondents surveyed), with the majority of fish species inhabiting the Kilombero valley reaches caught at this site. Fishing also contributes 87 percent of household revenue for the fishing communities in the reach. Fish as a basic food supply are similarly extremely important in the Udagaji River (also 100 percent of respondents) and Mpanga River (93 percent of respondents). In the Kilombero River-floodplain reaches, food fish remain a vital provisioning service for around 97 percent of the community (Site 5).

Water for domestic use is an important flow-dependent factor for people at every site, both in availability and quality. In the Lwipa River, close to 90 percent of the community depends on shallow wells and boreholes within the floodplain for their domestic water supply, with the surface water-groundwater interaction that occurs due to the high water table being an important water quality and flow-related consideration. In the Kilombero River, floodplain groundwater sources for domestic use are highly important at Ifwema (95 percent) and Ifakara Ferry (81 percent). In the Mpanga and Udagaji rivers, very high proportions of the communities (97 and 95 percent, respectively) directly depend on river water for their domestic water supply.

In general, communities in the Kilombero study area are involved in crop cultivation (93 percent in the vicinity of the Udagaji River up to 100 percent in the Kilombero Ifwema reach), growing mainly rice and maize. Other crops include sesame, banana, and sunflower. Flood recession agriculture is also widely practiced, with nutrient-rich flood sediments highly valued. We found that over 75 percent of households across the sites depended on wild (natural) harvested vegetables and fruits for food (not sale) while cultivated vegetables and fruits contributed financially to the household economy. Livestock grazing, recreation, and control of waterborne diseases (e.g., malaria, bilharzia) are some of the many additional valued benefits of the natural resource base.

4.6 Environmental and Social Objectives for Environmental Flow Setting

On the basis of the above findings, an EMC was assigned to each site for each component, summarizing the overall management objective or desired future state for the site, from A (natural) to D (largely modified); there were no instances where the EMC needed to reflect flow restoration from a lower (E or F) PES category. While the PES classes portray the condition or health of the respective river (and its components), the corresponding EMC classes lay the basis for describing the flow-related and other objectives that have to be achieved for future river maintenance to meet ecological and social needs.

The general flow objective for all the Kilombero sites is “Maintenance of the full range of flows presently in the river.” A full range of flows and their intra- and inter-annual variability is important to ensure availability and connectivity of aquatic habitats. It is important in understanding how fish species’ life cycles are cued to flow events and physical habitat. The various flows trigger plant biological clocks and germination through removal of litter, increase the seed bank in soils, reduce competitive exclusion, and promote seed dispersal. Aquatic invertebrate assemblages are also very sensitive to temperature, water chemistry, and flow regime interrelationships such that they are often used as indicators of the water quality and the general river health (as in this study). Fish, macroinvertebrates, and riparian and instream vegetation are used as primary biotic indicators of flow requirements. These indicators include highly sensitive species that reflect suitable water quality, hydraulic (physical) habitat, and flow levels. Geomorphological processes are also considered because they play an important role in determining the structure and functioning of riverine ecosystems, from determining the quality and availability of physical habitat, to maintaining channel form and transporting sediments through the system. For further explanation of various roles of flow in the ecosystem, see Section 3.1.3.

Annex O summarizes the flow-related objectives set and supporting rationale for the ecological, geomorphological, and social components of the river system for each site. Flow-related objectives were not established in the same way for water quality as they were for other components (see **Annex J** for explanation). The basis of the objectives hierarchies for each component is explained in **Annex D** and laid out in **Annex G** through **Annex N**.

4.7 Environmental Flow Recommendations for Kilombero River-Floodplain and Tributary Sites for Target Scenario

The environmental flow recommendations for each of the five river reaches are summarized in a series of EFA tables for both maintenance and drought year conditions, with corresponding graphs showing the overall environmental flow regimes proposed, contrasted with present-day average flow conditions. Note that the present-day average flow regimes in drought years are indicative only due to the limited number of very dry years of observed flows available and a limited level of clarity about the hydrological definition of drought based on gauged time series.

Ecological and social motivations for the low flow and high flow events recommended are summarized for each flow component below; **Annex P** provides the full set of reasons provided by the specialists. The confidence that specialists had in each set of component-specific reasons behind each flow event they recommended are also given (see also Section 4.8). **Annex P** further summarizes the potential consequences to the river reach of not providing each of the recommended flows. This sets the stage for implementation stage monitoring of the outcomes of environmental flow provision in each reach.

4.7.1 Environmental Flow Recommendations for Udagaji River (Site 2)

The environmental flow recommendations for the Udagaji River, as a representative piedmont spawning reach of the Kilombero system, are summarized in **Table 4.5** for both maintenance and drought year conditions, with the proposed environmental flow regimes for typical maintenance and drought situations presented in **Figure 4.12**. Supporting motivations for all ecological and social components are detailed in **Annex P** and summarized here.

> In maintenance (normal) years, the dry season low flow recommendation (October, 0.50 $m^3 s^{-1}$) was aimed at maintaining acceptable water quality conditions (i.e., low water temperatures, dissolved oxygen (DO), and nutrients from entrained organic detritus) for sensitive fish, invertebrates (e.g., Potamonautid shredders), and floating macrophytes (notably, the indicator species, *Vossia cuspidata*). It will allow vegetative reproduction and development of the grasses, ferns, and sedges assemblage (e.g., *Phragmites mauritianus, Penissetum purpureum, Cyperus cyperoides, C. involucratus*, *Pteridium aquilinum*) along the channel and banks, which is important as fish habitat and to sustain mosses. This discharge retains 90 percent of the diverse hydraulic habitat (mean weighted usable area [WUA]) to support the flow sensitive riffle fish, stoneflies, and caddisflies characteristic of this piedmont/spawning reach and to allow fish passage. It will provide nutrients and food in the drift for riffle fish, such as *Chiloglanis, Amphilius,* and *Parakneria*, and pool dwelling juveniles (e.g., *Barbus*, and mormyrids). It will also ensure fine sediment transport through the reach. The low flow needs of the community for a sufficiently good quality domestic water supply, natural vegetables and fruits, dry season farming, health, and other livelihood activities (e.g., recreation) will be met.
>
> In addition to several of the same motivations (e.g., for fish and invertebrate in-channel habitat), wet season low flows would facilitate plant reproduction and development, including indigenous riparian trees (e.g., *V. africana*, *F. exasperata*), flush out plant litter, and open up new grass/sedge habitats. Greater connectivity between aquatic, riparian, and floodplain ecosystems would promote the movement of seeds and plant propagules. It would ensure fish passage over obstacles for long distance migrants, including adult *Labeo,* which use this site as a breeding and nursery area. Cover and food availability for fish fry and juveniles and inputs of leaves for invertebrate shredders would also be important benefits. Community dependencies on crop farming (e.g., rice, maize) and fishing for food would be supported by maintaining these wet season low flows.
>
> A series of high flow pulses in October to December will maintain suitable water quality for human and ecological needs and wet the fields ready for

planting. The freshes will break the physiologically stressful dry season period for plants, provide germination cues for annuals and riverine woody species (e.g., *Voacanga africana, Lethowianthus stellatus*), and flush out grass stands. They will stimulate the growth and development of seedlings of annuals and perennial species. The maintenance of beaches and sand bars through sand and clay inputs will enhance habitat indicator trees (e.g., *F. exasperata* and *V. africana*). Removal of organic matter and fine sediment will maintain river channel substrates and water quality conditions important for fish and invertebrates and increase available habitat. These high flow pulses will also trigger longitudinal migrators for spawning (e.g., *Labeo, Barbus macrolepis)* and ensure habitat connectivity for their passage.

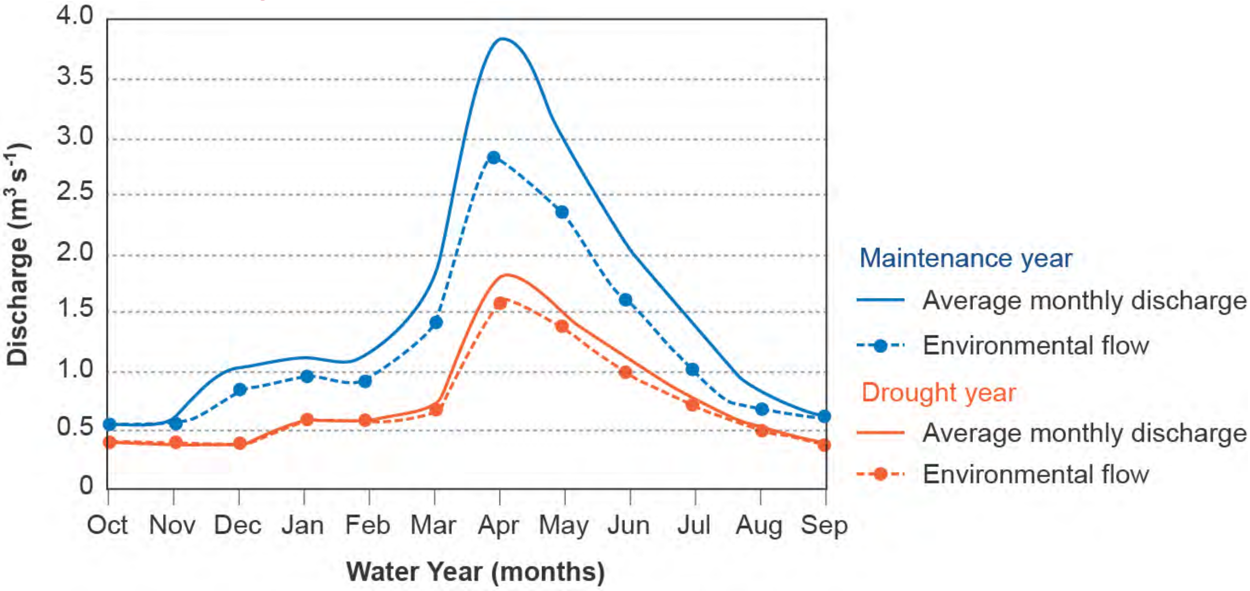
Two larger flood events in the wet season months of March and April, of a week's duration and 1-in-2 year return period, have several roles additional to those provided by smaller intra-annual floods. The inundation of higher parts of the banks opens up habitat for riparian species like *Lethowianthus stellatus.* The floods provide food for adult fish maturation. They also ensure highly productive habitats as nursery areas for fry and juveniles and for invertebrates (e.g., entraining organic matter accumulated in higher bank areas as food sources). They provide maximum connectivity of habitats for longitudinal movements and migration of fish. The floods would inundate ponds used for fish migration and breeding by important food species for people as well as recharge groundwater. Water oxygenation and nutrient levels (organic matter from riparian forest) would be maintained. Livelihood dependencies associated with flood-linked agriculture would be supported through the inundation of rice fields, provision of soil moisture to maize fields on higher ground and nutrient rich sediments (as fertilizer), and replenishment of livestock grazing areas.

Specific ecological and social motivations to support environmental flow recommendations for low flow and high flow events under drought conditions are given in **Annex P**. In addition to reduced low flows in both dry and wet seasons, smaller pulses in high flow at the onset of the short rains were reduced from three to only one event of similar magnitude and duration. A single, smaller magnitude and shorter duration large flood was recommended, but with a greater frequently of occurrence than under maintenance conditions.

Table 4.5: Environmental Flow Recommendations for Udagaji River (Site 2) for Target Scenario

Year	Index	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Annual
Maintenance	Average	0.5	0.6	1.0	1.1	1.1	1.8	3.8	3.0	2.1	1.4	0.8	0.6	1.5
	Monthly low flows													
	Magnitude (m^3/s)	0.50	0.57	0.85	0.92	0.92	1.41	2.80	1.62	1.62	1.13	0.71	0.57	
	Magnitude (Mm^3)	1.34	1.48	2.27	2.46	2.22	3.77	7.26	4.33	4.19	3.02	1.90	1.48	35.70
	% Average flow	100%	95%	85%	83%	83%	78%	74%	54%	77%	81%	89%	95%	
	% MAF	2.5%	2.8%	4.3%	4.7%	4.2%	7.1%	13.7%	8.2%	7.9%	5.7%	3.6%	2.8%	67.6%
	FDC % (individual month)	84%	61%	48%	63%	65%	68%	84%	95%	71%	61%	81%	84%	
	Flood pulses													
	Magnitude (m^3/s)	1.3	1.3	1.6			7.2	7.2						
	Magnitude (Mm^3)	0.34	0.45	0.69			4.35	4.35						10.19
	Duration (days)	3.00	4.00	5.00			7.00	7.00						
	% MAF	0.6%	0.9%	1.3%			8.2%	8.2%						19.3%
	Return period (years)	< year	< year	< year			2 yrs	2 yrs						
	Total	Mm^3												45.89
		% MAF												86.9%
Drought	Average	0.4	0.4	0.4	0.6	0.6	0.8	1.8	1.4	1	0.7	0.5	0.4	0.7
	Monthly low flows													
	Magnitude (m^3/s)	0.40	0.40	0.40	0.57	0.57	0.74	1.60	1.26	0.91	0.66	0.49	0.40	
	Magnitude (Mm^3)	1.07	1.04	1.07	1.53	1.38	1.99	4.15	3.37	2.37	1.76	1.30	1.04	22.06
	% Drought flow	100%	100%	100%	95%	95%	93%	89%	90%	91%	94%	97%	100%	
	% MAF	2.0%	2.0%	2.0%	2.9%	2.6%	3.8%	7.9%	6.4%	4.5%	3.3%	2.5%	2.0%	41.8%
	FDC % (individual month)	97%	94%	90%	87%	81%	97%	97%	106%	97%	103%	106%	100%	
	Flood pulses													
	Magnitude (m^3/s)			1.3				5.76						
	Magnitude (Mm^3)			0.34				1.99						2.33
	Duration (days)			3.00				4.00						
	% MAF			0.6%				3.8%						4.4%
	Return period (years)			< year				1.5 yrs						
	Total	Mm^3												24.39
		% MAF												46.2%

Figure 4.12: Recommended Environmental Flows for Udagaji River in Maintenance and Drought Years



4.7.2 Environmental Flow Recommendations for the Transition Zone: Lwipa River (Site 1) and Mpanga River (Site 3)

The environmental flow recommendations for the Lwipa River are summarized in **Table 4.6** for maintenance and drought years, with the corresponding environmental flow regimes presented in **Figure 4.13**. Similarly, the environmental flow recommendations for the Mpanga River are summarized in **Table 4.7** and **Figure 4.14**. While both these transition zone river-floodplain sites were assigned the same EMC, their present ecological and social status differ somewhat. For instance, the Mpanga River has less altered invertebrate communities and social conditions from natural, and the Lwipa River has a healthier, more intact riparian zone.

For the Lwipa River, in typical years, the recommended dry season flows (October) will help maintain sufficiently good water quality (including low water temperatures, DO levels) for the growth of emergent and floating plant species, fish inhabiting pools, and domestic water supply and livestock watering. It should also replenish groundwater supplies. This magnitude of low flow provides enough moisture for vegetative reproduction and development, including moist soils to sustain wild vegetables and fruits. It will retain physical habitat quality and quantity (WUA) at not less than 80 percent for sensitive fish (*Labeo*, *Hydrocynus*, large *Barbus* spp.) and macroinvertebrate families.

The recommended wet season low flow, in addition to the above functions, will facilitate the movement of adults and propagules of indicator macrophytes (e.g., *Vossia cuspidata*) for wider dispersal and colonization. It will support grasses (e.g., *Paspalum scrobiculatum)* and woody plant species (e.g., *Ficus exasperata),* which act as invertebrate refugia, and inundate areas of macrophytes and emergent vegetation along banks to increase habitat diversity. This elevated discharge removes dead matter from stands of grasses and supplies fresh nutrient-rich debris for the growth of *Phragmites* and other plants. It also supplies the moisture needed to establish natural vegetables such as *Barleria submollis* and *Sesbania sesban.* The discharge is expected to provide cues and longitudinal connectivity for fish migration and spawning (e.g., *Labeo*, *Hydrocynus)* and a trigger for in-channel and floodplain spawning fishes (e.g., *Brycinus imberi*, *Petrocephalus catostoma*). It will displace dominant invertebrate competitors and allow drift of species into newly created habitats. Wet season low flows will fill main channel, swamps, oxbow lakes, and ponds important for the reproduction of valuable fishery species; provide more water to the floodplain for rice farming and recession agriculture; and replenish domestic groundwater.

Two 3-day high flow pulses, in November and December, will improve DO concentrations to levels suitable for instream biota. They will have multiple functions for vegetation, from breaking stress as plants come out of the dry season to removing litter to increase soil seed bank and understory light within the channel and floodplain, scouring grass stands and sediments and facilitating germination of plants on beaches and sand bars. They will also inundate fields ready for planting. The high flow pulses (including a further pulse in June) should also maintain macro channel features and provide habitat diversity. For fish, they play critical roles in stimulating hormonal change and gonad development in flow sensitive obligate floodplain spawners and longitudinal migrators. Such events stimulate macroinvertebrate community turnover and recruitment.

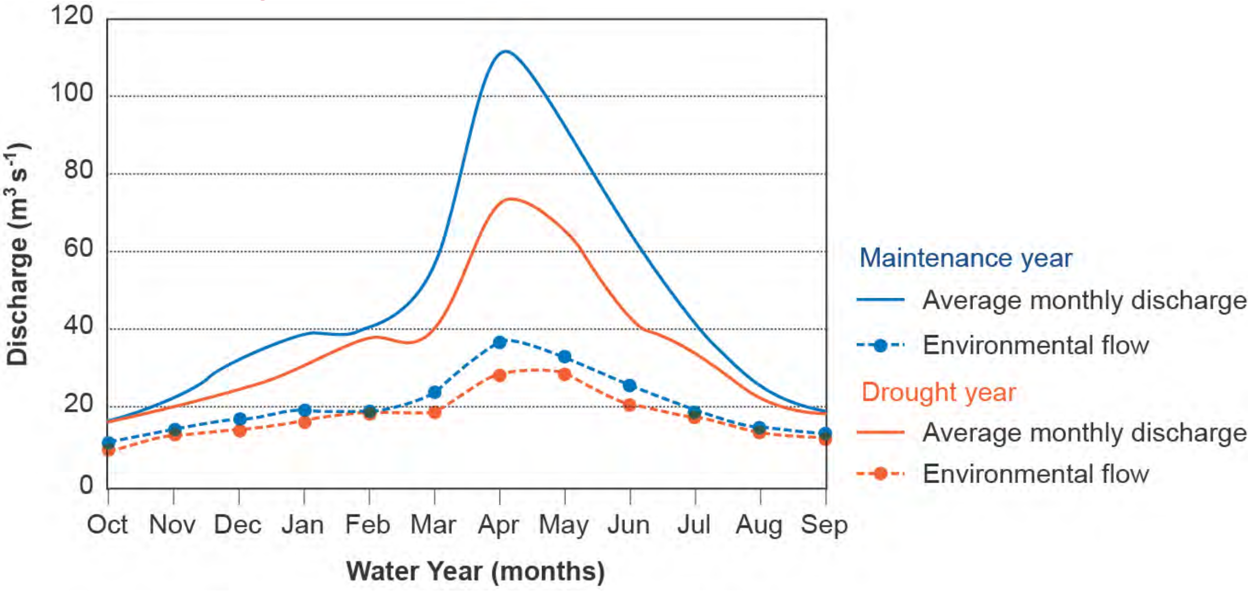
Larger magnitude high flow events, including the largest, the April flood, additionally inundate higher parts of the banks and floodplain to provide more habitats for riparian plant species and distinct communities (e.g., *Voacanga-Ficus-Acacia*). They promote connectivity of aquatic, riparian, and floodplain habitats and plant dispersal. They also enhance floodplain soil physical and chemical characteristics, replenishing soil moisture and fertility for flood recession agriculture and cultivated vegetables, inundate rice fields, and recharge groundwater over a large floodplain area. These large annual floods ensure the highest floodplain ecosystem productivity for fish populations (and invertebrates) as well as food sources for adult maturation and nursery areas for fry and juveniles. They maximize connectivity for longitudinal and transverse movements and migration of fish. The flood events replenish ponds and oxbow lakes for fishing and provide a navigation network to transport people and goods to markets.

Motivations for specified flow events under drought conditions in the Lwipa River are given in **Annex P**. In addition to a reduction in low flow magnitudes in both dry and wet seasons, the number of high flow events was markedly reduced. While no smaller pulses in high flow were proposed during drought conditions, the two annual floods of March and April were retained, albeit at shorter durations. Ecological and social reasons for maintaining these floods are provided in **Annex P**.

Table 4.6: Environmental Flow Recommendations for Lwipa River (Site 1) for Target Scenario

Year	Index	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Annual
Maintenance	Average	16.50	22.80	32.90	39.30	41.00	56.70	110.50	93.00	66.80	43.20	26.00	19.40	47.3
	Monthly low flows													
	Magnitude (m^3/s)	11.50	14.55	17.28	19.01	19.47	23.71	36.90	33.52	26.44	20.07	15.42	13.63	
	Magnitude (Mm^3)	30.80	37.72	46.29	50.92	47.10	63.51	95.64	89.79	68.54	53.74	41.30	35.34	660.71
	% Average flow	70%	64%	53%	48%	47%	42%	33%	36%	40%	46%	59%	70%	
	% MAF	2.4%	2.9%	3.5%	3.9%	3.6%	4.9%	7.3%	6.9%	5.3%	4.1%	3.2%	2.7%	50.6%
	FDC % (individual month)	94%	65%	65%	77%	74%	94%	110%	106%	94%	94%	103%	100%	
	Flood pulses													
	Magnitude (m^3/s)		40	45			68	115		40				
	Magnitude (Mm^3)		10.37	11.66			23.50	39.74		24.19				109.47
	Duration (days)		3.00	3.00			4.00	4.00		7.00				
	% MAF		0.8%	0.9%			1.8%	3.1%		1.8%				8.4%
	Return period (years)		< year	< year			< year	1		< year				
	Total	Mm^3												770.18
		% MAF												59.0%
Drought	Average	16.3	20.1	24.7	30.4	37.9	39.8	71.5	65.1	43.4	34.5	23	18.5	35.5
	Monthly low flows													
	Magnitude (m^3/s)	9.90	13.34	14.89	16.81	19.33	19.98	28.50	28.50	21.19	18.19	14.31	12.80	
	Magnitude (Mm^3)	26.52	34.57	39.87	45.02	46.77	53.50	73.87	76.33	54.92	48.72	38.34	33.17	571.61
	% Drought flow	61%	66%	60%	55%	51%	50%	40%	44%	49%	53%	62%	69%	
	% MAF	2.0%	2.6%	3.1%	3.4%	3.6%	4.1%	5.7%	5.8%	4.2%	3.7%	2.9%	2.5%	43.8%
	FDC % (individual month)	97%	68%	74%	84%	76%	95%	106%	123%	97%	97%	97%	110%	
	Flood pulses													
	Magnitude (m^3/s)						46.7	89.6						
	Magnitude (Mm^3)						7.78	7.78						15.55
	Duration (days)						3.00	3.00						
	% MAF						0.6%	0.6%						1.2%
	Return period (years)						< year	< year						
	Total	Mm^3												587.16
		% MAF												45.0%

Figure 4.13: Recommended Environmental Flows for Lwipa River in Maintenance and Drought Years



For the Mpanga River in maintenance years, the recommended dry season flows will help maintain water quality (including temperature, DO, and nutrient and organic carbon concentrations) at an acceptable level for people and biota (e.g., *Vossia cuspidata*), minimizing any detrimental effects of agrochemical pollutants accumulating in the system during the short rains. They will ensure sufficient moisture for vegetative reproduction and development, including for riparian trees such as *Acacia xanthophloea* and *Ficus exasperata*, and for wild vegetables and fruits important to people. Instream hydraulic habitat will remain suitable for all fish and benthic macroinvertebrates. Hydrological connectivity will enable the drift of nutrients and food for fish (e.g., *Brycinus*, *Bagrus*, *Labeo*, and *Anguilla*). The flow levels will be sufficient to sustain livelihood activities (e.g., fishing, dry season farming) and domestic groundwater supply.

The recommended wet season low flow (April, 44 $m^3 s^{-1}$) will facilitate the dispersal and colonization of macrophyte and other plant adults and propagules, and provide moisture for the growth and reproduction of plants such as *Paspalum scrobiculatum* and *Acacia xanthophloea*, and socially important wild vegetables/fruits. It will help clear decayed plant matter from marginal grass stands, supply fresh detritus for Phragmites growth, and increase understory light by removing leaf litter (thereby enhancing recruitment processes). The inundation of different vegetation zones will provide high habitat diversity for both fish and invertebrates. These wet season flows will contribute to increased longitudinal and lateral river-floodplain connectivity (e.g. for navigation by canoes) and cues for fish migration and spawning (e.g., *Labeo*, *Brycinus imberi*, and limnophilic species), as well as filling channels, swamps, oxbow lakes and ponds, thereby enhancing fish reproduction. The replenishment of groundwater supplies for domestic use and of floodplain soil moisture for rice farming and recession agriculture will occur.

A series of within-year higher flow events in the Mpanga River from January onwards will additionally act as cues for plant germination and maintain the development of seedlings and saplings of various plant species. They will also inundate agricultural fields important for crop cultivation. Beaches and sand bars, which are important substrates for plants (such as the indicator *Ficus exasperata*) will be maintained, as will key macro channel features and habitats. These flushing flow events will clean the river substratum of accumulated organic matter and fine sediments, improving habitat conditions for invertebrates and fish. These flow events will lower water temperatures and stimulate the reproductive cycles of sensitive fish species (e.g., *Hydrocynus*, *Labeo*, *Barbus macrolepis*). They will also benefit recruitment of sensitive invertebrate taxa.

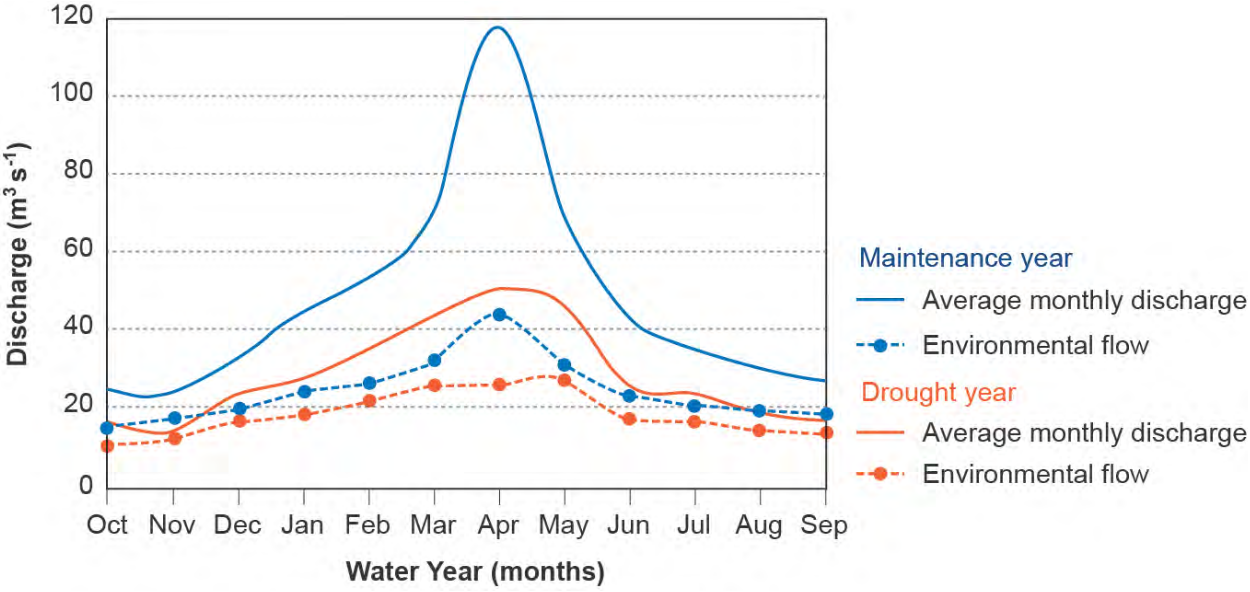
Longer-duration (7 days), larger magnitude floods in the peak of the wet season, including the 1:3 year return period large flood, were recommended to inundate higher parts of banks and floodplains to increase the connectivity and availability of aquatic, riparian and floodplain habitats (including oxbow lakes, swamps and ponds), as well as improve the movements and dispersal of plant seeds and other propagules. These floods provide extensive, productive nursery areas for fish fry and juveniles spawned during the short rains, and maximal connectivity of habitats for the longitudinal and transverse movements and migration of fish, helping ensure breeding success for obligate longitudinal migrators and obligate floodplain spawners. As it inundates a vast area of the local floodplain, the April (251.0 $m^3 s^{-1}$) flood stimulates the maximum productivity of the ecosystem, including invertebrate and fish production (and other food sources essential for the maturation of adults of species important to the local fishery). These flood events will improve floodplain soil's physical and chemical characteristics, which in turn will enhance growth and reproduction. The large flood is particularly important for replenishment of floodplain ground water resources, inundation of rice farms and replenishment of soil moisture and fertility for flood recession agriculture and vegetable cultivation.

Environmental flows for drought years in the Mpanga reach included low flow magnitudes during both wet and dry seasons that were reduced from those of maintenance years. Likewise, while a similar number and timing of high flow events was recommended, they were of reduced magnitude in all instances (see **Annex P**, which also provides the corresponding social and ecological motivations for these flows).

Table 4.7: Environmental Flow Recommendations for Mpanga River (Site 3) for Target Scenario

Year	Index	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Annual
Maintenance	Average	24.5	24.2	32.7	45.4	54.1	71.0	117.4	69.0	43.9	35.3	30.5	27.2	47.9
	Monthly low flows													
	Magnitude (m^3/s)	15.00	17.88	20.52	24.51	27.20	32.49	44.00	31.85	24.02	21.33	19.83	18.82	
	Magnitude (Mm^3)	40.18	46.33	54.96	65.64	65.81	87.01	114.05	85.30	62.25	57.12	53.10	48.78	780.53
	% Average flow	61%	74%	63%	54%	50%	46%	37%	46%	55%	60%	65%	69%	
	% MAF	3.0%	3.4%	4.0%	4.8%	4.8%	6.4%	8.4%	6.3%	4.6%	4.2%	3.9%	3.6%	57.4%
	FDC % (individual month)	91%	63%	81%	84%	97%	94%	100%	97%	91%	94%	84%	75%	
	Flood pulses													
	Magnitude (m^3/s)				60	60	79	251						
	Magnitude (Mm^3)				15.55	15.55	47.78	151.80						230.69
	Duration (days)				3	3	7	7						
	% MAF				1.1%	1.1%	3.5%	11.2%						17.0%
	Return period (years)				< year	< year	< year	3						
	Total	Mm^3												1,011.22
		% MAF												74.3%
Drought	Average	16.1	14.2	23.3	27.2	34.5	43.0	49.7	46.3	25.4	23.2	19.0	16.8	28.2
	Monthly low flows													
	Magnitude (m^3/s)	11.00	12.43	16.49	18.26	21.51	25.28	26.00	26.78	17.42	16.43	14.55	13.60	
	Magnitude (Mm^3)	29.46	32.21	44.16	48.91	52.04	67.71	67.39	71.73	45.15	44.02	38.98	35.25	577.01
	% Drought flow	68%	88%	71%	67%	62%	59%	52%	58%	69%	71%	77%	81%	
	% MAF	2.2%	2.4%	3.2%	3.6%	3.8%	5.0%	5.0%	5.3%	3.3%	3.2%	2.9%	2.6%	42.4%
	FDC % (individual month)	97%	94%	91%	91%	116%	125%	156%	119%	106%	103%	100%	103%	
	Flood pulses													
	Magnitude (m^3/s)			30	30		44	80						
	Magnitude (Mm^3)			7.78	7.78		11.40	34.56						61.52
	Duration (days)			3	3		3	5						
	% MAF			0.6%	0.6%		0.8%	2.5%						4.5%
	Return period (years)			< year	< year		< year	< year						
	Total	Mm^3												638.53
		% MAF												46.9%

Figure 4.14: Recommended Environmental Flows for Mpanga River in Maintenance and Drought Years



4.7.3 Environmental Flow Recommendations for Kilombero River-Floodplain: Upper Reach at Ifwema (Site 4) and Downstream Lower Reach at Ifakara Ferry (Site 5)

The environmental flow recommendations for the Kilombero River at Ifwema are summarized in **Table 4.8** for maintenance and drought years. The corresponding environmental flow regimes are shown in **Figure 4.15**. For the Kilombero River at Ifakara Ferry, the environmental flow recommendations are presented in **Table 4.9** and **Figure 4.16**.

The supporting ecological and social recommendations for low flow and high flow events under maintenance conditions for the lower river-floodplain sections of the Kilombero (Sites 4 and 5) are detailed in **Annex P**.

For Site 4 on the Kilombero, the recommended dry season low flows (October, 73.0 $m^3 s^{-1}$) will maintain suitable water quality (temperature, DO, organic matter, nutrients, ammonia), including for the growth of hippo grass and aquatic plants. Many of these, such as the macrophyte, *Vossia cuspidata*, are important habitats for juvenile and adult fishes, as well as food for hippopotamuses. Water levels will also support the growth and reproduction of riparian vegetation, grasses, sedges, and other flora. These low flows maintain habitat quantity and quality for fish and macroinvertebrates, including 80% of the mean WUA for sensitive species. They provide nutrients and food to support pool and upstream spawning migratory fish species (e.g., *Bagrus, Labeo)* and maintain the hydrological connectivity that enables the latter guild to access breeding sites. The flows will sustain fishing, and provide the moisture needed for dry season cultivation, pasture for livestock, and wild vegetables and fruits. The flow levels will allow navigation along and across the river for community access to local markets and hospitals.

The more sizeable wet season low flows, in addition to some of the above roles, will also facilitate the dispersal and colonization of seeds and macrophyte propagules, remove decayed organic matter from stands of grasses and supply fresh materials for *Phragmites* growth, and support the moisture levels needed for establishment and development of indicator grasses and sedges (which are also refuge habitats for fish and macroinvertebrates), and important wild vegetables for people. A greater number and diversity of habitats needed for both fish and macroinvertebrate assemblages will be available, including large areas of macrophytes and emergent vegetation along riverbanks. In addition to cues and connectivity for fish longitudinal migration and spawning, these flows will allow some limnophilic fish species to migrate and recolonize floodplain habitats. Successful invertebrate recruitment and restructuring of assemblage composition will occur (e.g., displacement of dominant oligochaetes, chironomids). For communities on the floodplain, the wet season low flows will help replenish aquifers for domestic supply, inundate rice farms and replenish soil moisture and fertility. They will fill floodplain oxbow lakes and ponds and connect them to the main river, facilitating fish capture.

The two 3-day high flow pulses (November to December) will perform important flushing functions for substratum quality (removal of organic matter and fine sediments) and vegetation particularly, and break the dry season stress of plants on the floodplain. These within-year high flows provide cues for the germination of annual seed plants on river beaches and along the banks. They support the growth and colonization of aquatic plants, and marginal and floodplain grasses and sedges. They also maintain beaches and sand bars through sediment inputs, which enhances the habitats of indicator species such as *Phragmites mauritianus*. Water temperatures in the river channel will be lowered to the levels required for the life cycles of fish (and invertebrate) communities, thereby initiating hormonal changes and gonad development in sensitive fishes (*Hydrocynus, Labeo, Barbus macrolepis*). For fishes, these high flow pulses will ensure the availability of suitable habitat for and breeding success of obligate floodplain spawners, and enable the migration of obligate longitudinal migrators. They will similarly support the population dynamics and recruitment success of macroinvertebrates. The flows will provide water, sediments and nutrients to farms and floodplain areas, for the crops and wild vegetables on which communities depend.

The large 7-day flood, with recurrence interval 1 in every 2 years, has multiple functions for this river-floodplain reach (as well as several of those performed by the smaller floods). These functions include large-scale inundation of the banks and floodplain, promoting the establishment and increased abundance and richness of plants, including species that supply people with wild fruits and vegetables. This flood will ensure habitat turnover and the removal of large objects (e.g. tree debris, stones) from the floodplain, to provide further habitats for plant species establishment. It will improve the physical and chemical characteristics of floodplain soils, for natural vegetation, livestock pastures, and cultivated crops. It will increase soil moisture content and deposit fertilizing nutrient-rich sediments on rice farms and on maize farms located at higher ground. Groundwater recharge for domestic water supply will also be achieved. The flood will maintain channel-floodplain morphology, and mobilize, rework and move sediment suspended and bed loads through the system. For fish, this flood inundate ponds and oxbow lakes and ensures maximal connectivity of habitats for longitudinal and transverse passage and migration. Sensitive species need this event to migrate and reproduce, and it ensures the habitat suitability (quantity and quality) and breeding success for obligate floodplain spawners. It also provides nursery habitat for fry and juveniles spawned during the short rains hydro-period, and maximizes invertebrate and fish productivity.

For the reach of the Kilombero river-floodplain represented by Site 5 (Ifakara Ferry), the environmental flow recommendations for low flows for the dry season (**Table 4.9** and **Annex P**) focused on a similar set of motivations to those of the upper reaches of the river-floodplain (see Site 4 Ifwema discussion above) - from improved physical habitat conditions for instream biota, to good water quality, including the lower water temperatures needed to initiate spawning by those fish species which are early spawners. For local communities, the flows will be sufficient to meet their needs for, among others, food fish availability, dry season cultivation, and the maintenance of wild riparian and floodplain vegetables and fruits.

Similarly, wet season low flows will maintain suitable water quality (e.g., low temperatures, high DO), despite increased inputs of pollutants, such as agrochemicals, organic matter, and pathogens, from the local catchment. For vegetation, the elevated low flows during the wet season will, among other functions, trigger the flowering and reproduction of adult aquatic macrophytes, flush out leaf litter and detritus, and open up gaps and new habitats for the establishment and development of floodplain plant species. Habitat diversity for fish and invertebrates, including for ecologically important bivalves and their fish hosts, will be increased through inundation of large areas of lower and middle bank aquatic vegetation and edge habitats. Cues and connectivity for the longitudinal migration and spawning of *Labeo* and *Hydrocynus* will be provided. In addition, some limnophilic fishes will be able to migrate to and recolonize floodplain habitats. These flows will meet the habitat requirements for *Macrobrachium* spp., which require downstream longitudinal connectivity to the estuary for spawning, as well as for other flow-sensitive macroinvertebrate taxa. For communities, these flow levels will replenish aquifers for domestic water supplies; fill the important biophysical features (i.e., ponds, oxbow lakes and seasonal rivers) that connect to the main channel to ensure fish availability; inundate rice farms and replenish floodplain soil moisture and fertility; sustain wild vegetable and fruit species; and maintain flows for navigation by local river ferry and canoes.

Given the marked similarities between the two Kilombero river-floodplain reaches, the only high flow event recommended at Site 5, a large 1:5-year return period flood over 7 days, at the peak of the wet season, will achieve many of the benefits described above for the large flood event proposed for the Ifwema site. It will, for example, inundate higher parts of the banks and floodplains to suppress non-floodplain species (preventing terrestrialization) and extend lateral connectivity to the outer edges of the floodplain inhabited by partially flow-dependent tree species. The flood will mobilize large seeds within the floodplain and riparian zones. The inundation and recharge of a large area of the floodplain will increase shallow groundwater levels, leading to an increased plant abundance and richness. Benefits for fish and invertebrates will be similar to those at Site 4, and will include the enhanced connectivity needed for different fish species' life cycles, and drift of aquatic invertebrate species into new, high-quality habitats. The benefits to people and livelihoods will be complement those at other times of the wet season, but at a greater scale of benefit.

Table 4.8: Environmental Flow Recommendations for Kilombero River at Ifwema (Site 4) for Target Scenario

Year	Index		Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Annual
Maintenance	Average		94.9	94.7	148.1	223.4	264.7	321.0	406.2	326.9	199.8	166.7	144.6	110.0	208.4
	Monthly low flows														
	Magnitude (m^3/s)		73.0	89.4	129.7	186.5	217.8	260.2	308.0	264.7	168.7	143.7	127.1	101.0	
	Magnitude (Mm^3)		195.5	231.6	347.4	499.6	526.9	697.0	798.3	709.0	437.3	384.9	340.3	261.7	5,429.6
	% Average flow		77%	94%	88%	84%	82%	81%	76%	81%	84%	86%	88%	92%	
	% MAF		3.0%	3.5%	5.3%	7.6%	8.0%	10.6%	12.1%	10.7%	6.6%	5.8%	5.2%	4.0%	82.3%
	FDC % (individual month)		82%	43%	75%	76%	76%	83%	97%	83%	72%	76%	48%	48%	
	Flood pulses														
	Magnitude (m^3/s)			150.0	109.5			525.0	861.0						
	Magnitude (Mm^3)			38.9	28.4			317.5	520.7						905.5
	Duration (days)			3	3			7	7						
	% MAF			0.6%	0.4%			4.8%	7.9%						13.7%
	Return period (years)			< year	< year				2 yrs						
	Total	Mm^3													6,335.2
		% MAF													96.0%
Drought	Average		79.3	76.7	120.3	178.5	210.9	276.9	327.2	245.7	160.7	134.2	106.9	91.1	167.4
	Monthly low flows														
	Magnitude (m^3/s)		62.0	75.5	115.6	169.1	198.9	259.6	290.0	230.9	152.8	128.4	103.3	88.8	
	Magnitude (Mm^3)		166.1	195.8	309.7	453.0	481.2	695.3	751.7	618.6	396.1	343.9	276.6	230.1	4,917.8
	% Drought flow		78%	98%	96%	95%	94%	94%	89%	94%	95%	96%	97%	97%	
	% MAF		2.5%	3.0%	4.7%	6.9%	7.3%	10.5%	11.4%	9.4%	6.0%	5.2%	4.2%	3.5%	74.6%
	FDC % (indiv month)		86%	82%	89%	86%	83%	83%	121%	90%	83%	79%	86%	86%	
	Flood pulses														
	Magnitude (m^3/s)					80			400						
	Magnitude (Mm^3)					20.7			241.9						262.7
	Duration (days)					3			7						
	% MAF					0.3%			3.7%						4.4%
	Return period (years)					< year			1.5 yrs						
	Total	Mm^3													5,180.5
		% MAF													79.0%

Note: The original maintenance year April low flow recommendation of 438 $m^3 s^{-1}$ was reduced to 308 $m^3 s^{-1}$ during the post-workshop hydrological extrapolation process to reflect availability in the record.

Figure 4.15: Recommended Environmental Flows for Kilombero River at Ifwema in Maintenance and Drought Years

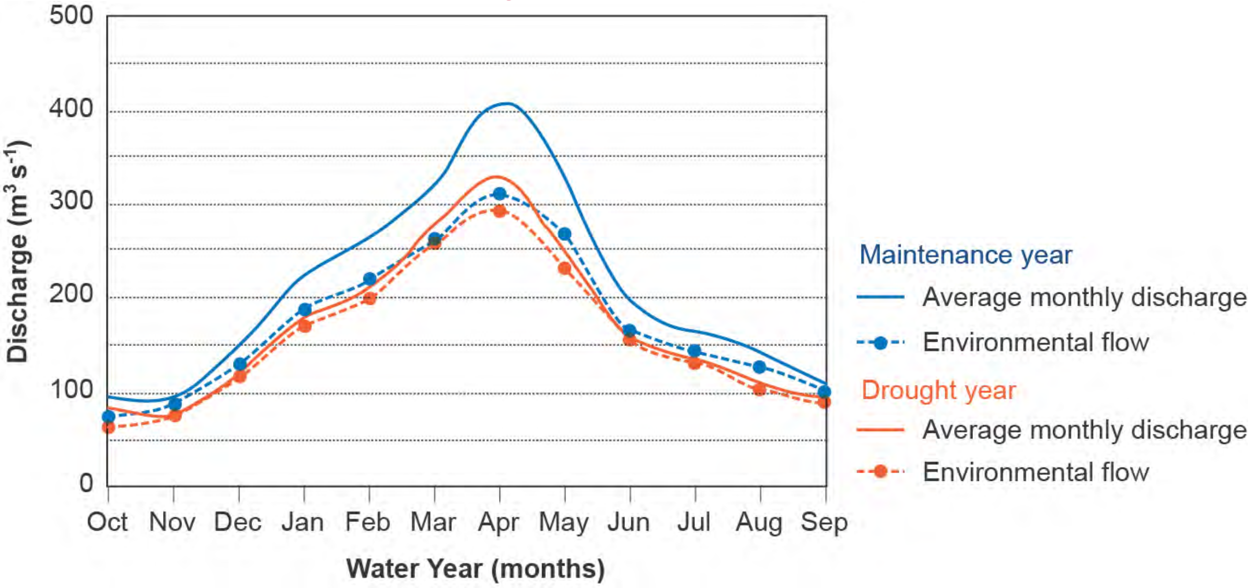
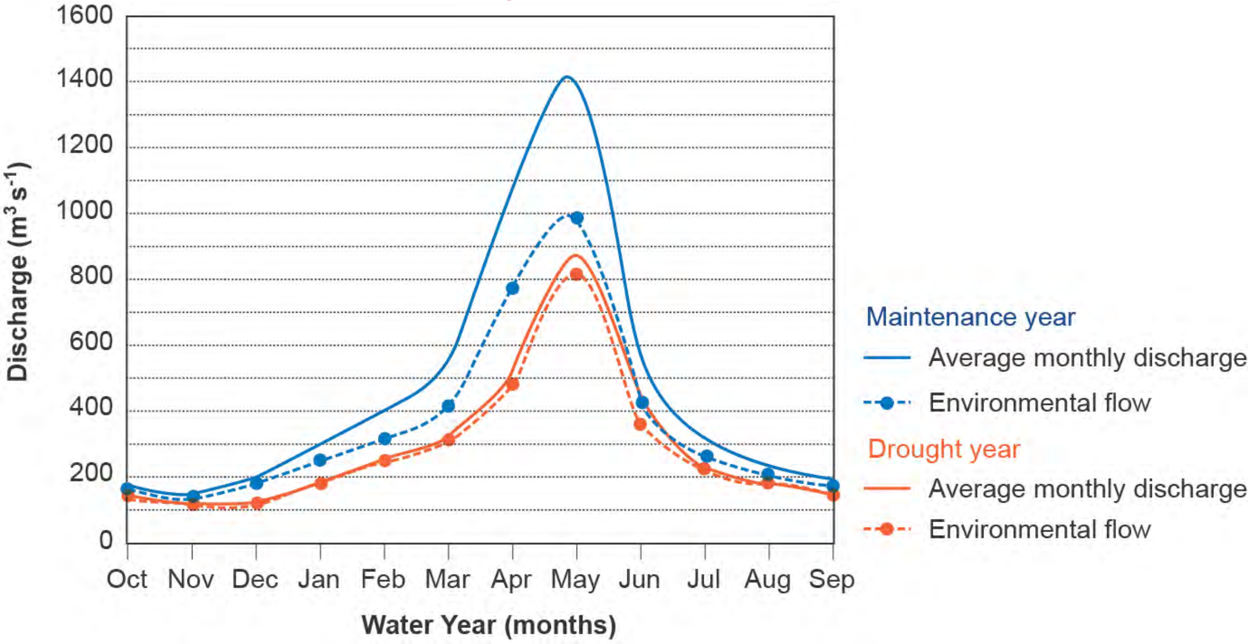


Table 4.9: Environmental Flow Recommendations for Kilombero River at Ifakara Ferry (Site 5) for Target Scenario

Year	Index	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Annual
Maintenance	Average	159.9	153.3	208.3	306.8	403.6	552.0	1,085.6	1,392.4	561.3	318.9	235.6	191.3	464.1
	Monthly low flows													
	Magnitude (m^3/s)	152.8	138.0	185.6	252.4	318.1	418.6	770.0	988.3	424.9	260.6	204.2	174.1	
	Magnitude (Mm^3)	409.3	357.7	497.2	676.0	769.5	1,121.2	1,995.8	2,647.2	1,101.4	698.1	546.9	451.3	11,271.7
	% Average flow	96%	90%	89%	82%	79%	76%	71%	71%	76%	82%	87%	91%	
	% MAF	2.7%	2.3%	3.2%	4.4%	5.0%	7.3%	12.9%	17.2%	7.1%	4.5%	3.5%	2.9%	73.0%
	FDC % (individual month)	58%	77%	58%	58%	54%	65%	73%	69%	77%	73%	73%	62%	
	Flood pulses													
	Magnitude (m^3/s)							1,200.0						
	Magnitude (Mm^3)							725.8						725.8
	Duration (days)							7						
	% MAF							4.7%						4.7%
	Return period (years)							1.5						
	Total	Mm^3												11,133.0
		% MAF												72.1%
Drought	Average	144.8	124.3	128.0	188.0	255.8	337.1	533.0	868.8	437.3	228.4	185.0	148.1	298.2
	Monthly low flows													
	Magnitude (m^3/s)	143.0	120.0	127.5	183.2	246.3	321.8	500.0	816.2	415.0	220.8	180.4	146.2	
	Magnitude (Mm^3)	383.1	311.0	341.4	490.8	595.8	861.9	1,296.0	2,186.2	1,075.6	591.3	483.2	378.9	8,995.3
	% Drought flow	99%	97%	100%	97%	96%	95%	94%	94%	95%	97%	98%	99%	
	% MAF	2.5%	2.0%	2.2%	3.2%	3.9%	5.6%	8.4%	14.2%	7.0%	3.8%	3.1%	2.5%	58.3%
	FDC % (indiv month)	77%	92%	88%	88%	85%	85%	135%	90%	81%	88%	92%	92%	
	Flood pulses													
	Magnitude (m^3/s)							533						
	Magnitude (Mm^3)							322.4						322.4
	Duration (days)							7						
	% MAF							2.1%						2.1%
	Return period (years)							< year						
	Total	Mm^3												9,317.6
		% MAF												60.4%

Figure 4.16: Recommended Environmental Flows for Kilombero River at Ifakara Ferry in Maintenance and Drought Years



4.8 Synopsis of Confidence Ratings for Site Environmental Flow Recommendations

Annex P contains the full listing of the confidence ratings, reasons, and further work required for the various social and ecological components used to substantiate the environmental flow recommendations at each study site.

Confidence in the water quality predictions was expressed as generally low to moderate at all sites, mainly because of a lack of historical data, so that predictions had to be based on the one or two samples taken during the project year. Perceptions by local inhabitants of pollution, mainly from agrochemicals, could not be checked and remain unconfirmed. For riparian and floodplain vegetation, confidence in flow recommendations was moderate to high for all sites, due to the intensive field sampling, backed up by the perceptions of local inhabitants. There was some uncertainty in calculating flow requirements because of a lack of detailed knowledge of flow requirements for many species. For fish and macroinvertebrate communities and their flow-related requirements, confidence was high at Udagaji (Site 2) because extensive habitat mapping and sampling was conducted during the study period. It was also the only site where data-driven models were developed. At the other sites, confidence was moderate, and it was low at Ifwema (Site 4) because of a lack of correspondence between hydraulics and hydrology and because, with only one value of depth, velocity, substrate, and cover for each cross-section, the models for several fish (especially *Labeo* sp. and small *Barbus*) did not predict habitat suitability accurately.

Despite the very extensive interviews and fieldwork, confidence in the socio-economic aspects of flow recommendations was moderate at most sites although slightly higher at Udagaji (Site 2). The main reasons for uncertainty included lack of information about floodplain flows and recession agriculture; little knowledge of the relationship between occurrence, timing, and intensity of diseases and water flows in the river and in the oxbow lakes, swamps, and ponds across the floodplain; and no information about groundwater levels.

In summary, the specialist team expressed moderate to high confidence overall in the environmental flow recommendations. As previously mentioned (Section 3.4), confidence ratings are inherently subjective. Therefore, they provide a general impression of the usability of the recommended flows at each site rather than allowing for statistical analysis of any uncertainties identified.

The confidence ratings usefully guided the specialists to consider what additional research and monitoring should be done for the Kilombero system to most effectively improve confidence in the EFA results. Recommendations included improved modeling of the floodplain to more accurately predict inundation of fields and wetlands in relation to flood recession agriculture; more comprehensive habitat suitability modeling; and further cross-section flow measurements to verify the hydraulic modeling. Section 4.10 summarizes the additional work conducted immediately following the EFA workshop to improve modeling outcomes.

Lack of information about riparian vegetation would necessitate additional sampling to be done in the future, especially on the floodplain, as well as cross-referencing of collected specimens with those species considered important by riparian villagers. There was almost no historical water quality data so that perceived pollution from pesticides, domestic waste, and fish poisoning was difficult to verify. Specialists recommended the establishment of a monitoring program for biodiversity as well as water quality.

4.9 Environmental Flow Recommendations for Increased Use Scenario

The proposed environmental flow regimes for the different river reaches under the increased use scenario of approximately one class decrease in EMC, with assumed future increases in flow regulation and water abstraction, are presented in **Figure 4.17** through **Figure 4.20** for both maintenance and drought year conditions at each site. Complementary tables with the supporting summary flow statistics are also provided in each instance (**Table 4.10** through **Table 4.13**). As explained in Section 3.4, no environmental flow recommendations were generated for the increased use scenario for the Udagaji River (Site 2).

Specialists focused on an explanation, for each ecological and social component, of the likely implications of such a flow-related decline in EMC under increased use, building on the deep understanding of flow ecology and flow-social relationships developed for the target scenario. A complete summary of these various implications and reasons behind them, for each site, are given **Annex Q** and are not addressed further here.

Table 4.10: Environmental Flow Recommendations for Lwipa River (Site 1) for Increased Use Scenario

Year	Index	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Annual
Maintenance	Average	16.50	22.80	32.90	39.30	41.00	56.70	110.50	93.00	66.80	43.20	26.00	19.40	47.3
	Monthly low flows													
	Magnitude (m^3/s)	10.00	12.53	14.53	15.80	16.13	19.24	28.60	26.42	21.24	16.57	13.17	11.86	
	Magnitude (Mm^3)	26.78	32.48	38.92	42.31	39.03	51.53	74.13	70.77	55.05	44.38	35.26	30.74	541.41
	% Average flow	61%	55%	44%	40%	39%	34%	26%	28%	32%	38%	51%	61%	
	% MAF	2.1%	2.5%	3.0%	3.2%	3.0%	3.9%	5.7%	5.4%	4.2%	3.4%	2.7%	2.4%	41.5%
	FDC % (individual month)	97%	71%	77%	84%	81%	95%	116%	129%	103%	110%	116%	119%	
	Flood pulses													
	Magnitude (m^3/s)			25				112						
	Magnitude (Mm^3)			6.48				29.03						35.51
	Duration (days)			3.00				3.00						
	% MAF			0.5%				2.2%						2.7%
	Return period (years)			< year				1						
	Total	Mm^3												576.92
		% MAF												44.2%
Drought	Average	16.3	20.1	24.7	30.4	37.9	39.8	71.5	65.1	43.4	34.5	23	18.5	35.5
	Monthly low flows													
	Magnitude (m^3/s)	8.00	9.91	10.63	11.53	12.71	13.01	16.70	17.00	13.58	12.18	10.36	9.65	
	Magnitude (Mm^3)	21.43	25.68	28.48	30.88	30.75	34.85	43.29	45.53	35.20	32.61	27.76	25.03	381.49
	% Drought flow	49%	49%	43%	38%	34%	33%	23%	26%	31%	35%	45%	52%	
	% MAF	1.6%	2.0%	2.2%	2.4%	2.4%	2.7%	3.3%	3.5%	2.7%	2.5%	2.1%	1.9%	29.2%
	FDC % (individual month)	106%	94%	94%	90%	94%	113%	129%	135%	113%	119%	126%	135%	
	Flood pulses													
	Magnitude (m^3/s)	9.2		20				60						
	Magnitude (Mm^3)	2.38		5.18				15.55						23.12
	Duration (days)	3.00		3.00				3.00						
	% MAF	0.2%		0.4%				1.2%						1.8%
	Return period (years)	< year		< year				< year						
	Total	Mm^3												404.61
		% MAF												31.0%

Figure 4.17: Recommended Environmental Flows for Lwipa River in Maintenance and Drought Years for Increased Use Scenario

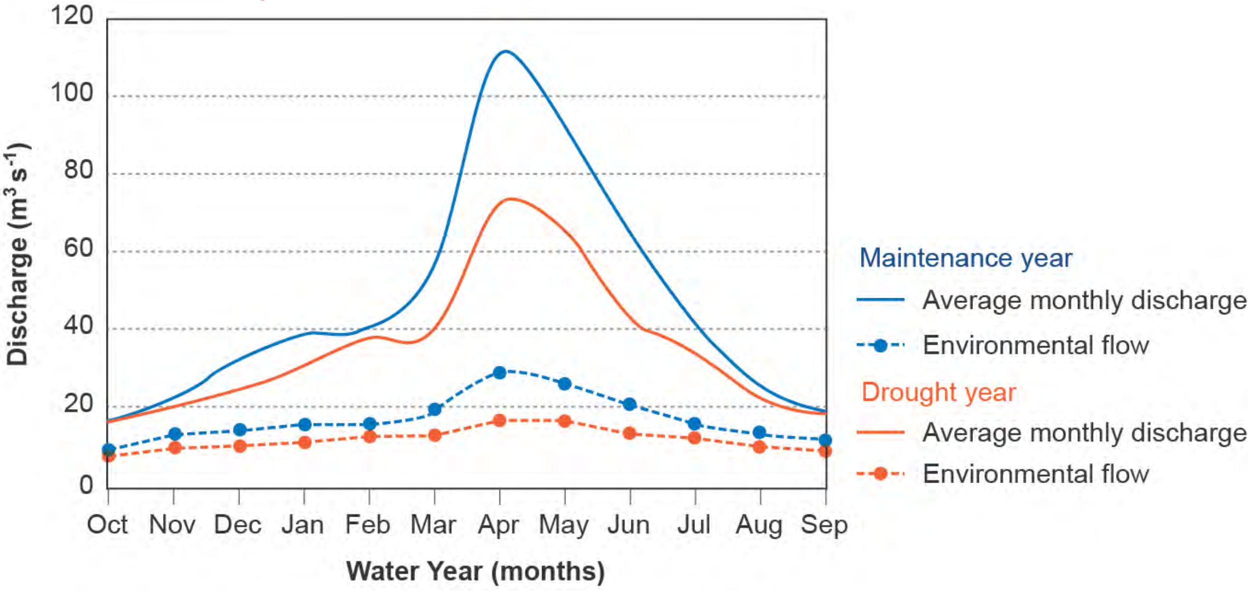


Table 4.11: Environmental Flow Recommendations for Mpanga River (Site 3) for Increased Use Scenario

Year	Index	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Annual
Maintenance	Average	24.5	24.2	32.7	45.4	54.1	71.0	117.4	69.0	43.9	35.3	30.5	27.2	47.9
	Monthly low flows													
	Magnitude (m^3/s)	13.00	15.53	17.45	20.34	22.29	26.12	34.00	25.65	19.98	18.03	16.95	16.22	
	Magnitude (Mm^3)	34.82	40.26	46.74	54.47	53.92	69.95	88.13	68.71	51.79	48.30	45.39	42.04	644.51
	% Average flow	53%	64%	53%	45%	41%	37%	29%	37%	46%	51%	56%	60%	
	% MAF	2.6%	3.0%	3.4%	4.0%	4.0%	5.1%	6.5%	5.0%	3.8%	3.5%	3.3%	3.1%	47.4%
	FDC % (individual month)	91%	81%	88%	88%	109%	109%	131%	106%	100%	103%	97%	84%	
	Flood pulses													
	Magnitude (m^3/s)				45		64	100						
	Magnitude (Mm^3)				11.66		38.71	60.48						110.85
	Duration (days)				3		7	7						
	% MAF				0.9%		2.8%	4.4%						8.1%
	Return period (years)				< year		< year	1						
	Total	Mm^3												755.36
		% MAF												55.5%
Drought	Average	16.1	14.2	23.3	27.2	34.5	43.0	49.7	46.3	25.4	23.2	19.0	16.8	28.2
	Monthly low flows													
	Magnitude (m^3/s)	11.00	12.43	16.49	18.26	21.51	25.28	26.00	26.78	17.42	16.43	14.55	13.60	
	Magnitude (Mm^3)	29.46	32.21	44.16	48.91	52.04	67.71	67.39	71.73	45.15	44.02	38.98	35.25	577.01
	% Drought flow	68%	88%	71%	67%	62%	59%	52%	58%	69%	71%	77%	81%	
	% MAF	2.2%	2.4%	3.2%	3.6%	3.8%	5.0%	5.0%	5.3%	3.3%	3.2%	2.9%	2.6%	42.4%
	FDC % (indiv month)	97%	94%	91%	91%	116%	125%	156%	119%	106%	103%	100%	103%	
	Flood pulses													
	Magnitude (m^3/s)				20			70						
	Magnitude (Mm^3)				5.18			30.24						35.42
	Duration (days)				3			5						
	% MAF				0.4%			2.2%						2.6%
	Return period (years)				< year			< year						
	Total	Mm^3												612.43
		% MAF												45.0%

Figure 4.18: Recommended Environmental Flows for Mpanga River in Maintenance and Drought Years for Increased Use Scenario

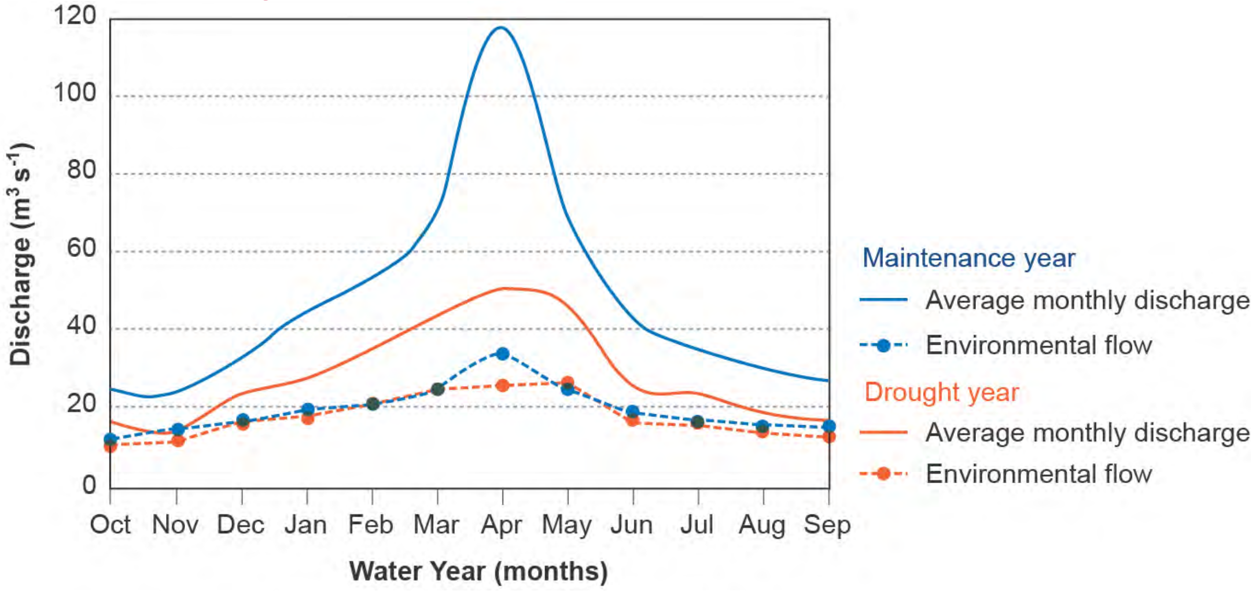


Table 4.12: Environmental Flow Recommendations for Kilombero River at Ifwema (Site 4) for Increased Use Scenario

Year	Index	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Annual
Maintenance	Average	94.9	94.7	148.1	223.4	264.7	321.0	406.2	326.9	199.8	166.7	144.6	110.0	208.4
	Monthly low flows													
	Magnitude (m^3/s)	60.0	87.6	130.2	190.2	223.1	268.0	308.0	272.7	171.4	145.0	127.4	99.9	
	Magnitude (Mm^3)	160.7	227.1	348.8	509.4	539.8	717.7	798.3	730.3	444.2	388.4	341.2	258.8	5,464.8
	% Average flow	63%	93%	88%	85%	84%	83%	76%	83%	86%	87%	88%	91%	
	% MAF	2.4%	3.4%	5.3%	7.7%	8.2%	10.9%	12.1%	11.1%	6.7%	5.9%	5.2%	3.9%	82.8%
	FDC % (individual month)	86%	50%	75%	72%	72%	83%	97%	76%	72%	76%	48%	62%	
	Flood pulses													
	Magnitude (m^3/s)			120.0				820.0						
	Magnitude (Mm^3)			31.1				495.9						527.0
	Duration (days)			3				7						
	% MAF			0.5%				7.5%						8.0%
	Return period (years)			< year				>200 yrs						
	Total	Mm^3												5,991.80
		% MAF												90.8%
Drought	Average	79.3	76.7	120.3	178.5	210.9	276.9	327.2	245.7	160.7	134.2	106.9	91.1	167.4
	Monthly low flows													
	Magnitude (m^3/s)	46.0	71.3	107.1	155.0	181.7	236.0	250.0	210.3	140.4	118.6	96.1	83.1	
	Magnitude (Mm^3)	123.2	184.7	287.0	415.2	439.5	632.0	648.0	563.3	363.9	317.6	257.3	215.5	4,447.2
	% Drought flow	58%	93%	89%	87%	86%	85%	76%	86%	87%	88%	90%	91%	
	% MAF	1.9%	2.8%	4.4%	6.3%	6.7%	9.6%	9.8%	8.5%	5.5%	4.8%	3.9%	3.3%	67.4%
	FDC % (individual month)	104%	86%	89%	91%	91%	93%	124%	93%	90%	97%	90%	90%	
	Flood pulses													
	Magnitude (m^3/s)				80			380						
	Magnitude (Mm^3)				20.7			229.8						250.6
	Duration (days)				3			7						
	% MAF				0.3%			3.5%						3.8%
	Return period (years)				< year			1.5						
	Total	Mm^3												4,697.79
		% MAF												71.2%

Figure 4.19: Recommended Environmental Flows for Kilombero River at Ifwema in Maintenance and Drought Years for Increased Use Scenario

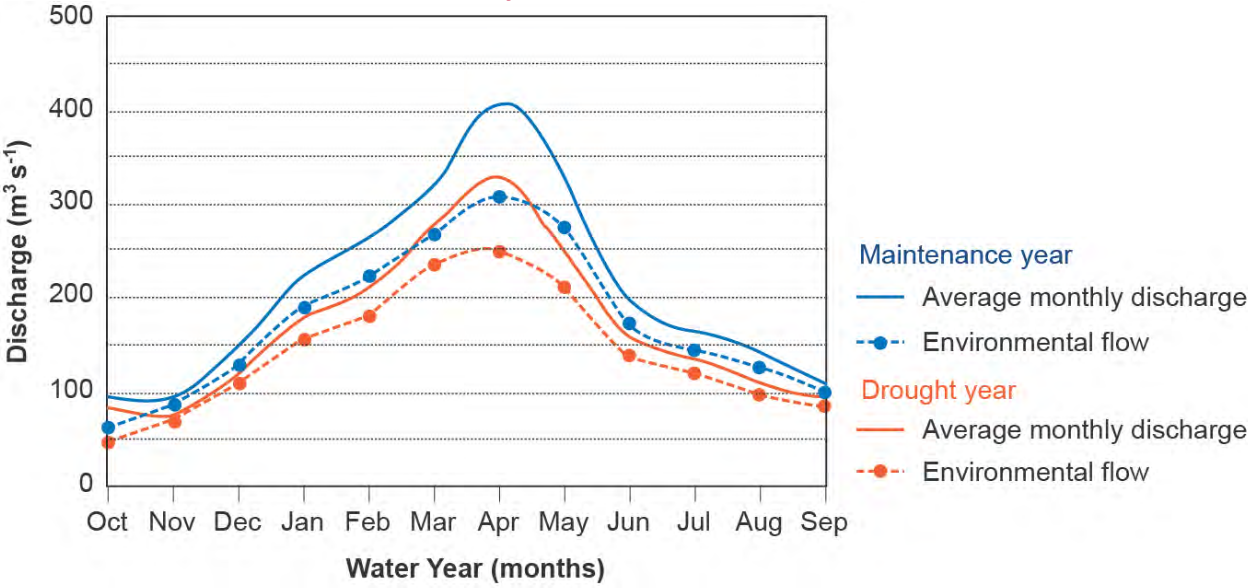
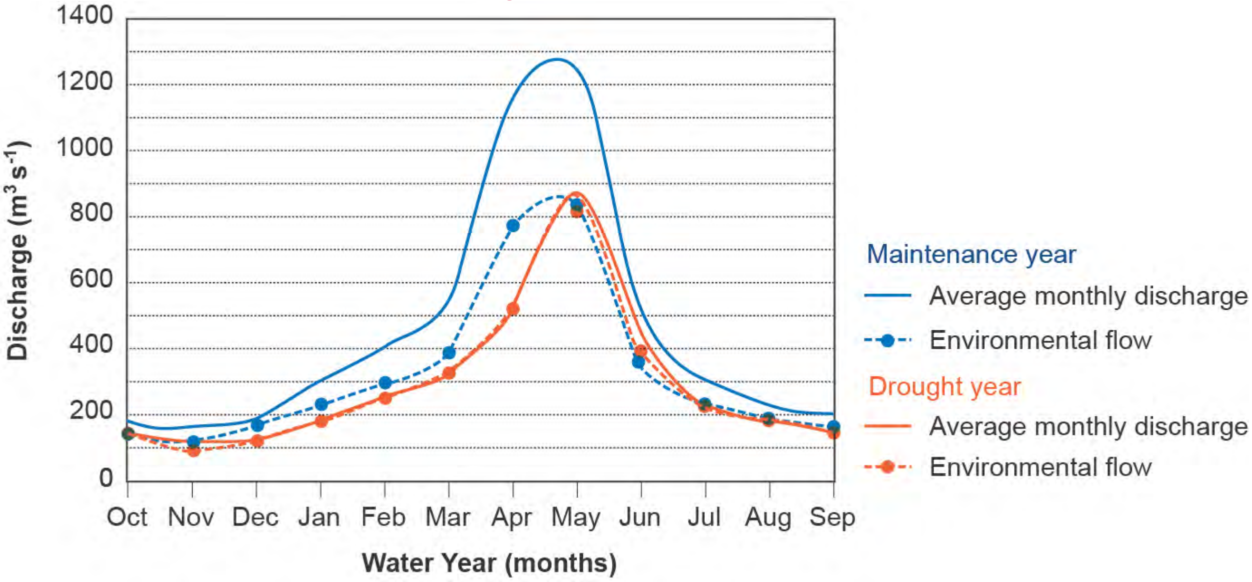


Table 4.13: Environmental Flow Recommendations for Kilombero River at Ifakara Ferry (Site 5) for Increased Use Scenario

Year	Index	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Annual
Maintenance	Average	162.5	154.6	194.5	296.6	399.4	547.7	1,161.4	1,235.9	496.6	300.3	226.5	185.7	446.8
	Monthly low flows													
	Magnitude (m^3/s)	147.4	120.0	168.1	234.0	300.4	396.1	770.0	840.4	363.1	236.4	188.8	162.4	
	Magnitude (Mm^3)	394.9	311.0	450.2	626.8	726.6	1,060.9	1,995.8	2,251.0	941.2	633.2	505.6	420.9	10,318.3
	% Average flow	91%	78%	86%	79%	75%	72%	66%	68%	73%	79%	83%	87%	
	% MAF	2.6%	2.0%	2.9%	4.1%	4.7%	6.9%	12.9%	14.6%	6.1%	4.1%	3.3%	2.7%	66.9%
	FDC % (individual month)	65%	92%	73%	62%	58%	69%	73%	88%	88%	85%	85%	81%	
	Flood pulses													
	Magnitude (m^3/s)							1,200.0						
	Magnitude (Mm^3)							725.8						725.8
	Duration (days)							7						
	% MAF							4.7%						4.7%
	Return period (years)							1.5						
	Total	Mm^3												11,044.1
		% MAF												71.6%
Drought	Average	144.8	124.3	128.0	188.0	255.8	337.1	533.0	868.8	437.3	228.4	185.0	148.1	298.2
	Monthly low flows													
	Magnitude (m^3/s)	143.8	100.0	127.4	186.1	252.5	332.0	500.0	852.4	430.1	225.6	183.2	147.1	
	Magnitude (Mm^3)	385.2	259.2	341.4	498.6	610.9	889.2	1,296.0	2,283.2	1,114.7	604.3	490.6	381.3	9,154.6
	% Drought flow	99%	80%	100%	99%	99%	98%	94%	98%	98%	99%	99%	99%	
	% MAF	2.5%	1.7%	2.2%	3.2%	4.0%	5.8%	8.4%	14.8%	7.2%	3.9%	3.2%	2.5%	59.3%
	FDC % (individual month)	77%	96%	88%	88%	81%	85%	92%	88%	81%	88%	88%	92%	
	Flood pulses													
	Magnitude (m^3/s)							700						
	Magnitude (Mm^3)							423.4						423.4
	Duration (days)							7						
	% MAF							2.7%						2.7%
	Return period (years)							1						
	Total	Mm^3												9,578.0
		% MAF												62.1%

Figure 4.20: Recommended Environmental Flows for Kilombero River at Ifakara Ferry in Maintenance and Drought Years for Increased Use Scenario



4.10 Refinement and Validation of Kilombero Valley Environmental Flow Recommendations

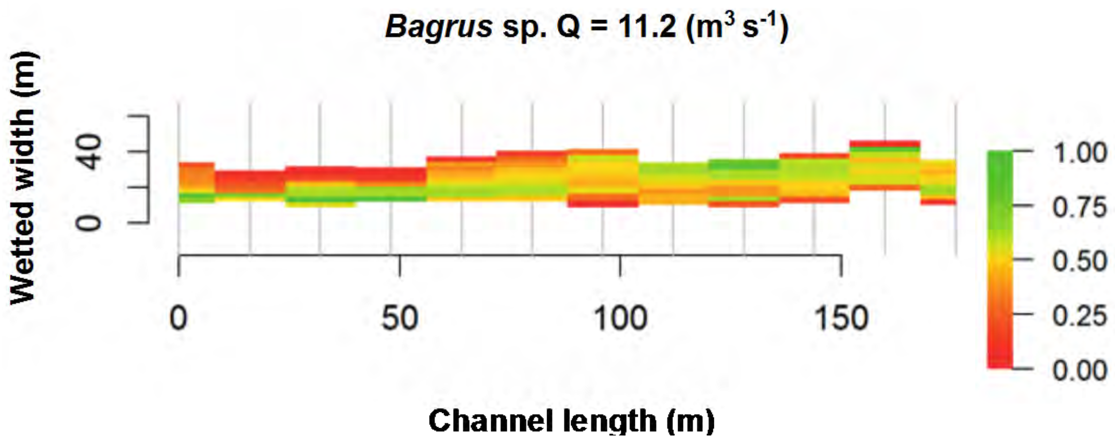
The assessment of sites in the Kilombero Sub-Basin was largely concluded during the June 2015 flow setting workshop. Original plans to conduct a follow-up set of field studies to validate the flow recommendations had to be canceled in order to synchronize the final EFA report with the feasibility studies of the irrigation schemes. It was noted by the expert review panel that this might limit the level of confidence in the flow recommendations generated. However, follow up analyses were continued on three topics not requiring additional fieldwork. First, the habitat suitability modeling was extended using more detailed and spatially distributed hydraulic data (Section 4.10.1). This was intended to increase the level of confidence in the initial values generated using simpler hydraulic data. Secondly, efforts were initiated to model flooding patterns in the area of the Kilombero floodplain between Sites 4 and 5 (Section 4.10.2). Finally, additional geomorphological modeling was conducted to assess the potential longer-term impacts of modified flow levels on the evolution of river morphology (Section 4.10.3). Results from each of these analyses have served to either improve our level of confidence in the final results or extend our understanding of the system in time and space, but no changes in the flow recommendations were required as a result of the additional analyses. In the paragraphs that follow, we briefly describe each of these activities and the results derived from them.

4.10.1 Model Refinement of Physical Habitat Suitability for Instream Biota to Improve Environmental Flow Recommendations

Physical habitat simulation typically combines two elements (Leclerc et al. 2003; Conallin et al. 2010; Jowett and Duncan 2012). One element is a simple one-dimensional or a more complex two-dimensional hydraulic model, simulating spatial and temporal variations in hydraulic predictors (water depth, velocity, substrate composition, and cover) with discharge. The other is a habitat suitability model for the target species at an ecologically meaningful scale (see **Annex M** for examples of different species' habitat preference models based on expert-knowledge Takagi-Sugeno-Kang fuzzy rules: Takagi and Sugeno 1985).

For the purposes of the EFA workshop, a one-dimensional hydraulic simulation was performed with Hydrologic Engineering Centers River Analysis System (HEC-RAS), and an averaged single value per river transect and flow was used for the habitat suitability assessment for fish and invertebrates. Flow-habitat suitability relationships were not modeled for the Kilombero River at Ifakara Ferry (Site 5) at that time. Post-workshop refinement of the habitat simulation analysis was performed (August 2015) to add to the rationale for flows at Ifakara and strengthen confidence in the flow-habitat recommendations. Flow event-hydraulic habitat relationships formed the basis of a number of the specific flow recommendations made for fish and invertebrate species in the workshop (see Section 4.7 and **Annex M**). In this refined set of physical habitat simulations, the method was improved by discretizing every cross section into several cells, thus, varying the substratum type and availability of different cover types cell-by-cell across the channel for each hydraulic cross-section. This allowed for far more accurate habitat-flow predictions than a single average value per cross-section based on curves of WUA as an indicator of habitat (quality and quantity) against discharge for every target organism. In the same manner as was done during the EFA workshop, recommended low flows were calculated as the different flows that ensured at least the 90, 80, or 70 percent of the WUA in the lowest flow month for a maintenance or drought year for the most demanding species at each site. This phase of analysis allowed the development of a more advanced set of habitat suitability maps as depicted in **Figure 4.21** for a fish from the Lwipa River. This also allowed direct comparison between assessments using habitat suitability models based on experimental data (Takagi-Sugeno-Kang fuzzy models) and those based on data collected through interviews with fishers (for fish spp. and freshwater shrimps).

Figure 4.21: Habitat Suitability Map for Bagrus sp. at Discharge of 11.2 m^3/s in Lwipa River



Note: The 0-1 bar reflects increasing habitat suitability from zero (red) to a maximum of 1 (green).

Comparison of the specific recommended discharges for all of the sites before and after this model refinement showed negligible or small changes in WUA-discharge values, thus, not materially changing any of the previous flow recommendations. However, the more sophisticated, finer-scale species' hydraulic habitat assessments and improved calibration of the model increased the level of confidence in the results. As reflected in a comparison of assigned confidence ratings from pre- to post-workshop, there was a substantial improvement from at least moderate to high confidence for four of the sites and a significant increase from moderate confidence to absolute certainty in flows recommended to maintain suitable physical habitat for instream biota in the Udagaji River (**Table 4.14**). More generally, this example also underscores the importance of considering such ratings relative to the desired level of confidence needed in the environmental flow figures.

Table 4.14: Comparison of Confidence Ratings for Flow Recommendations Based on Maintenance of Suitable Physical Habitat for Target Fish and Invertebrate Groups

Study Site	Lwipa (Site 1)	Udagaji (Site 2)	Mpanga (Site 3)	Ifwema (Site 4)	Kilombero (Site 5)
EFA workshop rating	3	3	3	3	3
Final (post-refinement rating)	4	5	4	4	4

Note: See Section 3.1.3: Table 3.4 for an explanation of the confidence rating scale

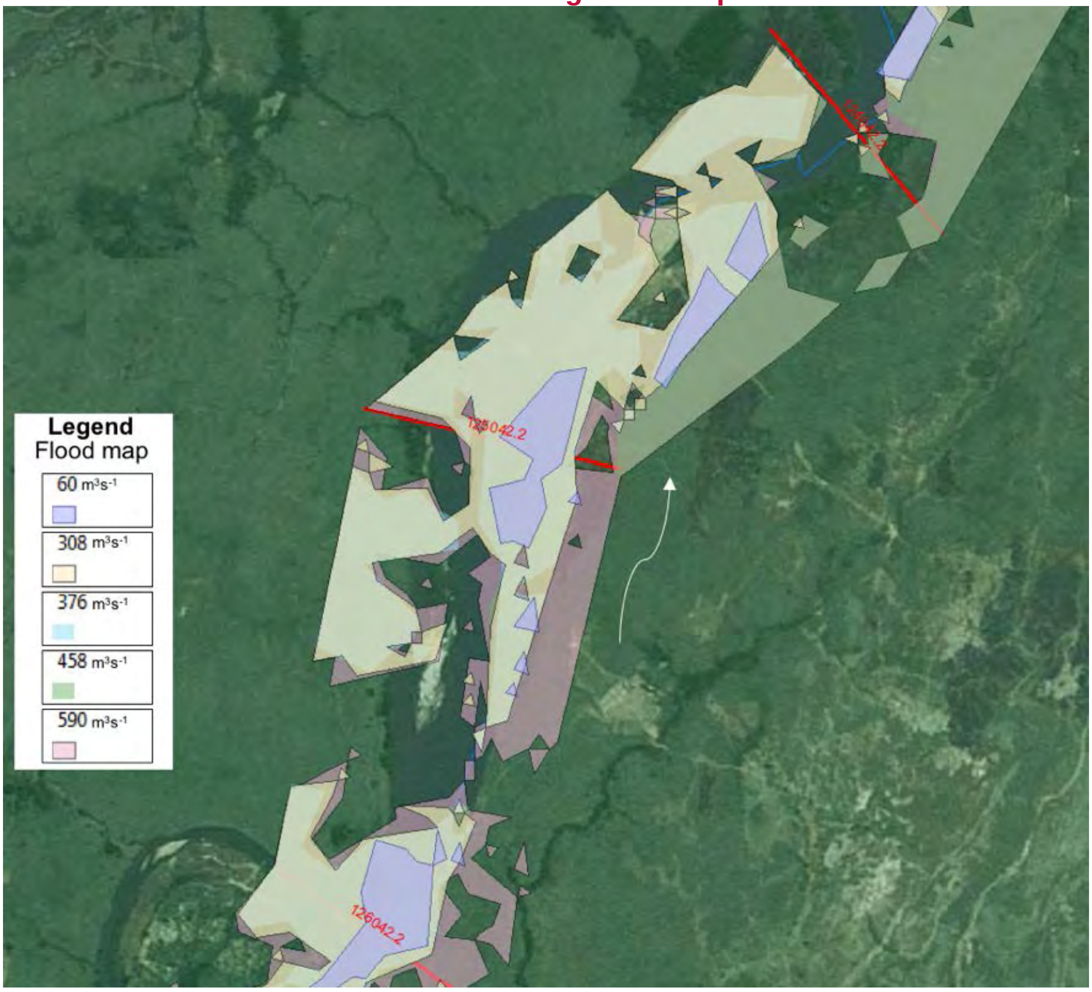
4.10.2 Modeling to Advance Understanding of Kilombero River-Floodplain Hydrodynamics and Implications for Environmental Flow Recommendations

During the flow setting workshop, recommending flood flow levels at Sites 4 and 5 (Ifwema and Ifakara Ferry) was made difficult by the complexity of the river network on the floodplain. In the standard BBM approach, the river channel and its adjoining floodplain are considered as a single unit linked according to the contours of the topographic cross-sections transecting the surveyed reach. This condition generally held for Sites 1, 2, and 3. However, as the Kilombero River flows into its floodplain at Sites 4 and 5, it splits into numerous channels that distribute flood waters across the plain in complex patterns such that floodwaters adjacent to a given reach may not be directly correlated with flood extent in the neighboring plain. This, as well as the compounding effects of the confluences of multiple tributaries with the mainstem, limited our ability to estimate the extent of flooding expected due to a single discharge level.

In an attempt to more accurately represent flooding patterns near Sites 4 and 5, we developed a simple flood inundation model using the same HEC-RAS software that was used in the analysis of hydraulic habitat dynamics in the study reaches. In this application, we simulated the extent of flooding over an extended 100 km reach of the river. Unfortunately, the accuracy of our model was limited by the quality of the Shuttle Radar Mission digital elevation model (DEM, 30 m) available for the site. The flat topographic profile of the floodplain was not accurately represented in the DEM; therefore, it was impossible to investigate the full complexity of flooding patterns on the floodplain.

The results of the analysis still proved useful in demonstrating that at our recommended flood levels for the Kilombero River at Ifwema (Site 4) inundation is expected over a wide area of floodplain, including areas used as nursery grounds for young fish and areas harboring important floodplain vegetation (**Figure 4.22**). In other reaches of the river, these areas will correspond to river margins used for flood recession agriculture by local communities. Additional attention should be given to increasing knowledge of flow and flood relations to ensure that the most socially and ecologically significant floods are maintained in the basin.

Figure 4.22: Simulated Extent of Flooding at Ifwema (EFA Site 4) along Kilombero River Floodplain at Flow Levels Considered during Environmental Flow Setting Workshop



4.10.3 Geomorphological Modeling to Assess Potential Implications of Additional Water Abstraction in Kilombero System

Typically, geomorphological studies conducted using the BBM will concentrate on reach-level dynamics that determine the type and distribution of geomorphic features that act as important habitats for aquatic and riparian organisms, such as channel bars and terraces. These processes are certainly important and were considered in our assessment. However, we further recognized that abstracting water from the river would initiate longer-term changes in the river system related to changes in the equilibrium between bed level and water depth. The method used is based on equilibrium theory (Jansen et al. 1979), resulting in simple quantifications. The results provide a basic idea of the order of magnitude of the changes that can be expected in the rivers and other morphological aspects. More details of the analysis can be found in **Annex I**.

The planimetry of rivers in the transition zone of the Kilombero Valley is believed to have been rather stable over the last 50 years, suggesting that rivers are in a state of dynamic equilibrium. However, when water is abstracted from the river, equilibrium theory holds that there will be a decrease of flow velocity and sediment transport capacity in the river, resulting in progressively increasing sediment settling. Increased sediment deposition will occur first near the point of water withdrawal and then move progressively downstream. During this period, the mean sediment size of the riverbed will become finer. With time, the progression of sediment deposition near the point of withdrawal steadily increases the slope of the reach downstream of the intake where, due to the higher slope, the water depth progressively decreases and the flow velocity increases. This results in a progressive decrease of deposition rates. Net sediment deposition stops when the flow velocity is again able to transport all sediment input from the upstream catchment. This happens when the longitudinal slope has reached a certain threshold value.

In our analysis of rivers downstream of the proposed irrigation schemes in the Kilombero Valley, we found that all river reaches are likely to experience increased sediment deposition over time with water withdrawal, leading to a rise in their bed levels, with related changes in bed sediment sizes and increased frequency of flood events. No specific confidence ratings were assigned to this effect. These aggradation effects and related channel avulsion are expected to be most pronounced over a 20- to 50-year period in the Lwipa and Mpanga rivers. Commensurate impacts on riparian and instream ecology, as well as on social uses, are to be expected. The effects will be much smaller in the spawning zone of the Udagaji River and in the mainstem reaches of the Kilombero River-floodplain.

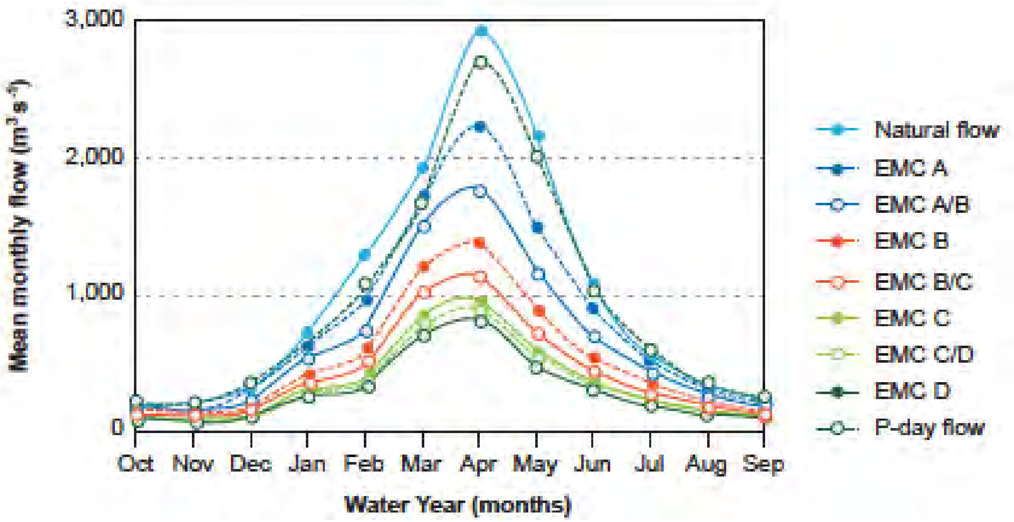
4.11 Extending Environmental Flow Assessment into Lower Rufiji Sub-Basin

Environmental flow requirements in the Lower Rufiji Sub-Basin and at the Rufiji Delta are of critical importance. This is especially true because they represent a cumulative environmental flow regime, comprising not only the sum of upstream discharge magnitudes but also their pattern, timing, and quality. The Lower Rufiji hosts some of the most important social-ecological systems of the entire basin, including the mainstem river itself, a series of expansive floodplain and associated lake environments, Stiegler’s Gorge, the Rufiji Delta, and adjacent nearshore coastal ecosystems of the Rufiji-Mafia-Kilwa Marine Ramsar Site and adjoining areas (Section 2.4 and **Figure 2.10**; Hamerlynck et al. 2011). To the best of our knowledge, the RBWB has not set specific environmental objectives for the Lower Rufiji, but the value of these social-ecological systems is likely to warrant a high ecological management class.

As part of the Rufiji IWRMD planning process, the Desktop Reserve Model (DRM) was applied to estimate environmental flow levels needed to achieve different environmental management classes in the Lower Rufiji Delta (Kashaigili 2013). The results of that analysis are summarized in **Figure 4.23**. The DRM builds on the South African Desktop Reserve Model described in Hughes and Hannart (2003). In the Tanzanian case, it is based on a relationship between the annual water requirements of different category rivers during both normal (maintenance) years and drought years, derived from the results of several local river EFAs and an index of hydrological variability (as developed for South Africa). Therefore, it is strongly reliant on the relationships developed between individual EMCs and the proportions of the flow regime to be recommended for environmental purposes. Hughes and Hannart (2003) acknowledged that the DRM is a relatively simple model, originally designed for very rapid and low confidence ecological reserve (quantity) determinations based on extrapolations from previous, higher confidence EFAs. As such, it has all the attendant limitations of a methodology of this type (see Tharme 2003). Moreover, the underpinning relationships have not been explicitly calibrated for the diversity of Tanzanian river ecotypes or for particularly complex and diverse large river deltas or floodplain systems. As the results of additional environmental flow studies, using the

BBM or similar holistic approaches, are built up over time in Tanzania, it will be possible to advance this method, thereby, increasing the level of confidence that can be placed in its results. However, it will remain constrained by its desktop nature such that for river systems or reaches where a high level of confidence is needed in the reserve estimation for water resource or environmental reasons a more comprehensive, social-ecologically grounded methodology will be required. Therefore, at present, it is important to note that the existing environmental flow recommendations used in the IWRMD Plan necessarily represent low confidence values.

Figure 4.23: Lower Rufiji Hydrographs of Desktop EFA Results



Source: WREM International 2015i

The desktop assessment estimated that Category A status could be maintained by sustaining a total annual discharge roughly equal to 70 percent of natural flows, with mean monthly flow percentages ranging from 62 to 81 percent of natural. Category B status could be maintained by retaining a total annual discharge roughly equal to 50 percent of natural flows, with mean monthly flow percentages ranging from 38 to 61 percent of natural. The assessment also acknowledged that present total annual discharge at the Delta is already reduced by nearly 10 percent (WREM International 2015i).

The estimated discharge levels to maintain an environmental management class of A are not unlike the values we found at the catchment outlet of the Kilombero River, but they lack social-ecological motivations that are specific to the Lower Rufiji system. The international science of assessing the environmental flow needs of estuarine and deltaic systems has advanced considerably in recent years (see a review of methods and frameworks used to determine the environmental water requirements of estuarine and similar environments: Adams 2014); however, the integration of these approaches with those for rivers remains weak. For the Lower Rufiji, specific elements of estuarine and lacustrine methodologies will need to be harmonized with the modified river-floodplain BBM applied in the Kilombero to better capture the breadth of components and diversity of relationships with flow that are involved.

We had originally planned to conduct a desktop, expert-knowledge based assessment of environmental flow requirements in the Lower Rufiji Sub-Basin, but time allowed only for a rapid review of the literature. Based on this review, we offer the following first observations on some of the expected flow dependencies of the Lower Rufiji System, supported by evidence from readily available scientific literature.

Hamerlynck et al. (2011) present a detailed 7-year study of the ecohydrological connections between a series of seven floodplain lakes, from three floodplain zones upstream of the Rufiji Delta, and the river, focused on lake fishery catches during high flow periods. During large floods, connections between the river and the lakes (termed *kingo* in Kiswahili) led to peaks in fish biomass and intensive harvesting by people. During drought periods, loss of hydrological connectivity occurred due to the reduced flood magnitudes. This led to a loss of fish species and dominance by the habitat generalist *Oreochromis urolepis*.

Little appears to have been published on the low and high flow dependencies of biota and people on the numerous floodplain lakes located upstream within the borders of the Selous Game Reserve, but they are likely critical biodiversity refuges (Hamerlynck et al. 2011). Local knowledge may provide insights into the hydro-ecological relationships. Similarly, recent published information on the mainstem Rufiji appears limited.

The highly variable, often biannual, flood peaks are beneficial to local communities despite the damage incurred by very large floods (Duvail and Hamerlynck 2007). Traditional flood recession agriculture (*mlao* cultivation) is well adapted to the spatial complexity of the topography, the patchiness of sub-ecosystem types and soil conditions, and how these various factors dynamically relate to particular flood events. Hamerlynck et al. (2010) describe these relationships from historical and present-day perspectives, including the important role of the nutrient-rich sediments and water transported by key flood events in maintaining soil and agricultural productivity, often for many years in succession. Turpie (2000) provides an in-depth perspective of the economic benefits of the Rufiji system’s ecosystem services on livelihoods. Communities clearly benefit from the harvesting of natural resources, flood recession agriculture, and rain-fed farming. The direct use value of freshwater habitats and of agricultural land were estimated by Turpie (2000) to be in the order of 42 US dollars and 63 US dollars per hectare per year, respectively.

To date, scenarios of water resource development for the lower basin have tended to focus on the low flow component of the hydrograph. There has been a lack of sufficient attention to the functional roles of the flood regime on the delta and nearshore coastal zone in terms of hydrological criteria such as timing, peak magnitude, duration, return period, hydrograph shape, and accession/recession rates. As discussed above, the delta system can be expected to be intimately connected ecologically and socially with a range of high flow events.

Freshwater inflows to the marine ecosystem and nearshore coastal ecosystems of the Lower Rufiji (the marine Ramsar Site and adjoining areas) perform various functions that are essential for the health and productivity of the system. These include maintaining delta build-out through transport of sediments, supporting trophic structure and plankton populations as food sources for the pelagic fishery, and stimulating the productivity cycles of economically important coastal fisheries resources for people.

The fin and non-fin fisheries of the nearshore coastal and marine zones of the Rufiji Delta are economically important for livelihoods and the regional economy and are intimately tied to the freshwater-saltwater dynamics and associated flows of water, sediments, and nutrients (e.g., Shao et al. 2003). In an example from the nearby Zambezi Estuary, catch rates of shrimp in the Sofala Bank have been decreasing in the last two decades due to reduced freshwater inflows from the Zambezi River. These inflows exert a significant influence on the dynamics of the shelf, which in turn influences the availability and distribution of nutrients and shrimp recruitment (Hoguane 1997). The implications for the Rufiji coastal systems are obvious, especially given the strong dependencies of people on the fishery for their livelihood.

Several ecologically and nutritionally important fish recorded from the Kilombero River-floodplain reaches (including in this study: **Annex L**) are long-distance longitudinal migrants that likely depend on the Lower Rufiji system at various times of their lifecycle, particularly during high flow events. These fish notably include catadromous fish species such as the eels, *Anguilla bengalensis labiata,* and *A. mossambica*, which are highly vulnerable to both changes in the hydrograph at times critical to migration and interruptions to longitudinal connectivity. For the survival of these anguillids, adults must be able to migrate downstream to the sea to spawn, and juveniles must migrate upstream again to their freshwater feeding and maturation areas in the Kilombero River. Eel larvae are carried from their spawning grounds into the Indian Ocean, and the juveniles (glass eels) later enter coastal rivers of Tanzania, including the Rufiji River, during December and January each year and migrate upstream. It is vital that freshwater cues reach the ocean during this period to attract the juveniles into the delta distributary mouths, although how much freshwater is required to provide these cues, and for what duration, remains unknown.

The vast mangrove system of the Rufiji Delta is of international, East African and local importance (Section 2.4). It is well established that mangrove assemblages and their freshwater-brackish water species composition and relative abundance are highly dependent on upstream inflow regimes to bring vital nutrients and sediments to the system and flush out accumulated detritus and poor water quality (Semesi 1992). Their growth and species balance are also dependent on the position of the saline wedge and associated freshwater-saltwater ratio, which is strongly influenced by freshwater inflows to the estuarine zone. This is expected to be a primary component of concern in the Lower Rufiji. While the structural composition of the Rufiji mangroves appears to be well known, ranging from freshwater tolerant species to those preferring high salinities (Punwong et al. 2013), there appears to be less specific published information on flow requirements. In addition to mangroves, the sea grass beds and coral reefs that occur near the Rufiji mouth also can be expected to depend on freshwater flows from the Rufiji River for their productivity, health, and ecosystem services for coastal communities.

Further effort will be necessary to collect much needed new primary data and consolidate all available secondary data, scattered expert knowledge (through focused interviews and consultations), and the traditional ecological knowledge held by local communities to develop and apply a workable methodology for assessing the flow dependencies of the social-ecological system of the Lower Rufiji river-floodplain and estuary-delta.

5 ENVIRONMENTAL WATER MANAGEMENT IN THE CONTEXT OF FUTURE RUFIJI BASIN DEVELOPMENT

5.1 Environmental Flow Recommendations for Kilombero Sub-Basin

The detailed environmental flow recommendations and associated motivations presented in Section 4 are the main output from this EFA. They provide the best estimate, with our present state of knowledge, of the reserve needed in rivers downstream of the planned irrigation schemes to meet specific social-ecological objectives set by basin stakeholders and comply with Tanzanian water law. In the Lwipa, Udagaji, and Mpanga river reaches, these environmental flow recommendations can be factored directly into the design of planned irrigation schemes and associated water abstraction plans. For the main stem reaches of the Kilombero River, these environmental flow recommendations must be considered in the context of larger, basin-wide water resource planning. Similarly, for the wider Rufiji Basin, these recommendations serve as a valuable, but limited, input to wider water resource planning.

We provide environmental flow recommendations for two types of year, a maintenance and a drought year (see Section 3.4 for definitions), and for two scenarios, a target scenario and an increased use scenario. Maintenance year recommendations include baseflow and flood flow recommendations to meet all established social-ecological objectives during most years when sufficient water is available. Drought year recommendations include baseflow and flood flow recommendations to meet a reduced set of objectives during occasional years when there is not sufficient water to meet all objectives. These recommendations are standard practice in EFAs and provide the water manager with flexibility to cope with variability in available water from one year to the next. It is important to emphasize that the maintenance and drought year flows provide only two elements of the range of flow conditions expected and required in the rivers if the environmental objectives are to be met. Once the environmental flows are implemented, it is expected that natural climatic triggers (such as rainfall or gauged flow changes in the upper catchments) would be used to indicate the required flows during any season. During very wet years, flows would be expected to be higher than the maintenance recommendations, and during dry years, they would be expected to be between maintenance and drought levels (but never lower than drought flow recommendations) (see Section 3.4 for more explanation).

We have addressed the alternative scenarios at the request of the Ministry of Water, which has recommended that reserve determinations should provide such a range of conditions and flow scenarios for consideration. The purpose of the scenarios is to better illustrate the social-ecological consequences of setting a lower flow level for the reserve. We would like to reaffirm that the target scenario matches the objectives of the basin stakeholders, and the increased use scenario likely would lead to degradation of the riverine ecosystems and associated services that some stakeholders would find unacceptable.

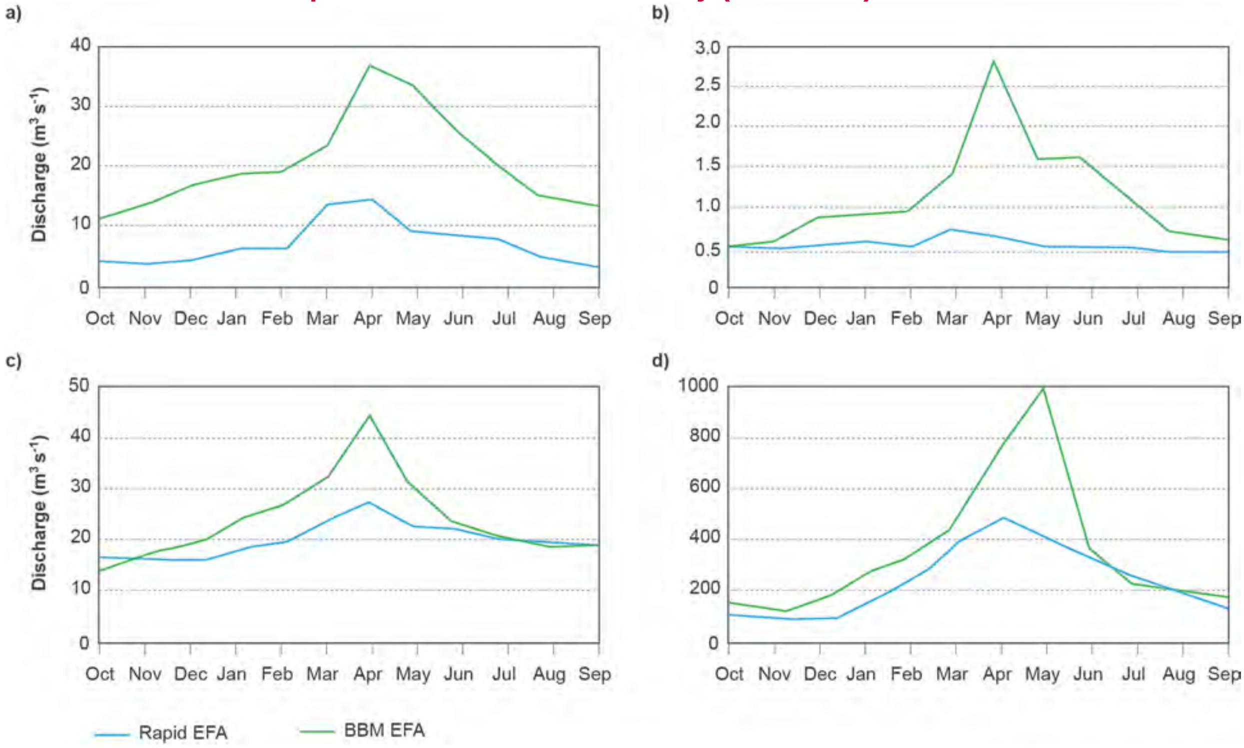
Our environmental flow recommendations are based on field studies conducted over a single 6-month season and on modeling activities dependent on available historical data. These limitations introduce a degree of uncertainty into the results, but based on the generally moderate to high level of confidence expressed by the specialist team in its recommendations, there should be no hesitation in applying the results forthwith. In accordance with the 2009 Tanzanian Water Resources Management Act (Part V, Section 31), these environmental flow recommendations would be included in the Rufiji Basin integrated water resource management plan as requirements of the reserve for the water bodies in which the recommendations were made. Part VI, Section 33 of the 2009 Water Act specifies that the Minister shall determine the reserve by notice in the Gazette.

However, the environmental flow recommendations and the reserve must be reassessed with some regularity as part of a normal adaptive management cycle. This is essential given the larger basin dynamics, including basin-scale development activities and climate change that will continually alter the context in which environmental flow recommendations are made. The 2009 Water Act calls for integrated water resource management plans to be reviewed at least once per 5-year period, and this schedule is also appropriate for review of these environmental flow recommendations. Proper reassessment will depend on collection of monitoring data to determine whether the objectives of the reserve are being met. However, monitoring of social-ecological parameters related to environmental flow objectives is not considered in the Basin Monitoring Plan prepared as part of the Rufiji IWRMD Plan (WREM International 2015d). Detailed monitoring of social-ecological parameters is considered within the 2004 Environmental Management Act and related 2005 Environmental Impact Assessment and Audit Regulations, but rules under these regulations relate to individual projects rather than basin-scale resource management activities. We advise the RBWB to take up this matter and assess how best to ensure that reserve determinations can be monitored, reviewed, and updated to ensure that the objectives of the law are met.

Environmental flows can only address flow-related environmental issues. Thus, the achievement of the predicted objectives and EMCs will depend on effective management of other non-flow-related issues in the basin, such as pollution or erosion, in addition to flow. For example, despite the practically natural flow regimes, none of the PES classes at any of the sites are in an A (near natural) class, some are in a C (moderately modified) class, and geomorphology in the Udagaji tributary is in a D (largely modified) class because of poor land management. It appears that some of the degradation at sites may be caused by extensive use of agrochemicals for agriculture and the use of poisons for fishing. However, there may also be other non-flow stressors that did not become apparent in this largely flow-focused study. Unless these other causes of environmental degradation are also addressed as part of a fully integrated catchment management plan, flow management alone will not achieve the required outcomes.

This study was intended to add site specificity to the rapid EFA conducted under IRRIP2 in November 2013 (Kashaigili 2013) prior to the current study. In **Figure 5.1**, we illustrate the differences between our recommendations and those of the rapid assessment. Our recommendations are in all instances higher than those of the rapid EFA, but the explanation for these differences is not uniformly due to the site specificity added by our analysis. In the case of Lwipa and Udagaji (**Figure 5.1**, panels a and b), the differences may be attributed to differences in the hydrological analysis, as the natural flow levels estimated in the rapid EFA were considerably lower than those used in our analysis. At Mpanga and Ifakara (**Figure 5.1**, panels c and d), the hydrological analyses were more consistent, and the differences can be attributed more to site specificity. In both cases, we found dry season recommendations of the rapid EFA and our analysis to be consistent, while our site analyses found that higher environmental flow levels were needed to maintain ecological processes and related services during the wet season.

Figure 5.1: Comparison of Monthly Baseflow Recommendations for Maintenance Year from Rapid EFA and from This Study (BBM EFA)



Notes: Month 1 is October, start of hydrologic year. Recommendations shown for a) Lwipa, b) Udagaji, c) Mpanga, and d) Kilombero River at Ifakara Ferry.

The purpose of an EFA is to assess the flow regime that must be maintained in given river reaches to achieve specific social-ecological objectives. The purpose of the EFA is not to assess how this regime can be maintained. Maintaining environmental flow levels, or the reserve in this case, is a task for water managers in the context of water resource management planning and using all of the instruments and tools available to meet resource allocation objectives. The results of this EFA do, however, illustrate differences between flow requirements in different zones of the basin that may influence future planning and decision-making. We offer the following observations to illuminate these relevant issues without intending that they be interpreted as recommendations for future management actions. These observations primarily relate to the dry season, as wet season flows, including flood events, are not expected to be significantly affected by the proposed irrigation schemes.

We found that environmental flow requirements in the spawning zone of the Udagaji River (Site 2) account for 80 to 100 percent of mean monthly flows during the dry season of maintenance years, indicating that this river reach and likely other piedmont spawning reaches in the basin are highly sensitive to dry season flow reductions. This suggests that significant water withdrawal points should be placed downstream of these reaches unless water stored during the wet season can be released to maintain dry season flows. In cases where weirs or other barrages are placed between these spawning reaches and the Kilombero floodplain, great care should be taken to build in fish passages, allowing seasonally migrating species to access piedmont spawning areas.

We found that environmental flow requirements in the transition zones of the Lwipa (Site 1) and Mpanga (Site 3) rivers account for 50 to 70 percent of mean monthly flows during the dry season of maintenance years, indicating that these river reaches are less sensitive to dry season flow reductions than upstream foothill reaches or downstream floodplain reaches. This finding reinforces the observation that water abstractions would be best focused in this zone, especially in the absence of storage structures.

We found that environmental flow requirements in the floodplain zones of the Kilombero River at Ifwema and Ifakara again account for greater than 80 percent of mean monthly flows during the dry season of maintenance years. This indicates that, in the absence of storage, full development of the allocable water resource (flow levels in excess of the reserve) in river reaches of the valley transition zone likely will lead to degradation of floodplain social-ecological conditions and services during the dry season. Future studies might find that dry season flow releases from planned reservoirs on the Ruhudji, Mpanga, and Mnyera rivers can both meet larger dry season irrigation requirements and environmental flow requirements of the floodplain. However, it seems likely that floodplain dry season environmental flow requirements will be a decisive factor in upstream allocation decisions.

Likewise, environmental flow requirements determined in the Kilombero River around Ifakara Ferry will serve as a control point for allocation decisions upstream of this point. Environmental flow recommendations at Ifakara Ferry account for approximately 70 percent of total annual discharge from the basin, which amounts to an estimated 10.4 bcm y^{-1} of discharge to the Lower Rufiji Sub-Basin. Given that the total projected irrigation water requirement for the Kilombero Sub-Basin may be 2.5 bcm y^{-1} by 2035 (WREM International 2015i) and that the total annual discharge of the sub-basin is estimated in the same assessment at near 14 bcm y^{-1}, there is potential within the sub-basin to meet projected irrigation water requirements. The Kilombero Sub-Basin cannot, however, be managed in isolation, and its plans and environmental flow requirements should be considered in the context of the broader Rufiji Basin.

The timing of this EFA, before any significant reduction in flows, is well planned. For the vast majority of rivers, environmental flows are only considered when serious problems are experienced because of over-abstraction and allocation. This then requires that existing water uses must be curtailed in order to increase river flows, and the resulting resistance of affected users is obvious. For the Kilombero, the recommended environmental flows are still in the river, so that implementation is a matter of planning to retain the necessary flows (flow protection) rather than reinstating them (flow restoration). This EFA has demonstrated that there is still potential for considerable additional development of the water resources of the Kilombero, if carried out carefully and with attention to seasonal requirements, without a societally unacceptable level of environmental degradation.

5.2 Present Understanding of Additional Rufiji Basin Environmental Flow Needs

The ultimate goal and responsibility of the RBWB is to set environmental flows for all water bodies in the Rufiji Basin. However, setting environmental flows at the level of detail we applied in the Kilombero River Valley is not feasible in the immediate term at the full basin scale (though feasible with sufficient allocation of resources; e.g., see Poff et al. 2010 for one viable approach). At a basin-wide scale, the Rufiji IWRMD Plan sets the precautionary goal of limiting the modification of river flow regimes to no more than 20 percent variation from natural flow levels. This is arguably a suitable approach for areas of the basin under low pressure for water resources development. In areas targeted for more significant development, the next level of analysis is the application of desktop EFA methodologies. This approach was initially applied under IRRIP2 in the Kilombero Valley in 2013 (Kashaigili 2013) and has recently been applied in the Lower Rufiji Sub-Basin (and again in the Kilombero) as part of the Rufiji IWRMD planning process (WREM International 2015i). This approach provides more detailed recommendations, but they lack specificity to meet local social-ecological objectives. Where significant development of water resources is imminent, or already implemented, it is recommended to conduct detailed holistic environmental flow assessments that set environmental flow levels based on detailed studies that provide the highest possible level of confidence in meeting local social-ecological objectives of the reserve. In this subsection, we review the status and needs for environmental flow analysis in the other three sub-basins of the Rufiji Basin, with special attention to the Lower Rufiji Sub-Basin.

5.2.1 Environmental Flows for Great Ruaha Sub-Basin

The Great Ruaha is the most heavily utilized of the major tributaries in the Rufiji River Basin and already experiences severely depleted river flow levels in certain reaches during the dry season. The most impacted river reaches are near the Usangu wetlands and downstream of Ngiriama in Ruaha National Park. For this reason, these reaches were the focus of a holistic environmental flow assessment carried out by WWF from 2008 to 2010. It is noteworthy that the EFA for the Middle Great Ruaha River was considered by the assessors to be a contingency measure, simply designed to get some flowing water into the river within the mainstem reach in the National Park during the dry season. Most of the effort was spent looking at options for short-term implementation of some flow into the river downstream of the Usangu Wetlands (e.g., a dam and transfer of water from the Ndembera tributary, which presently flows into the wetlands, into the Great Ruaha downstream). Therefore, the recommended dry season flows were considered very low and should be refined and increased to sustainably meet specific ecological objectives. However, the results of this assessment remain valid and have been addressed in the Rufiji IWRMD Plan (WREM International 2015a). The Little Ruaha River has also undergone significant development over recent decades and does not yet have a full EFA. It has been prioritized for assessment within the Rufiji IWRMD Plan. Both Usangu and the Little Ruaha are targeted for major development in SAGCOT plans, but it is unlikely that targets can be fully realized without further significant declines in the ecological status of the sub-basins’ rivers and adjoining wetlands.

Management responses in the Rufiji IWRMD Plan include ambitious targets for reduced consumptive water use through improved technologies for irrigation, water abstraction, and conveyance. Carefully placed and operated storage is also considered, noting that increased storage should not be used solely to expand irrigation, but also to provide for dry season environmental flows. Other measures are recommended, including better monitoring of water withdrawals from rivers and wells, enforcement of stricter penalties for illegal water abstraction, implementation of a watershed-based water permitting assessment process, pricing strategies encouraging water conservation, and other incentives toward higher water use efficiency, including switching to less water intensive crops (WREM International 2015a). Overall, the precautionary goal of altering natural flow regimes by no more than 20 percent is set for the Great Ruaha Sub-Basin.

5.2.2 Environmental Flow Needs of Luwegu Sub-Basin

The Luwegu is currently a free-flowing river and is expected to remain free flowing for the foreseeable future, with the majority of the 25,288-km^2 catchment contained in protected reserves (**Figure 2.10**). Moreover, the consumptive water demands of the roughly 90,000 people living in the basin are expected to grow by a factor of less than two over the same period. Because of the protected status of the sub-basin and absence of immediate threats to river flows, the Rufiji IWRMD Plan (WREM 2015a) includes no specific management actions.

In the longer term, however, there are significant plans for irrigation development in the sub-basin (including water intensive crops such as sugarcane and rice) that could seriously deplete dry-season flows (in August to December for up to 60 percent of the time) in the Luwegu River to below an EMC A class under 2015 to 2035 water use scenarios. Ecological repercussions would be likely as well as a similar risk of agricultural water deficits if only surface water is used (WREM International 2015j). Impacts are anticipated to be potentially even more significant in the specific regions where development is planned, but this cannot be assessed at present given the current poor hydrological understanding of the sub-basin. There is evidence that the sub-basin has significant groundwater reserves, but far greater understanding of their potential for use is needed. Therefore, a precautionary conjunctive groundwater-surface water strategy has been recommended for the future under the IWRMD Plan along with hydrogeological investigation of the aquifer and systematic groundwater and surface water monitoring. Ongoing and planned future mining activity in the upper catchment could have some future implications in terms of increased water abstraction and decreased downstream water quality. Moreover, although a water-abundant region, climate change is expected to progressively reduce freshwater resources in the region by 10 percent over the long term such that projections for combined climate and water use impacts could exceed 18 percent by 2035.

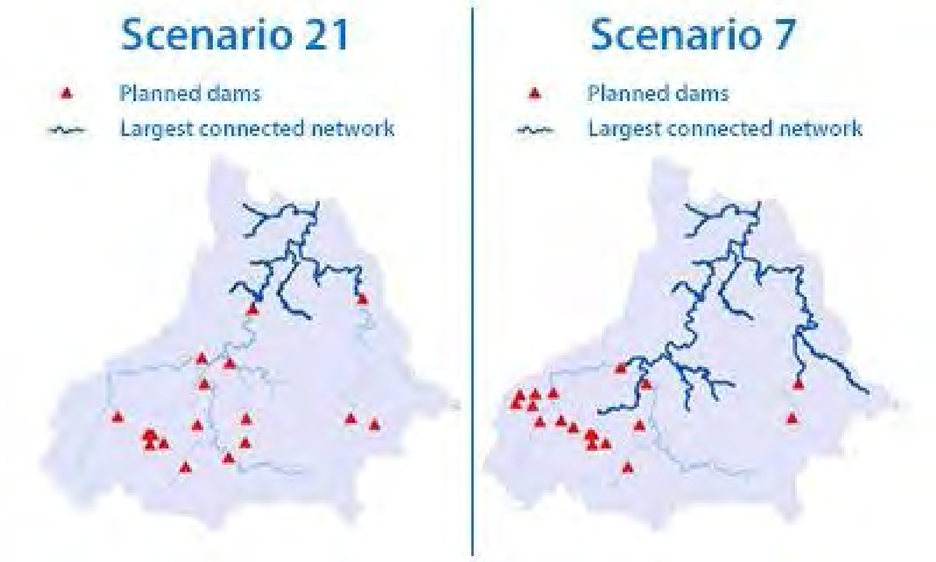
Importantly, the present preservation of flows in the Luwegu River is a positive factor for the Lower Rufiji Sub-Basin, as the Luwegu is estimated to supply approximately 20 percent of its flow. It also has the potential to act as a refugium for riverine biota and re-set mechanism for the ecology and geomorphology of the mainstem Rufiji. No recent assessments of the river health and value of the Luwegu system appear to have been conducted.

5.2.3 Importance of Maintaining River System Connectivity in Rufiji Basin

It is vital to consider the Rufiji River in its entirety as an interconnected network where environmental flows and other key factors combine to maintain the system's integrity (see also Section 4.11). The lower reaches of the Rufiji ecosystem are particularly at risk from the network fragmentation effects of both physical (e.g., a dam or high weir) and functional (e.g., a major change in natural thermal regime from warm to cold water or from turbid to clear water) barriers on the system. Moreover, the detrimental effects on overall system integrity and connectivity have the potential to be propagated in both upstream and downstream directions through the river network. For instance, the Kilombero EFA revealed several species that use the lower reaches for feeding, migration, and spawning passage between the marine, estuary, and upstream freshwater environments. These include catadromous *Anguilla* spp. (which spend most of their lives in fresh water then migrate to the sea to breed), various long-distance migratory fish species that spawn in the headwater streams of the Kilombero River, and migratory crustaceans (e.g., *Macrobrachium* spp.; **Annex L**). As yet, many of these species' movements and associated requirements are poorly understood. Therefore, there is a real risk of negative impacts associated with potential disconnection of and loss of access to ecologically and socio-economically vital parts of the river network in the case of the Rufiji system.

Case study examples highlighting this issue include the Coatzacoalcos Basin, the seventh largest basin in México (Barajas et al. 2014) and an Amazon sub-basin (Opperman et al. 2015). The Coatzacoalcos Basin, México, serves as an illustrative case, based on data from some 30 planned hydropower projects (Barajas et al. 2014). The Federal Electricity Commission (Comisión Federal de Electricidad), The Nature Conservancy (TNC), and the National Commission for Knowledge and Use of Biodiversity (Comisión Nacional para el Conocimiento y Uso de la Biodiversidad) worked together, using multiple criteria – technical, social, and environmental – to screen individual hydropower projects and compare scenarios of possible dam configurations. They demonstrated how early stage integrated infrastructure and environment planning can have a significant positive impact on the health of the downstream river network and its human communities at the scale of the entire basin.

Figure 5.2: Comparison of Two Scenarios of Future Hydropower Development in Coatzacoalcos River Basin, México



Source: Barajas et al. 2014; Opperman et al. 2015.

Comparing just two of the 25 future scenarios they examined (**Figure 5.2**), we can see that one configuration, Scenario 21, which includes a hydropower project in the lowermost reaches of the river system (as is proposed for the Lower Rufiji at Stiegler's Gorge), severely reduces flow regime quality and aquatic connectivity, leaving 970 km of the watercourse fragmented. By contrast, Scenario 7 leaves less than half as much (452 km) of the river system fragmented. Notably, despite their vastly different ecological and social sustainability outcomes, both scenarios in this example were demonstrated to have similar potential hydropower generation output.

The proposed hydropower dam at Stiegler's Gorge is anticipated to have a positive impact on the Rufiji River in mitigating expected upstream impacts on low flows from future irrigation abstraction (according to WREM 2015j). This is arguably an environmentally inappropriate rationale under the wetland mitigation hierarchy: 'avoid' as the first priority, then mitigate (e.g., through environmental flows), and finally, offset. There are also few cases to date, particularly in relatively underdeveloped river basins with limited large water resources infrastructure in place, where a dam of the scale proposed in the Lower Rufiji would benefit the downstream ecosystem. It does allow for environmental flow releases to be made, including floods, and could afford some sediment passage if designed with these two operational requirements in mind. The potential negative impacts presented by the physical (hard) infrastructure barrier are important considerations. In the lower river system, such physical barriers may exert detrimental ecological impacts in concert with the impacts of so-called 'soft barriers' (due to the presence and mode of operation of a dam or other flow regulation structure) such as altered thermal, nutrient, and sediment regimes.

6 CONCLUSIONS AND RECOMMENDATIONS

In this report, we have presented and discussed the results of a holistic, field-intensive environmental flow assessment of rivers adjacent to four proposed irrigation schemes on northern tributaries of the Kilombero River Sub-Basin in the Rufiji Basin of Tanzania. Our assessment focused on reaches immediately downstream of the schemes and at upstream and downstream margins of the Kilombero River Valley Ramsar site, as these river reaches and social-ecological systems would be most impacted by the proposed water withdrawals. We also identified the main flow dependencies of the Lower Rufiji Sub-Basin based on available literature and reviewed the status of environmental flow determinations basin wide (Section 4.11). Environmental flow requirements at the mouth of the Rufiji ultimately will control the total level of consumptive water use and flow regulation that is allowable throughout the upstream basin.

In the Kilombero Sub-Basin, we distinguished between three river zones, which exhibited distinct flow related social-ecological characteristics, and we investigated study reaches in each. The most upstream zone was the piedmont spawning zone, positioned at the foot of the Udzungwa Mountains on the northern divide of the sub-basin. Here, we assessed environmental flow requirements at one site on the Udagaji River, adjacent to the proposed Udagaji and Mgugwe schemes. We found this zone to be vulnerable to future water withdrawals, as monthly environmental flow recommendations amounted to 67.6 percent of MAF. In the transition zone beyond the foot of the mountains, we assessed environmental flow requirements in the Lwipa River adjacent to the proposed Kisegese Scheme and the Mpanga River adjacent to the proposed Mpanga Scheme. These transition zone river reaches were less vulnerable to water withdrawals, with monthly environmental flow recommendations of 50.6 and 57.4 percent of MAF. Finally, we investigated two sites on the mainstem Kilombero River at Ifwema and Ifakara Ferry, upstream and downstream of the Kilombero River Valley Ramsar Site. Here we again found higher vulnerabilities to water withdrawals, especially in the reach of the Kilombero River at Ifwema, near the upstream margin of the Ramsar site. At these sites on the mainstem, the monthly environmental flow recommendations were 82.3 percent of MAF. Near the outlet of the Ramsar site at Ifakara Ferry, the monthly environmental flow recommendations amounted to 67.4 percent of MAF.

These percentages all relate to maintenance years when sufficient water is available to meet all social-ecological objectives targeted in the EFA. During drought years, environmental flows require a higher percentage of total river discharges. The environmental flow recommendations also included recommended high flow events, which are expected to occur naturally in the absence of significant dams and reservoirs. If dams and reservoirs are constructed on the Mpanga, Ruhudji, and Mnyera rivers, these high flow pulses may need to be programmed into the operational rules for downstream flow releases from the dams.

In the Lower Rufiji Sub-Basin, the desktop environmental flow recommendations of WREM International (2015i) amount to 50 to 70 percent of MAF to maintain the river in a category B to A environmental management class, respectively. These recommendations, while not based on site-specific social-ecological characteristics, are within the range of recommendations made for the detailed Kilombero study sites. They also appear feasible given planned water use projections in the Rufiji IWRMD Plan, but additional analysis will be required to arrive at recommendations of similar confidence level to those provided for the Kilombero sites.

6.1 Using the Results of this Study

Environmental flow recommendations generated in this study are intended as inputs to water allocation planning by the RBWB, which has the responsibility to approve, issue, and revoke water use permits. The total amount of water available for allocation in any water body (the allocable resource) is the difference between the natural flow and the reserve, which will vary seasonally and from year to year, depending on the type of water year (wet, normal, or dry). The flow recommendations presented in this report are intended to inform the RBWB on reserve levels recommended for the Udagaji, Lwipa, and Mpanga rivers and sections of the mainstem Kilombero River, extending from Ifwema to Ifakara Ferry.

Based on these environmental flow recommendations and natural flow levels in these rivers (also estimated in this study), the RBWB can calculate the allocable resource. The finest practical time interval for quantifying the allocable resource is monthly. Our environmental flow recommendations are also made at monthly intervals, distinguishing between maintenance and drought years. Because "maintenance" refers to years in which sufficient water is available to meet all specified social-ecological objectives, the recommendations for maintenance years apply to both wet and normal water years. Monthly recommendations can be integrated at seasonal or annual levels if desired. The environmental flow recommendations also include high flow pulses. These are important in situations where river flows are regulated by storage in reservoirs large enough to absorb flood peaks. In such situations, flood pulse releases may be incorporated into the operational schedule of the dam. In situations without significant storage, it is expected that flood pulses will occur naturally in the river.

Water use permit applications in Tanzania ask the applicant to specify the volume of water needed in units of m^3 day^{-1}, and the volume applied for is not necessarily granted to the applicant. Information is not requested about how this daily volume might vary in response to seasonal and inter-annual climatic conditions (especially rainfall levels). We do not know exactly how the RBWB evaluates these daily requested volumes relative to their information on the allocable resource or how they reflect this need in the actual permit, but our recommendations would allow for their calculation and the eventual permit to be expressed in units of average daily availability/abstractions per month.

6.2 Recommendations for Follow-up Activities

The detailed environmental flow recommendations resulting from this study are ready for adoption by the RBWB in its basin planning and water allocation activities. They will be relevant to the issuing of water use permits for new irrigation schemes developed adjacent to the northern tributaries of the Kilombero River Valley (or other abstractors). In addition, the detailed flow recommendations set for the Kilombero River at Ifwema and Ifakara Ferry may be used to set an upper limit for the total combined volume (quantified monthly) of water use permits advisable upstream of these points. The high flow pulse recommendations are also ready for adoption in the operational schedules of newly constructed dams and reservoirs. These recommendations should be reviewed on a regular schedule (e.g., each 5 years), especially in consideration of future definition of the flow requirements of the Lower Rufiji Sub-Basin. It will be necessary for the RBWB to consider how, specifically, it will apply the recommendations in the calculation of permitted abstractions in water use permits.

The information summarized in this report on the flow dependencies of the Lower Rufiji Sub-Basin highlight some of the main social-ecological justifications for establishing environmental flow recommendations. They complement the desktop environmental flow recommendations made by WREM International (2015i) using the DRM, which include a range of recommended monthly flows related to different levels of social-ecological protection (A through D). Comparisons between our holistic flow assessment and applications of the DRM in the Kilombero Sub-Catchment revealed a moderate degree of correlation, but our detailed recommendations tended to call for higher flows (on the order of 20 percent higher). Given that the environmental flow requirements of the Lower Rufiji Sub-Basin will ultimately control the total level of water abstractions and regulation possible in other sub-basins, it is imperative to conduct a detailed environmental flow assessment of the mainstem and delta reaches of the Lower Rufiji prior to committing to further major consumptive water allocations or regulation upstream, including in the SAGCOT area. Assessing the environmental flow requirements of the brackish and saline components of the Lower Rufiji Delta and Estuary will require special expertise and analytical approaches.

Across the larger Rufiji Basin, there is a need to develop environmental flow recommendations in a hierarchical fashion. This is achieved by establishing simple precautionary recommendations at a basin scale (as done in the IWRMD Plan), applying desktop approaches in priority areas ahead of any specific development activities, and applying detailed holistic approaches in the context of project feasibility planning (as has been done in the northern tributaries of the Kilombero Valley). The Ministry of Water is in the process of establishing national guidelines for the determination of environmental flows, and these should be applied as soon as possible after being finalized (URT 2016). The application of other international basin-scale approaches, such as the Ecological Limits of Hydrologic Alteration (Poff et al. 2010) may also help to expedite the environmental flow setting process.

Members of the Expert Review Panel for this report, in addition to recommending many improvements to the text, were asked to consider next steps needed in implementation. They concur that environmental flow recommendations in this study should be adopted in the IWRMD Plan for the relevant rivers of the Kilombero Valley. They also recommend that additional assessment efforts be carried out in headwater sections of the basin and in the Lower Rufiji Sub-Basin. In the Kilombero Sub-Basin, they recommend additional assessment activities near other long-term hydrological measurement stations such as the Ruhudji River at Mwanamulungu (station 1KB10), the Mnyera River at Taveta (station KB9), and the Lumemo River at Ifakara (station 1KB14A). Members called for clear and understandable communication of the results of this assessment to the widest possible number of stakeholders. They also suggested that the results of the present EFA should be viewed in a wider perspective, basin-scale (e.g., Rufiji IWRMD Plan), nationally (e.g., institutional and legal framework), and internationally (e.g., Ramsar Convention). They considered this as important as avoiding unnecessary conflicts among the various interests within the basin. Noting the importance of having the draft national EFA guidelines in place as soon as possible, they reiterated the imperativeness of conducting a full EFA in the Lower Rufiji Sub-Basin.

We wish to highlight the importance of linking the results of this EFA back to multiple levels of planning and the regulations needed to achieve sustainable development of Tanzania's water resources. These include (1) the Rufiji IWRMD Plan and decision support system, (2) national law/policy, (3) international conventions and commitments such as the Ramsar convention to which Tanzania is a signatory, (4) environmental flows framework for Tanzania, and (5) capacity development – technical and institutional. While the main objectives of this study were the detailed assessment of environmental flow requirements of rivers of the Kilombero Valley and review of flow related social-ecological processes in the Lower Rufiji Sub-Basin, consideration was also given to development of local capacity to continue conducting high-quality EFAs. Emphasis should continue to be placed on developing the technical and coordination capacity of Tanzanian professionals in the execution of EFAs.

Environmental flow assessment and future monitoring of the performance of management plans rely on the availability of high quality data about the hydrology, hydraulics, geomorphology, ecology, and socio-economics of river systems. Information about these topics is limited in the Rufiji Basin, and this hampers efforts to provide reliable guidance in planning and regulation of development activities. We recommend that the RBWB and related institutions prioritize efforts to improve data collection and system monitoring. Considerable effort is already being devoted to this, and development partners are stepping in to assist in refurbishing monitoring equipment. We also recommend that the RBWB seek out new and innovative partnerships, especially with Tanzanian and international knowledge institutions that will contribute to continued and coordinated information gathering and knowledge generation about the basin and its resources. Priority areas should include freshwater biodiversity surveys, river health assessments, and state of the basin reporting. Improved information on water abstractions and efficiency of water use is also needed. New information and knowledge should be incorporated into the Rufiji Decision Support System for application in planning and decision-making.

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ANNEXES

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Technical Assistance to Support the Development of
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