Environmental Flow Recommendations for the Ruvu River Basin,

Tanzania

Tanzania Integrated Water, Sanitation and Hygiene (iWASH) program

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Environmental Flow Recommendations for the Ruvu River Basin

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List of Acronyms

BBM	Building Blocks Methodology
BWB	Basin Water Boards
BWO	Basin Water Offices
DO	Dissolved Oxygen
EF	Environmental Flows
EFA	Environmental Flow Assessment
EMC	Ecological Management Category
FIU	Florida International University
GLOWS	Global Water for Sustainability
IEFA	Initial Environmental Flow Assessment
IFIM	Instream Flow Incremental Methodology
IUCN	International Union for Conservation of Nature
iWASH	Integrated Water, Sanitation and Hygiene
NAWAPO	National Water Policy
SEAS	School of Environment, Arts and Society
USAID	U.A. Agency for International Development
WADA	Water and Development Alliance
WRBWO	Wami/Ruvu Basin Water Office

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Institutional Collaborators

The Tanzanian Ministry of Water

The Tanzanian Ministry of Water main offices are located at Ubungo, Dar es Salaam. The Ministry has several Directorates responsible for Urban Services, Rural Services, Water Resources Management, Policy and Planning, and Public Administration and Human Resources. For the purpose of water resources management, Tanzania has established Basin Water Boards in the nine main catchment areas: Rufiji Basin, Wami/Ruvu Basin; Pangani Basin; Internal Drainage Basin; Lake Victoria Basin, Lake Tanganyika Basin, Ruvuma Basin, Lake Nyasa Basin, and Lake Rukwa Basin. The Ruvu and Wami environmental flow analyses were implemented in collaboration with the Wami/Ruvu Basin Water Office, under the auspices of the Directorate for Water Resources.

Wami/Ruvu Basin Water Office

The Wami/Ruvu Basin Water Office (WRBWO) is tasked with management of water resources in three of the country's most important areas: the Wami River Basin, the Ruvu River Basin, and the coastal drainages. Administratively, all three of these are collectively referred to as the Wami/Ruvu Basin. The WRBWO was established in July 2002 with its headquarters in the town of Morogoro and the two Basin offices located in Dodoma Municipality and Dar es Salaam City. Its jurisdiction area covers parts of the administrative regions of Dodoma, Manyara, Morogoro, Coast, Tanga, and the whole of Dar es Salaam. The WRBWO is one of nine basin water offices in Tanzania under the overall structure of the Tanzanian Ministry of Water.

Florida International University (FIU) / Global Water for Sustainability (GLOWS) program

Florida International University (FIU) in Miami, Florida, USA, is one of the 25 largest universities in the USA, with student enrollment in excess of 50,000. FIU is the largest minority serving institution in the USA. FIU is the lead institution for the Global Water for Sustainability (GLOWS) program (globalwaters.net), a multi-partner initiative that aims to promote integrated water resources management and find solutions to water-related problems worldwide. The Environmental Flow Assessment (EFA) for the Ruvu River Basin initiative was coordinated under the GLOWS program with participation of researchers from the School of Environment, Arts and Society (SEAS) which includes the Department of Earth and Environment (earthenvironment.fiu.edu), the Department of Biological Sciences (biology.fiu.edu), a Geographic Information Systems Center (gis.fiu.edu), and the Southeastern Environmental Research Center (serc.fiu.edu).

Tanzania Integrated Water, Sanitation and Hygiene (iWASH) program

iWASH is one of the USAID funded GLOWS initiatives aimed at improving the health and economic resiliency of poor communities through supporting sustainable, market-driven water supply, sanitation, and hygiene services within an integrated water resource management framework. iWASH has adopted an innovative and holistic approach to provision of WASH services, including water for productive uses. These activities are nested within a larger watershed management approach, which aims to build capacity of local institutions mandated with water resource management responsibilities, to build capacity of communities to better manage their water resources, and to increase the knowledge and information available for more informed water resource planning and decision making.

Water and Development Alliance (WADA)

The Water and Development Alliance (WADA) is a collaboration between the Coca-Cola System (including corporate, foundations and bottling partners) and the U.S. Agency for International Development (USAID) to improve water resource management and expand access to improved drinking water and sanitation services for poor and marginalized people in developing countries. WADA has impacted more than 374,000 people with improved water access in Africa, Asia and Latin America. Additional people have been impacted through sanitation, watershed restoration, sustainable agriculture, conservation and other activities.

USAID is the lead U.S. Government agency that works to end extreme global poverty and enable resilient, democratic societies to realize their potential. Through the assistance programs, USAID plays an active and critical role in the promotion of U.S. foreign policy interests. The investment made in developing countries has long-term benefits for America and the American people.

Acknowledgments

In early 2007, the Tanzanian Ministry of Water's Wami/Ruvu Basin Water Office (WRBWO) and Florida International University began a collaborative effort to better understand rivers of the Wami/Ruvu Basin and to operationalize components of the new water policies in Tanzania as related to maintaining adequate quantity, quality, and timing of flows for ecosystems. To that end, an initial Environmental Flow Assessment (EFA) of the Wami River Basin was conducted in 2007, and as part of this effort a team of Tanzanian scientists primarily from the University of Dar es Salaam was assembled. We are grateful to the University of Dar es Salaam for offering a space for the involvement of these scientists, most of whom continue to work on EFA and have also been part of this initiative in the Ruvu River Basin.

Since 2007, the Ruvu Basin has loomed as the target for another EFA initiative. The entire team is grateful for the opportunity to have studied both the Wami and now the Ruvu river systems, two of East Africa's most important. The information presented here is the result of these scientific studies, but also represents a 7-year process of collaboration and capacity building in EFA in Tanzania.

We would like to extend our most sincere thanks to the Tanzanian Ministry of Water, in particular the Directorate for Water Resources for their continuous and positive guidance to these initiatives in first the Wami and now the Ruvu Basin. But we also offer them our thanks for their staunch support of EFA in Tanzania in general. The institutional and legal framework for EFA is stronger in Tanzania than in the overwhelming majority of countries worldwide, and this fact is largely due to the dedication of the staff from the Directorate for Water Resources. Neither this Ruvu EFA, nor its predecessor in the Wami, would have been possible without the continuous support and interest on the part of the Wami/Ruvu Basin Water Office (WRBWO). The involvement of numerous staff from the WRBWO has helped to broaden and deepen the knowledge of EFA in Tanzania, and the WRBWO has emerged as a national leader in this area. It is our hope that the process, collaborations, and the present document serve as support for the management tasks under the WRBWO's responsibility.

A long list of colleagues from diverse institutions contributed their time and expertise to provide guidance to the Ruvu EFA at various stages. In particular we would like to thank Michael McClain, Jay O'Keeffe, Amanda Subalusky, and Chris Dutton for their interest in the Ruvu EFA from start to finish.

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The work was funded under the Water and Development Alliance (WADA), a collaboration between The Coca-Cola Africa Foundation (including corporate, foundations and bottling partners) and the U.S. Agency for International Development (USAID) to improve water resource management and expand access to improved drinking water and sanitation services for poor and marginalized people in developing countries. Our sincerest recognition goes to Gilbert Kajuna of USAID/Tanzania and Kyle Sucher of the GETF-WADA team for their encouragement of this initiative.

Executive Summary

The Ruvu Environmental Flow Assessment (EFA) was an interdisciplinary effort to develop a first set of environmental flow recommendations for rivers of the Ruvu Basin, Tanzania. EFAs have become a common and scientifically accepted method for determining the quantity, quality, and timing of flows needed to sustain freshwater ecosystems and ecosystem services. EFAs recognize that rivers have natural periods of both high and low flows, and that these variations play important roles in river ecosystem functioning and thus should be protected as components of the reserve. In Tanzania, national water policies and laws call for the protection of the reserve or environmental flows in all aquatic ecosystems. In fact, freshwater needs for ecosystems are accorded second priority in decision-making about water allocations in Tanzania, following basic domestic uses of water. Toward this end, the Ruvu EFA aimed to fill an important gap in scientific information for management of water resources in the basin. This effort was conducted by a diverse team, which included the Tanzanian Ministry of Water, the Wami/Ruvu Basin Water Office (WRBWO), and Tanzanian and international scientists (hydrologist, hydraulic engineer, aquatic ecologist, fluvial geomorphologist, and riparian specialist).

The Ruvu River is one of the major East African rivers that drain the Eastern Arc Mountains, with a basin area of approximately 18,000 km^2. This basin is typically sub-divided into smaller catchments: the Mgeta, Ngerengere, Upper Ruvu of the Morogogo region, and the Middle and Lower Ruvu in the Coast Region. The Ruvu River and its tributaries are one of the systems that form part of the Wami/Ruvu Basin, an administrative designation by the Tanzanian Ministry of Water under which the Ruvu, Wami, and coastal drainages are collectively managed by the WRBWO.

The Ruvu EFA was a process-based approach to EFA, which relied on components of internationally accepted EFA methodologies, most notably the Building Block Methodology and the Savannah Process. The Ruvu EFA process began in 2012, when the project team was assembled and literature reviews of information on the basin were conducted. Five focus sites within the Ruvu Basin were selected during a reconnaissance study in 2012. These sites were: Ruvu River at Kibungo, Mgeta River at Duthumi, Ngerengere River at Mgude, Ruvu River at Kidunda, and Ruvu River at Kongo. Sites were selected on the basis of their representativeness of critical areas of the larger Ruvu Basin, or because of their importance to management. Field campaigns during dry and wet seasons took place in 2012 and 2013, respectively. All existing data from previous studies and newly collected data from the Ruvu EFA sponsored field campaigns were synthesized into two starter documents, which formed the basis of information to prepare for establishing environmental flow recommendations at the five sites.

Management objectives were established and environmental flow recommendations were developed during two workshops that brought together the entire Ruvu EFA team. Discussions considered the overall trends in the Ruvu Basin and the current challenges facing the WRBWO and Tanzania in terms of sustainable use of water resources. For each of the five sites, a facilitated set of exercises and discussions established the present ecological state, trajectories of change, and ecological or social sensitivity; on the basis of these considerations, an environmental management class (EMC) of A-D and goal (maintain, restore, accept degradation) was established. This management goal then helped guide further facilitated exercises and discussion about the flow needs of ecosystems at each site, during drought years and maintenance years, and during dry and wet months of each of those years. Scientific experts used data collected from the Ruvu Basin, existing information, and professional judgment to make specific suggestions for environmental flows for different components of the river system (e.g., fish, macroinvertebrates, riparian vegetation, water quality, sediment transport, etc.). For each of the five sites, a final environmental flow recommendation was agreed upon by scientific consensus, following consideration of each of the experts' perspectives, and with input from the WRBWO. A summary of the goals for environmental flows at each site follows:

- Ruvu River at Kongo: Environmental flow recommendations were set with the goal of halting current negative trajectories toward degradation and maintaining the site in the present condition.
- Mgeta River at Duthumi: Environmental flow recommendations were set with the goal of restoring the site to a desirable management class that is higher than the present state.
- Ruvu River at Kidunda: Environmental flow recommendations were set with the goal of maintaining this site in a C class, although this will be a challenge given all of the impending changes. A buffer zone restoration program would also be of interest at this site.
- Ngerengere River at Mgude: environmental flow recommendations were set with the goal of restoration of this site and improvement to a higher class than the present state.
- Ruvu River at Kongo: environmental flow recommendations were set with the goal of first stopping the negative trajectory and then maintaining the site.

The Ruvu River Basin is now the fifth major river basin in Tanzania for which there exists a comprehensive EFA study. Collaboration between water managers and scientists was a cornerstone of the Ruvu EFA. The realization of the Ruvu EFA has helped to continue the process of capacity building around EFA in Tanzania, and has helped to solidify the advances that the East Africa region has made in recognizing the importance of freshwater flows for ecosystems and of allocating water accordingly. The flow recommendations made by the Ruvu EFA should be revisited periodically, either as conditions of the landscape or of rivers in the basin change, as new management challenges arise, or as additional scientific information becomes available.

Figure 1: The Ruvu River

Introduction: Why an Environmental Flow Assessment in the Ruvu Basin?

Freshwater resources are essential to human life and livelihoods, as well as important components of natural landscapes, sustaining both aquatic and terrestrial ecosystems. The challenging task facing those charged with management of freshwater resources is balancing human needs for water with those of nature to ensure adequate access to water resources without undue environmental degradation. This equilibrium approach to management requires sound understanding of freshwater systems and human uses of water, clear policies and strong legislation that recognize the environment as a user of fresh water, and capable institutions to guide the management process. Freshwater ecosystems harbor a disproportionate amount of global species richness in both plants and animals, which require minimum flows to be sustained. At the same time, rivers provide numerous ecosystem services for human populations, including clean drinking water, food, building materials, and religious and cultural values. These freshwater ecosystem services also require minimum flows to ensure their quality and availability.

Environmental Flow Assessments (EFAs) have become a common and scientifically accepted method for determining the quantity, quality, and timing of flows needed to sustain freshwater ecosystems and ecosystem services. EFAs are structured, science-based approaches that combine hydrological information about a river system with social, physical and biological indicators to determine the minimum sustainable flow levels needed to maintain all components of the river ecosystem. EFAs recognize that rivers have natural periods of both high and low flows, and that these variations play important roles in river ecosystem functioning and thus should be protected as components of the reserve. More than 200 different methodologies have been applied worldwide in determining environmental flows (Tharme, 2003) trending in recent years towards those approaches that consider water needs of ecosystems in a 'holistic' or multidisciplinary framework. At the opposite end of the EFA spectrum, other approaches are to protect only those flow levels that are equal to 10% of average annual flow or those flows that are exceeded 95% of the time according to a daily flow duration curve, a value also known as Q95. Although these flows occur naturally at times, they are insufficient to sustain all the components and processes of a healthy river ecosystem over time. Thus, in river systems in which more detailed information is available or can be attained, EFAs represent a further development in the process of determining and protecting sufficient reserve flows for riverine ecosystems.

This report presents an overall summary of the process and outcomes of the Ruvu EFA, conducted over the period 2012-2014. A large number of supporting studies were completed as part of the Ruvu EFA process by the project's scientific collaborators, and these are listed in this document's References section. The present document draws on information from these studies. The Ruvu EFA (Figure 1) was conducted under the Tanzania Integrated Water, Sanitation and Hygiene (iWASH) program and its component project, the Tanzania Water and Development Alliance II (WADA II); both of these initiatives are implemented through the Global Water for Sustainability (GLOWS) program with funding from the U.S. Agency for International Development (USAID), and in the case of WADA II, joint financial support from the Coca-Cola Foundation.

Context for Environmental Flow Assessment in Tanzania

Tanzanian national water policies and laws call for protection of reserve flows in all aquatic ecosystems (URT 2002, 2009). These reserve flows generally correspond to the quantity, quality and timing of water that needs to remain flowing in a river system in order to sustain basic human needs and aquatic ecosystems (Figure 2).

In general, water resources management in Tanzania is governed by the Water Resources Management Act No. 11 of 2009. For administration, Tanzania is divided into nine basins managed by the Basin Water Offices (BWO), which are under Basin Water Boards (BWB). These BWOs and BWBs were established as follows: Pangani (1991), Rufiji (1993), Lake Victoria (2000), Wami/Ruvu (2002), Lake Nyasa (2002), Lake Rukwa (2003), Internal Drainage (2003), Lake Tanganyika (2004) and Ruvuma and Southern Coast Rivers (2004). The Water Resources Management Act (2009) provides the institutional and legal framework for sustainable management and development of water resources. This act essentially has three objectives: it outlines the principles for water resources management; it provides for the prevention and control of water pollution; and it provides for participation of stakeholders and the general public in the implementation of the National Water Policy 2002.

Figure 2: Overview of the legal framework for water resources management and EFA in Tanzania highlighting recent advances in support for environmental flows.

Water resources management and EFA in Tanzania

Tanzania has recently passed legislation aimed towards ensuring access to safe water resources for all people, as well as sustaining the valuable ecosystems upon which these people depend. The principle of environmental flows is evident in the wording of these laws.

Tanzania National Water Policy (2002)
Recognizes the importance of environmental flows and prioritizes water use such that "Water for basic human needs in adequate quantity and acceptable quality will receive highest priority. Water for the environment to protect the eco-systems that underpin our water resources, now and in the future will attain second priority and will be reserved (Section 4.1.2)."

Tanzania Water Resources Management Act (2009)
Defines the reserve as "the quantity and quality of water required for (a) satisfying basic human needs… and (b) protecting aquatic ecosystems" and states that "the Minister shall…determine the reserve for the whole or part of each water resource which has been classified...and the Minister, the National Water Board, Basin Water Boards and all public bodies shall, when exercising any statutory power or performing any statutory duty, take into account and give effect to the requirements of the reserve (Section 37, 1-3)."

The National Water Policy (NAWAPO) passed in 2002, provides an overarching legal framework for water resources management, and the legal underpinnings for environmental flows. The goals of the NAWAPO 2002 are:

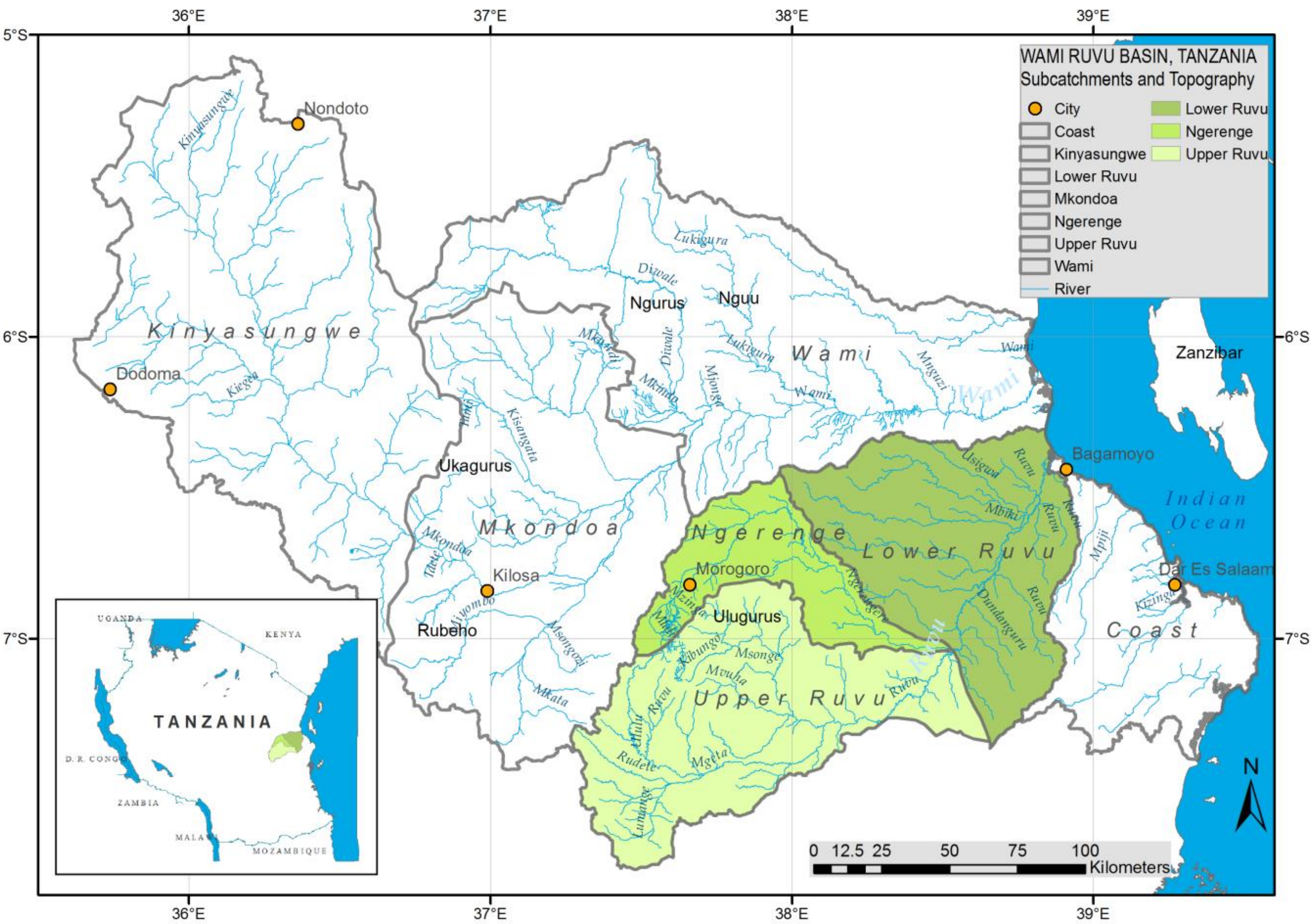
- To develop a comprehensive framework for sustainable development and management of the nation's water resources, putting in place an effective legal and institutional framework for its implementation.
- To ensure that beneficiaries participate fully in planning, construction, operation, maintenance and management of community-based domestic water supply schemes.
- To address cross-sectoral interests in water, watershed management and integrated and participatory approaches for water resources planning, development and management.
- To lay a foundation for sustainable development and management of water resources in the changing role of the government from service provider to that of coordination, policy and guideline formulation and regulation.

The priorities in water allocation as guided by NAWAPO 2002 are also noteworthy here. In allocating water for different uses, water for basic human needs in adequate quantity and acceptable quality receives highest priority. Sufficient water to protect the ecosystems that underpin Tanzania's water resources now and in the future attains second priority; this water will be reserved for the environment. Other uses will be subject to social and economic criteria, which will be reviewed from time to time. The Water Resources Management Act 2009 provides the institutional and legal framework for implementation of the policy.

Water Resources Management in the Wami/Ruvu Basin

Within Tanzania, the Wami/Ruvu Basin (Figure 3), with an estimated population of 7.28 million people (JICA 2013), is one of the most important areas of the country from both environmental and socioeconomic standpoints. The Wami/Ruvu Basin Water Office (WRBWO) was established in July 2002 with its headquarters in Morogoro, and two sub-basin offices located in Dodoma and Dar es Salaam. The WRBWO's jurisdiction covers parts of administrative regions of Dodoma, Manyara, Morogoro, Coast, Tanga and the whole of Dar es Salaam. The Wami/Ruvu Basin, as defined administratively, consists of the two main rivers of Wami and Ruvu—actually individual river basins from a geographic perspective—and the minor coastal rivers (Mpiji, Sinza, Mlalakuwa, Msimbazi, Mzinga, Kizinga and Mbezi) that all drain into the Indian Ocean, encompassing with a total area of 66,295 km^2 (Wami-43,742 km^2, Ruvu-17,789 km^2 and the Coastal-4,764 km^2; JICA 2013). The water resources in the basin are both surface and underground.

Figure 3: Wami/Ruvu River Basin, with the Ruvu Basin subcatchments colored in green. Inset shows location of Ruvu River Basin in Tanzania.



The WRBWO, responsible for management of water resources in the region, faces various challenges in the task of making informed and coordinated decisions regarding the allocation and planning of resource use in the basin. These include:

- having an appropriate institutional framework in place
- ensuring adequate data monitoring and data quality control
- ensuring compliance in water use and wastewater disposal
- financing of water resource development and management
- facilitating stakeholder participation
- conducting environmental flow assessments for rivers in the basin.

Environmental flow assessment (EFA) is a management tool that can assist the WRBWO to meet the challenges of balancing the diverse needs for water in a rapidly changing landscape. Specifically, EFAs are often used to draw the line between the amount of water that can be withdrawn from a river for human uses and the amount of water that the river needs to sufficiently maintain ecosystems. The process of conducting an EFA brings together specialists from different disciplines as well as stakeholders in the basin, and the emergent product is a quantitative estimate of the flow needs of the environment. Tanzania's water policies, by according the environment second priority as a user of water, provide the necessary legal backing for the EFA process. With its solid legal and institutional support for EFA, Tanzania has set a new standard for water resources management in East Africa. The Ruvu EFA, as described in this document, falls alongside other notable EFA efforts in the country in the Pangani, Mara, Wami, and Ruaha river basins.

The Ruvu Approach to EFA

More than 200 methodologies have been developed over the past half century to estimate the environmental flow requirements of a river as a proxy for answering the question that challenges freshwater ecologists and water resource managers worldwide: how much water does a river need (Richter *et al.*, 1997; Tharme, 2003)? Methodologies for environmental flow assessment (EFA) vary in levels of data requirements and complexity, and the majority fall into one of four general categories: (1) hydrology-based methodologies; (2) hydraulics-related methodologies; (3) habitat simulation methodologies; and (4) holistic methodologies, or hybrid methodologies derived from components of methodologies that fall in these different categories (Tharme, 2003).

In Tanzania, the main initiatives for EFA have fallen into the categories of hydrology-based methodologies, holistic methodologies, or hybrid methodologies. A review of EFA initiatives in four Tanzanian basins (Mara, Pangani, Wami, Ruaha) describes the strengths, limitations, and contributions to water resources management, and provides an overview of EFA approaches used (Dickens 2011). Noteworthy about the EFA processes in these four abovementioned river basins was that they involved Tanzanian scientists from the University of Dar es Salaam and other institutions and some were co-led by the respective Basin Water Offices of the Tanzanian Ministry of Water. Many of the same Tanzanian scientists participated in two or more of those EFA initiatives. Therefore in addition to providing additional information for water resources management, these EFAs also have helped to build in-country capacity for EFA in Tanzania.

The initiative presented here, the Ruvu EFA, has continued this same trend of improving information available for water resources management, while building capacity for EFA among the Ministry of Water staff and Tanzanian scientists. The Ruvu EFA process began in early 2012, starting with the formation of the Ruvu EFA team, and extended through January 2014, concluding with the setting of environmental flow recommendations for five sites in the Ruvu River Basin.

The approach employed by the Ruvu EFA was a hybrid of holistic methodologies, notably the Savannah Process (Richter *et al.* 2006) and the Building Block Methodology (BBM; King *et al.,* 2008). Both of these methodologies rely on the formation of a multidisciplinary team of scientific experts—a hydrologist, hydraulic engineer, geomorphologist, aquatic ecologist, riparian ecologist, and water quality scientist—to use their professional experience and judgment in the EFA process. Both methodologies also identify specific sites in a river basin where flow – ecology or flow – ecosystem services relationships are critical, or sites where a management intervention is needed, such as where a dam is being constructed. The BBM methodology incorporates field sampling campaigns during both wet and dry conditions, following which data from these field studies and information from the scientific literature are used to develop a flow 'prescription' for a river at a certain site (see King *et al.,* 2008 for full methodology description).

Figure 4: Critical indicators used to determine a river's natural flow regime and ecological health

Indicators of a river's natural flow regime and ecological health:

1. Functioning of natural sediment generation processes
    a. Presence of stable river banks
    b. Intact riparian zones
    c. Absence of large-scale erosion denuding landscapes
    d. Absence of excessive fine-scale sediment deposition in river channel
2. Occurrence of a variety of instream and riparian habitats to provide habitat for diverse species
    a. Adequate distribution of pools, runs and riffles
    b. Presence of lateral and channel bars
    c. Vegetated riparian zones that receive periodic inundation
3. Presence of sensitive species that reflect suitable water quality levels
    a. Rare or threatened fish species that depend on appropriate timing of variable flows for feeding and reproduction
    b. Sensitive invertebrate species that indicate subtle fluctuations in water quality and pollution levels
    c. Important riparian plant species that depend on seasonal inundation for germination
4. Adequate provision of human needs by water resources
    a. Year-round accessibility of water for domestic purposes
    b. High water quality to reduce the occurrence of disease
    c. Maintenance of tourism-dependent processes, such as water for wildlife habitats

In early 2012, five EFA study sites were identified in the Ruvu River Basin during a reconnaissance of the area. These sites are:

- Ruvu River at Kibungo
- Mgeta River at Duthumi
- Ngerengere River at Mgude
- Ruvu River at Kidunda
- Ruvu River at Kongo.

Sites were selected on the basis of their importance in the basin to management or to the overall environmental conditions of key areas of the basin, such as the estuary, in the case of Ruvu River at Kongo. They represent a range of geographies, from upper-middle to lower parts of the basin, and an array of management challenges as related to quality, quantity, and timing of river flows. The conditions at each site are discussed in more detail in a subsequent section.

Scientific Components of the Ruvu EFA (also see GLOWS 2012)

Hydrology

Objectives: Hydrological analysis of the study sites provides information on the past and present flow regime of the river. A river's flow regime includes not only the quantity of water that flows in its channels during different months of the year, but also the timing of small, annual floods and larger channel-shaping floods. The hydrological analysis is an important input to the overall EFA process because it determines the natural range of flow conditions under which the reserve flow recommendations must operate. The primary objectives of the hydrology study were 1) use historical gauging station and rainfall records to determine periods of low and high flows, 2) document discharge levels during field assessments, 3) guide the specialists in prescribing reserve flow recommendations within the natural range of the river's hydrological regime and 4) extrapolate the reserve flow recommendations across the natural shape of the river's hydrograph.

Hydraulics

Objectives: Local hydraulics and channel morphology are the primary determinants of availability of physical habitat which, in turn is a major determinant of ecosystem function (King et al. 2000). The study of hydraulic effects of a changing flow regime yields a series of relationships between discharge and other flow parameters, including wetted perimeter, water surface width, water depth and flow velocity, that can then be used by the other specialists to translate critical flow parameters into discharge recommendations. The hydraulic conditions are therefore the main link between the ecological requirements for habitat conditions (in terms of flow depth, velocity, wetted perimeter, etc.) and the hydrology (in cubic meters per second). The hydraulic analysis differs from the hydrologic analysis in that it focuses on instantaneous fine-scale relationships between discharge, depth, and velocity rather than longer term flow patterns. Primary objectives of the hydraulic survey were 1) establish transects at each site, 2) survey river cross section topography and water surface elevation, 3) establish river morphology structure, and 4) use hydraulic modelling to project critical variables over a range of discharge levels.

Geomorphology

Objectives: Geomorphologic assessment aids in selection of sampling sites in distinct geomorphological reaches of the basin and analyzes each study site in regards to the shape of the river channel and accumulation of sediments arising from fluvial processes such as erosion, transport and deposition. The low flow assessment describes geomorphologic units that determine critical ecological habitat for river health, and which may be lost during low flows. The high flow assessment determines necessary flows for maintenance of channel form. Understanding how flow level affects the shape of the channel and accumulation of sediment is critical because the resulting physical habitat influences the nature of the entire riverine ecosystem. Primary objectives of the geomorphology report were 1) provide a geomorphologic assessment of the Ruvu River Basin at a basin, reach and site scale, 2) determine the relationship between diverse channel morphological units and discharge at each site and 3) assess the likely pattern and direction of morphological change for each region of the Ruvu River.

Water Quality

Objectives: Water quality is defined as the physical, chemical, biological and aesthetic qualities of water that determine its fitness for human use as well as for maintenance of a healthy ecosystem. The Ruvu EFA water quality assessment provides information on the present state of the river and considers the influences of altered flow levels on the presence and concentration of compounds that could be harmful to humans and aquatic life. The primary objectives of the water quality survey were 1) conduct *in situ* and laboratory measurements of water quality parameters at EFA sample sites during low and high flows, 2) determine spatial and temporal variation in water quality throughout the basin, and 3) make recommendations about flow levels necessary to maintain suitable water quality.

Aquatic Ecology: Fish

Objectives: Fish are important indicators of environmental flows because discharge is the primary determinant of their productivity. Because they are more long-lived than macroinvertebrates, they can serve as integrated signals of the health of the river over a period of years. They are also one of the features of rivers most commonly observed and utilized by communities, so changes in their occurrence and abundance may be noticed more readily, and the health of fish populations may be directly important to the health of human communities nearby. The primary objectives of the fish survey were 1) describe and quantify fish communities at each site, 2) determine population structure of critical species**,** 3) assess species' dependence on flow level, and 4) identify species of conservation significance and invasive or introduced species.

Aquatic Ecology: Macroinvertebrates

Objectives: Aquatic macroinvertebrates are excellent critical indicators of sustainable flow levels because many families react predictably to changes in water quality, and their occurrence and abundance can serve as an integrated measure of the ecological health of the river over the previous weeks or months. Species used in these surveys included insects, worms, mollusks and crustaceans that occur on the riverbed or along the channel margins. The primary objectives of the macroinvertebrate survey were 1) describe and quantify important macroinvertebrate communities at each site during low and high flows, 2) assess the dependence of these communities on flow level, and 3) identify species of conservation significance and invasive or introduced species.

Riparian Vegetation

Objectives: Riparian vegetation is important for maintaining stability of river banks and reducing erosion, retaining and processing overland runoff before it enters the river, sustaining low flow levels through a storage effect, providing resources for instream fauna through input of vegetative detritus, and providing canopy cover that mediates water temperature. It is also used by many communities living on or near the river for food, medicine and building materials. Loss of riparian vegetation can threaten many of the environmental services it provides. Riparian vegetation is a good indicator of both low flow and high flow requirements, because individual species have different and often highly specific inundation and soil moisture requirements for their regeneration. Significant alterations in the natural flow regime of a river may eliminate overbank flooding or affect the floodplain water tables, which could lead to the loss of some species important for human use. The primary objectives of the riparian vegetation assessment were 1) describe important riparian plant communities at each study site, 2) assess the flow dependence of those communities, 3) identify species that may be flow sensitive and can serve as indicators of an appropriate flow regime.

The Ruvu EFA also helped to advance the state of knowledge of water resources in the basin, as part of the EFA process. The project team's hydrologist, with support from the WRBWO, conducted a thorough review and analysis of the hydrologic record for the five sites (Table 1). Dry and wet days were simply defined as those recording average daily discharge either less (for dry years) or more (for wet years) than one standard deviation from the long-term daily average discharge. The normal day discharge is that falling within the two bounds defining a dry and wet day discharge.

Table 1: Hydrologic record considered in analyses for each site.

EFA site	Period
Ruvu River at Kongo	1950-1989
Ruvu River at Kidunda	1950-1968
Ruvu River at Kibungo	1952-1989
Mgeta River at Duthumi	1953-1969
Ngerengere River at Mgude	1968-1990

Hydraulic data were collected and cross-sectional profiles established at the five sites during 2012-2013. These hydraulic data were supplemented by a separate but related initiative under which rating curves for six gauging sites in the Ruvu Basin were updated, some for the first time in decades. The dry and wet season sampling campaigns that examined instream and riparian ecological conditions were conducted in 2012-2013, and included at least one visit to each of the sites. During these visits, observations on channel geomorphology were also made, with particular attention to channel form, sediments, and bank stability. A full description of all methods for hydrologic analyses and fieldwork as well as the detailed results from those studies is presented in separate reports for each disciplinary expert and in one full summary report on dry season sampling (GLOWS-FIU, 2012) and one full summary report on wet season sampling (GLOWS-FIU, 2013).

Field sampling campaigns also included collection of data as related to biological indicators. Biological indicators of a river's intact flow regime include those groups of species most sensitive to short- and long-term changes in the depth, width or velocity of flow level. Biological indicators are typically riparian vegetation, aquatic macroinvertebrates and fish, as these groups are found in all river systems and the occurrence and abundance of certain species in each group can be tightly linked to flow levels. In many African Rivers, including the Ruvu, large wildlife including hippopotamuses and crocodiles are also affected by flow level, and prolonged periods of low flows as well as large floods could have negative effects on these groups. However, due to the size and mobility of these large wildlife, they are often less highly dependent on short-term changes in a river's flow regime. In the absence of more detailed studies on the flow-ecology linkages of large wildlife, this present effort assumes that flow levels that are adequate for more sensitive indicators, such as riparian plants, aquatic macroinvertebrates and fish, should be sufficient to provide for larger wildlife in the Ruvu as well. However, further biological studies would help to improve understanding of the flow needs of large wildlife and could lead us to discard this assumption.

Following field campaigns and corresponding data analysis, the project team convened two workshops to discuss river management objectives for the five Ruvu River EFA sites. At the first workshop, held in Kibaha in November 2013, the scientific team was joined by representatives from the Tanzanian Ministry of Water, staff from the Tanzania iWASH/WADA program, and two international facilitators. The group discussed at length the challenges and opportunities for flow management at the five sites, and through a facilitated process, identified an overall management category for each site and went through an initial discussion of flow needs for ecosystems. At the second workshop, held in Kibaha in January 2014, the scientific team, representatives from the Ministry of Water (including the Assistant Director for Water Resources), iWASH/WADA program staff, and one international facilitator reconvened to focus on determining environmental flow recommendations for each of the five sites. Because the establishment of management goals and the determination of environmental flow needs are so critical to the Ruvu EFA approach, the process is described in additional detail here.

Setting management goals and environmental flow recommendations

Environmental flow recommendations should be set to achieve certain management goals or conditions. These conditions have been defined in several ways across the world. In the case of the Ruvu EFA, we used the South African classification system that frequently is linked to the BBM and other flow assessment methodologies (King *et al.,* 2008).

At a workshop in November 2013, experts from the multiple disciplines associated with the Ruvu EFA were asked to evaluate three conditions for each of the five Ruvu EFA study sites: present state (A through F, according to South African system); trajectory of change (positive, neutral, negative); and importance or ecological sensitivity (low, moderate, high, or very high). On the basis of these three conditions, each expert offered a suggested Ecological Management Category (EMC) for each site, scored between A through D (Table 2). A thorough discussion ensued, in which the experts were asked to defend their recommendations for present state, trajectory of change, and importance or ecological sensitivity for each Ruvu EFA site. WRBWO staff and particularly the Basin Water Officer contributed information on the management challenges they faced at each site and on potential developments—such as dams or irrigation projects—that might be on the horizon. On the basis of these discussions, a consensus recommendation for Ecological Management Category (EMC) was made for each site.

Table 2: Summary of the ecological categories used in determination of the present state and the recommended ecological management class based on methods from South Africa.

Category	Description
A	Unmodified, natural.
B	Largely natural with few modifications.
C	Moderately modified. Changes have taken place but the ecosystem functions are largely unchanged.
D	Largely modified. Large changes have occurred and the resource base reserve has been reduced.
E	Seriously modified. Seriously reduced resource base reserve.
F	Critically modified. Changes may be irreversible.

Flow recommendations to achieve the suggested EMC at each site were made using a combination of information from the published scientific literature, field data gathered during both dry and wet season sampling campaigns (Figure 5), and professional judgment. The process for setting flow recommendations generally followed that outlined in BBM (King *et al.,* 2008). Scientific experts—the aquatic ecologist, riparian ecologist, water quality specialist, and geomorphologist—were asked to consider the flow needs as related to ecosystem structure or ecosystem function in four different periods: the dry season of a drought year; the wet season of a drought year; the dry season of a maintenance year; and the wet season of a maintenance year. They were also asked to consider the need for, magnitude, and timing of floods. All of the flow suggestions were backed up with detailed, written descriptions of the objectives of different kinds of flows—for instance, a high flow in the wet season—and the experts' professional motivations—based on field data or knowledge from the literature—for recommending these different flows during different seasons. Standardized flow objectives and motivations forms were completed by the respective scientists in advance or at the start of the January 2014 workshop. In some cases, for instance for the aquatic ecologist, it was easier to identify the habitat conditions associated with indicator species—such as velocity or depth—rather than try to recommend flows in cubic meters of water per second (cms or m^3/s); in these instances, the hydraulic engineer and hydrologist were able to provide the corresponding flows for these parameters.

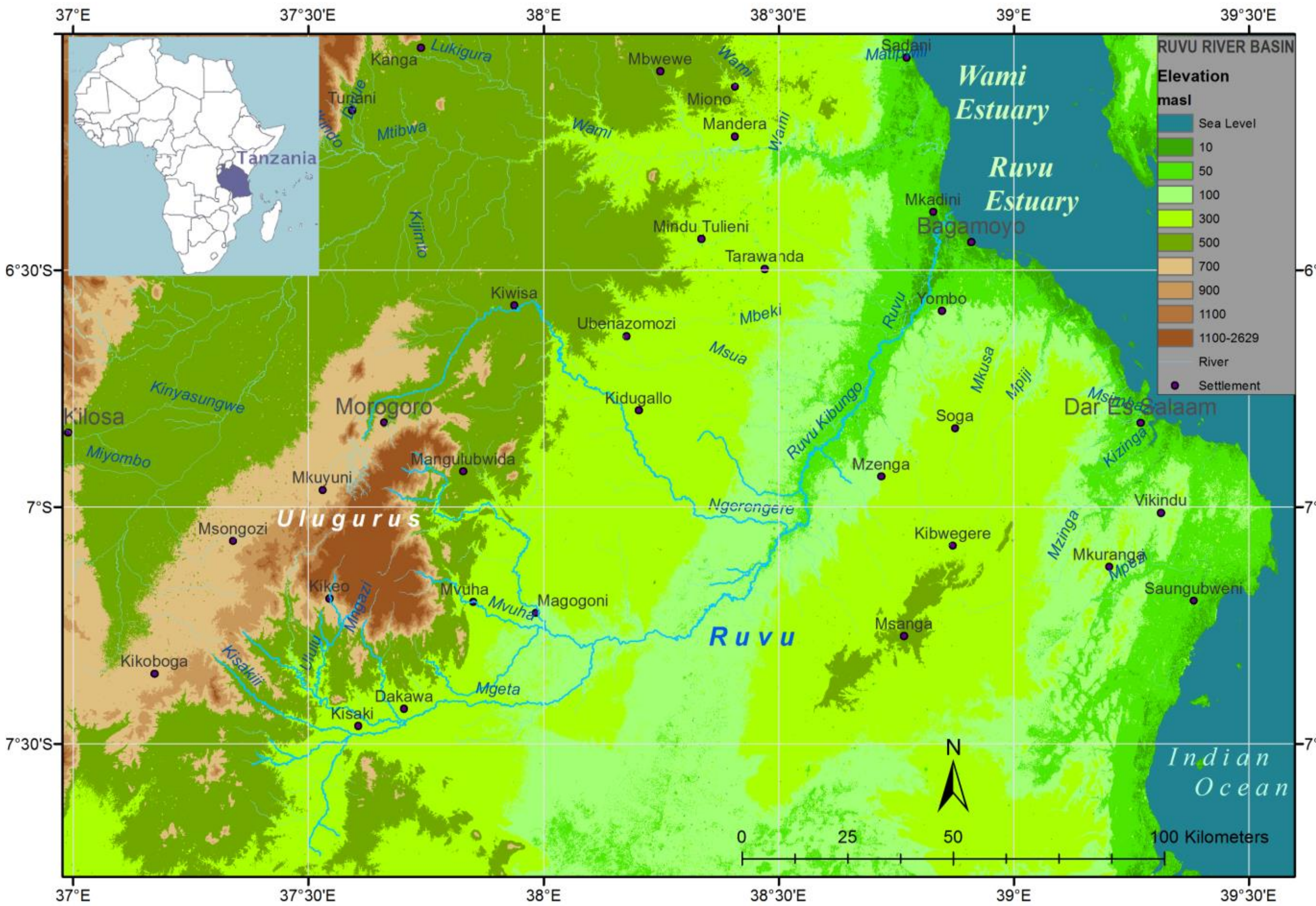
For all sites, a consensus decision was reached for a recommended environmental flow for the dry and wet season conditions in drought and maintenance years, and for floods. Each expert presented his suggested flow recommendations by discipline, and was asked to defend the reasoning behind those recommendations. Each expert also estimated his level of certainty that the recommended environmental flow would actually satisfy the needs for species or important ecosystem processes, like sediment transport. The discussion for each site was concluded only once a consensus for flow recommendations had been met, a facilitated process that typically lasted about two hours per site. The hydrologist then took the recommendations for the dry, wet, drought, maintenance, and flood conditions and extrapolated them across the year, following the BBM (King *et al.,* 2008). The resulting information constituted a prescribed environmental flow regime for each of the five sites, presented in the latter part of this document.

The Ruvu EFA process therefore has relied on a combination of historical records, modern field data, and professional judgment of those with years of experience working in Tanzanian rivers. The fact that the process is carried out as a team effort, in which all experts are together making decisions about sites for study, working side-by-side in the field, and then debating flow recommendations as a group, provides opportunities for team members to learn from each other and also question results. The involvement of the Tanzanian Ministry of Water and especially the WRBWO was a critical component of the Ruvu EFA process, given their leadership role in implementation of the flow recommendations made and also their broad knowledge of the Ruvu Basin's resources. Further, the Ruvu EFA represents another step in building capacity within Tanzania for EFA and the increasing recognition of a team of local experts in aquatic sciences and their management applications.

Technical Summary: Physical, Biological and Social Indicators

The Ruvu River and its tributaries are one of the systems that form part of the Wami/Ruvu Basin, an administrative designation by the Tanzanian Ministry of Water under which the Ruvu, Wami, and coastal drainages are collectively managed by the Wami/Ruvu Basin Water Office. The Ruvu is one of the major East African rivers that drain the Eastern Arc Mountains, with a basin area of approximately 18,000 km^2. This basin is typically sub-divided into smaller catchments: the Mgeta, Ngerengere, Upper Ruvu of the Morogogo region, and the Middle and Lower Ruvu in the Coast Region (Figure 3).

Figure 5: Topography of the Ruvu River Basin, Tanzania.



Apart from the headwater areas of the Ruvu Basin (Figure 6), draining the Uluguru Mountains and (>2000 m.a.s.l.) and other Eastern Arc blocks, the basin comprises mainly low lying areas along the Ruvu River and a slightly elevated hilly area with moderate undulation, extending from west to east around Morogoro town. Some isolated hills can be found along the middle reaches of the Ruvu, and low-lying alluvial floodplains are found in the lowermost, eastern edge of the basin, near the Indian Ocean coast. The Ruvu River's mouth is located near the city of Bagamoyo, where it discharges into the Indian Ocean.

The Ruvu Basin's climate is spatially and temporally variable. Mountainous areas in the Uluguru block receive more rainfall as compared to the lowlands, although rainfall even in these mountainous areas can also be patchy and spatially variable; the humid eastern slopes of the Uluguru's for instance receive mean annual rainfall >2500 mm. Other mountain blocks receive considerably less average annual precipitation: Nguru-Rubeho (800-1200 mm) and Ukaguru (1000-1800 mm). Average annual precipitation in coastal areas ranges between 800-1000 mm. Temperature is much less variable throughout the basin. The average annual temperature is about 26 degrees Celsius, with August being the coldest and February the hottest months through the basin.

The Eastern Arc Mountains and the surrounding areas are renowned for a high level of endemism among plants and terrestrial fauna and are considered one of the world's top conservation "hot spots" (Burgess *et al.*, 2007). The Ruvu River and some of its tributaries including Mgeta, Ruvu and Ngerengere originate from the Uluguru block of the Eastern Arc chain. Despite early exploration of this area during both German and British colonial periods, the freshwater fish and other aquatic fauna of this important river is still poorly known. The information that does exist (Table 3, 4) suggests that the fish fauna of the Ruvu River (Figure 7) has a lot in common with other easterly flowing rivers of Tanzania such as Wami, Pangani and Rufiji systems (Eccles, 1992). From an ichthyologic perspective the Ruvu River can be divided into the following three zones: the upland streams found in the upper sections of the Ruvu, Mgeta and Ngerengere rivers; the Midland stream zone in the middle section of the Ruvu River; and the lowland stream zone including the estuary (GLOWS-FIU, 2013).

Table 3: Fish species collected from Ruvu EFA sites in dry (February 2012) and wet (May 2013) season sampling.

Scientific/species Name	Ruvu Kibungo		Mgeta Dutumi		Ruvu Kidunda		Ngere ngere		Ruvu Kongo	
	Dry	Wet	Dry	Wet	Dry	Wet	Dry	Wet	Dry	Wet
Cyprinidae (Minnows and Carps)										
Barbus paludinosus					✓	✓		✓		
Barbus oxyrhynchus	✓			✓		✓				
Barbus macrolepis		✓								
Barbus kerstenii		✓								
Labeo cylindricus	✓	✓						✓		
Labeo coubie					✓					
Labeo congoro										✓
Opsaridium loveridgii	✓	✓								
Mochokidae										
Synodontis maculipina				✓	✓					✓
Chiloglanis deckenii	✓	✓				✓		✓		
Chanidae										
Kneria uluguru [V]		✓								
Citharinidae										
Citharinus latus					✓					✓
Distichodontidae										
Distichodus petersii [V]						✓				✓
Distichodus rufigiensis										✓
Schilbeidae (Schilbeid catfishes)										
Schilbe moebiusii [V]			✓							
Schilbe mystus									✓	
Eutropiellus longifilis			✓	✓						
Anguillidae (Eels)										
Anguilla bengalensis labiata	✓									
Amphillidae (Loach catfishes)										
Amphilius uranoscorpus	✓						✓			
Bagridae (Bagrid catfishes)										
Bagrus orientalis						✓			✓	✓

Scientific/species Name	Ruvu Kibungo		Mgeta Dutumi		Ruvu Kidunda		Ngere ngere		Ruvu Kongo	
	Dry	Wet	Dry	Wet	Dry	Wet	Dry	Wet	Dry	Wet
Clariidae (Airbreathing catfishes)										
Clarias gariepinus				✓	✓	✓		✓	✓	✓
Mormyridae										
Pollimyrus sp		✓								
Petrocephalus catostoma				✓					✓	
Petrocephalus staindachneri				✓						
Marcusenius macrolepidotus									✓	
Hippopotamyrus sp		✓								
Characidae (African tetras)										
Alestes stuhlmani [En]									✓	
Hydrocynus vittatus					✓	✓				
Brycinus affinis										✓
Brycinus imberi			✓	✓	✓	✓		✓	✓	✓
Cyprinidodontidae										
Nothobranchius sp										✓
Aplocheilichthyus sp										✓
Cichlidae										
Oreochromis niloticus [Ex]		✓		✓	✓	✓		✓	✓	
Tilapia zillii [Ex]			✓					✓		
Astatotilapia bloyeti		✓								
Astatotilpia sp		✓								
Lutjanidae										
Lutjanus argentimaculatus										✓
Palaemonidae										
Macrobrachium sp		✓						✓		✓

[En] Endemic; [Ex] Exotic; [V] Vulnerable

The lives and livelihoods of human populations throughout the Ruvu River basin are linked to freshwater resources, especially rivers. And water resources play a critical role for more commercial endeavors as well. Rivers, including the Ruvu mainstream, are a major source of domestic water for human populations within the Ruvu Basin, and also outside of the basin. For instance, the city of Dar es Salaam, Tanzania's largest, depends heavily on water from the Ruvu River for both domestic and industrial purposes; this water is abstracted from the lower Ruvu River and piped several dozen miles to this large city. Nearby populations in the cities of Kibaha and Bagamoyo are also reliant on the Ruvu River as a major source of fresh water supply for human populations. The Ngerengere and Morogoro Rivers are major sources of water for Morogoro town. Agriculture, both subsistence and commercial, is another use of water from the Ruvu River and its tributaries, as cultivated lands are found nearly throughout the entire basin. Irrigated agriculture is projected to increase in the future. Pastoralists rely on water from the Ruvu River and tributaries for their animals, in particular in the Mgeta River sub-basin.

Table 4: Other fish species reported from the Ruvu River sub-Basin based on available scientific literature.

Species	English Name	Local Name	Observed/cited by
Fish species reported in the upper sections of Ruvu & Mgeta Rivers in the Uluguru mountains			
Amphillidae (Loach catfishes)			
Amphilius leroyi			3
Amphilius n. sp. 1 (Undescribed)			3
Fish species reported in the Gonabis, middle and lower sections of the Ruvu River			
Cyprinidae (Minnows and Carps)			
Barbus radiatus		Kuyu	1
Barbus quadripunctatus		Kuyu	1
Barbus zanzibaricus		Kuyu	1
Characidae (African tetras)			
Petersius conserialis		Kasa	1, 2
Cichlidae			
Oreochromis urolepis hornorum En	Ruaha tilapia		1
Mochokidae (Squeakers catfishes)			
Synodontis panctulatus Synonym: *S. zembezensis*		Gogogo, Ngogo	2
Schilbeidae (Schilbeid catfishes)			
Eutropius grandis		Pate, Mbata	1
Distichodontidae			
Distichodus apleurogramm			1
Nothobranchiidae (Killifishes)			
Nothobranchius lourensi V	Annual Fish		5
Nothobranchius_foerschi En *&* V	Annual Fish		5
Nothobranchius flammicomantis V	Annual Fish		5
Nothobranchius janpapi	Annual Fish		5
Nothobranchius annectens V	Annual Fish		6
Anguillidae (Eels)			
Anguilla mossambica	African longfin eel	Mkunga	1, 2
Fish species reported in the Ruvu Estuary and river mouth			
Chanidae (Milkfish)			
Chanos chanos	Milkfish	Mwatiko	1, 4
Pristigasteridae (Herrings)			
Pellona ditchela	Indian Pellona	Chaa	1
Salmonidae (Sea trout)			
Salmo trutta Ex	Brown trout		1, 4
Mugilidae			
Mugil cephalus	Mullets		4
Ariidae (Sea catfishes)			
Arius sp.	Sea catfish		4
Scaridae (Parrotfishes)			
Scarus sp	Parrotfish		4
Lutjanidae (Snappers)			
Gerres sp.	Silver biddies		4

Species	English Name	Local Name	Observed/cited by
Tetraodontidae (Pufferfishes)			
Lagocephalus sp	Pufferfish		4
Teraponidae (Grunters)			
Terapon jarbua	Jarbua terapon	Kui	4
Crustacean species reported in the Ruvu River estuary			
Penaeidae (a family of marine prawns)			
Fenneropenaeus indicus Synonym: *Penaeus indicus*			4
Penaeus monodon			4
Penaeus japonicus			4
Metapenaeus monoceros			4

[En] Endemic; [Ex] Exotic; [V] Vulnerable

Original sources: 1 Bernacsek (1980); 2 Eccles (1992); 3 Vigliotta et al. (2008); 4 Semesi et al. (1998); 5 Huber (1996) and 6 Watters et al.

In terms of industry, mining activities are thought to be becoming more prevalent, although finding systematic and reliable activities on mining can be difficult. Artisanal gold mining activity has been observed near Morogoro, and by some accounts appears to be increasing. The industrial sector also relies on rivers in the Ruvu Basin for discharge of waste streams, the permitting and management of which presents a considerable challenge for the WRBWO and has been linked to degraded water quality in some rivers, in particular the Ngerengere. Freshwater fishing is a seasonal activity throughout the basin, and a continuous source of protein for some human populations (Table 5).

Human populations in and around the Ruvu Basin depend heavily on rivers, but the influence of these populations has also left its mark on the Ruvu's ecosystems. With all of the human activities in the basin—including land use, water abstraction, and use of rivers for waste assimilation—the Ruvu River is a highly altered system. Additionally, the Ruvu River's main tributary, the Ngerengere River, is impounded by the Mindu Dam. Another dam for water supply is currently under advanced study at Kidunda. Future change and human population growth in the eastern-central part of Tanzania is likely to further alter the Ruvu River and its tributaries.

Some assets and strengths as related to management and conservation of water resources were identified for riparian human populations in the Ruvu Basin as part of a review of social conditions in the basin (GLOWS-FIU, 2012). Many villages have a community forest, which oftentimes serves to protect springs and small streams, or can be an area of spiritual and cultural importance. Villages also often have environmental or water committees that help to manage water related issues at that level; they also can help to raise awareness about the protection of water resources, although power and influence is variable. Some villages have by-laws as related to wise use of stream and riparian resources.

Figure 6: Fish species collected from Ruvu EFA sites in dry (February 2012) and wet (May 2013) season sampling.

Fish species with specific habitat and feeding requirements, and/or requirements associated with riffles are likely to be most dependent on perennial flow. This dependence can often be related to their water quality requirements, such as a specific range of oxygen concentrations and water temperatures. Some true riffle dwelling species, such as the majority of *Chiloglanis* sp. and *Amphilius* sp. are the most flow sensitive and dependent on perennial flow during all stages of their life cycle (Skelton, 1993). According to Water for Africa (2008), *Chiloglanis* require fast-flowing water (≥ 0.3 m/s) during most phases of their life cycle.

Down below this scale some other riffle dwellers grouped under the lotic guild such as *Labeo*, *Kneria*, *Barbus (B. oxyrhynchus* and *B. macrolepis*) and *Opsaridium loveridgii* require fairly fast-flowing water (≥ 0.2) during most phases of their life cycle, although they can survive the dry season drought years at velocities lower than 0.2 m/s. *Labeo* are longitudinal migrants that move within the main river channel or up and down tributaries as juveniles seek riffle/rapid habitats and adults inhabit both riffles and pools. They require relatively high dissolved oxygen levels (second to riffle guilds) and as such they are sensitive to reductions in water quality and may locally disappear under eutrophic conditions or when their river is dammed and prevents migration. These differing requirements provide important pointers as to the magnitude, distribution and constancy of low flows needed during the dry season.

Apart from *Chiloglanis* sp., several truly catadromous fish species occur in the Ruvu River including the eel (i.e. *Anguilla bengalensis labiata*). It is of critical importance for the survival of these species that the adults are able to migrate downstream to the sea to spawn, and that the juveniles can migrate upstream again to their freshwater feeding and maturation areas. Eel larvae, for instance, are carried from their spawning grounds in the Indian Ocean and the juveniles, or glass eels, enter coastal rivers of Tanzania during December and January each year and migrate upstream. It is extremely important that freshwater cues reach the ocean during this period to attract these juveniles into the rivers.

Source: (GLOWS/FIU, 2013).

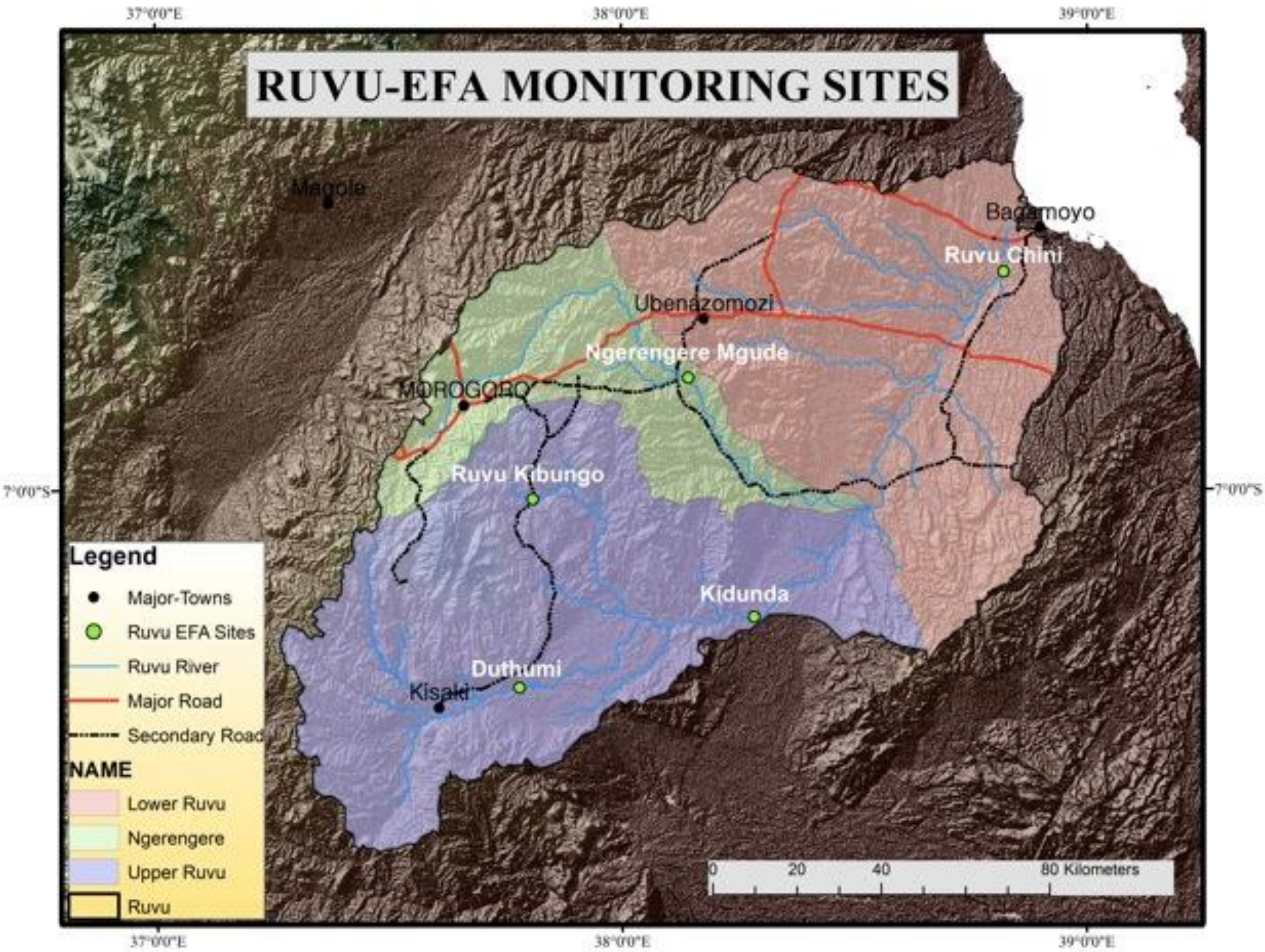
Table 5: Fishing season and months of high catches at EFA study sites.

Village	EFA reference site	Fishing seasons
Kibangile	Ruvu at Kibungo	August-March, with highest catches in May and June
Bony and Mbwade	Mgeta at Duthumi	Year-long, with highest catches from April to July
Kidunda	Ruvu at Kidunda	Year-long, with highest catches in May and June
Ngerengere	Ngerengere at Mguda	March – August, with highest catches in May and June
Kongo	Ruvu at Lower Ruvu	Year-long, with highest catches in May and June

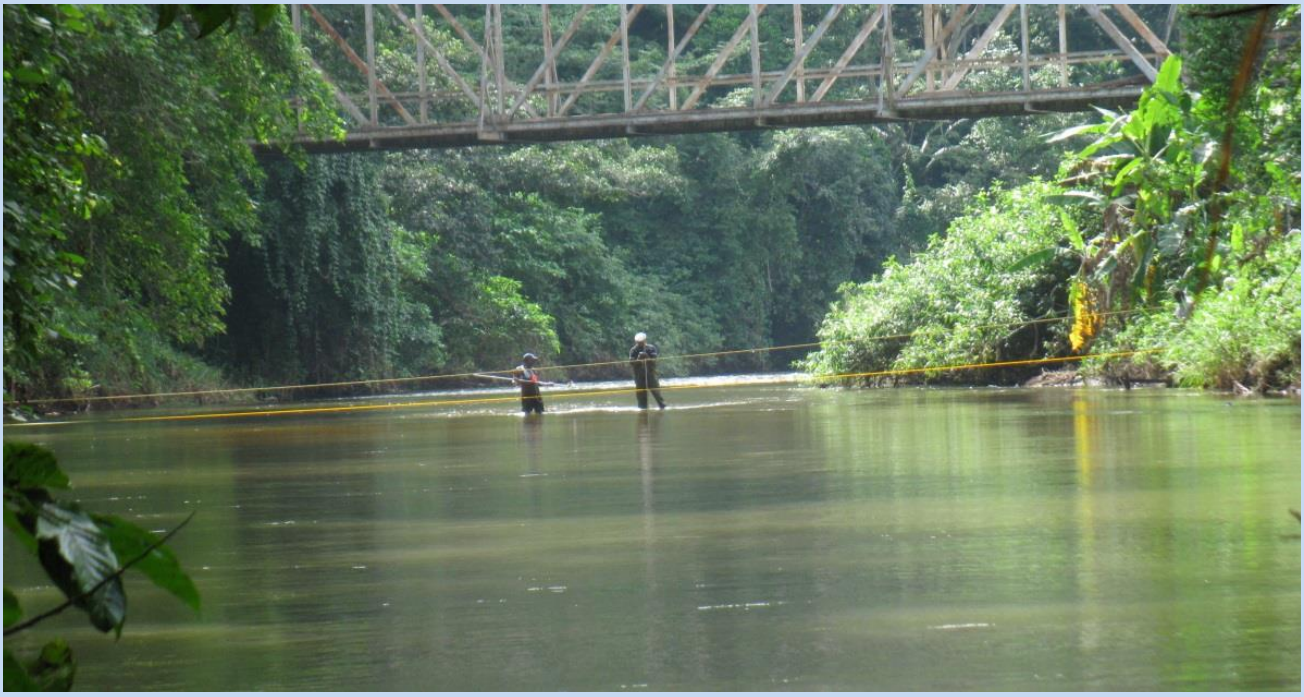
Ruvu EFA study sites: Selection and description

Study site selection began during a team meeting in mid-2012, where possible areas of the basin on which to focus EFA field work and that were in need of environmental flow recommendations for management purposes were discussed. Following these discussions, a sub-set of the team conducted a field reconnaissance of the Ruvu Basin, considering geomorphology, ecology, human demand for water, position in the basin, and management need in their evaluation of appropriate sites for EFA. The team selected six sites, of which five were retained for the Ruvu EFA process and described individually below (Figure 8). The sixth site was located in the middle of the Ruvu Estuary. Because of the complexity of the estuary, a separate study was commissioned in June 2013 (GLOWS-FIU Saha *et al.*, 2014). Each of the study sites selected exhibits fluvial processes that are characteristic of the macro-reach and incorporates smaller-scale habitat diversity, as the sites typically encompass several geomorphologic channel units like riffles, pools, or runs. And several of the sites are currently under the influence of water-related infrastructure or will be in the near future.

Figure 7: The Ruvu River Basin indicating the location of the five EFA sites. Clockwise from bottom left the Ruvu River at Duthumi, Kibungo, Ngerengere, Kongo, Kidunda (bottom right).



Site 1: Ruvu River at Kibungo



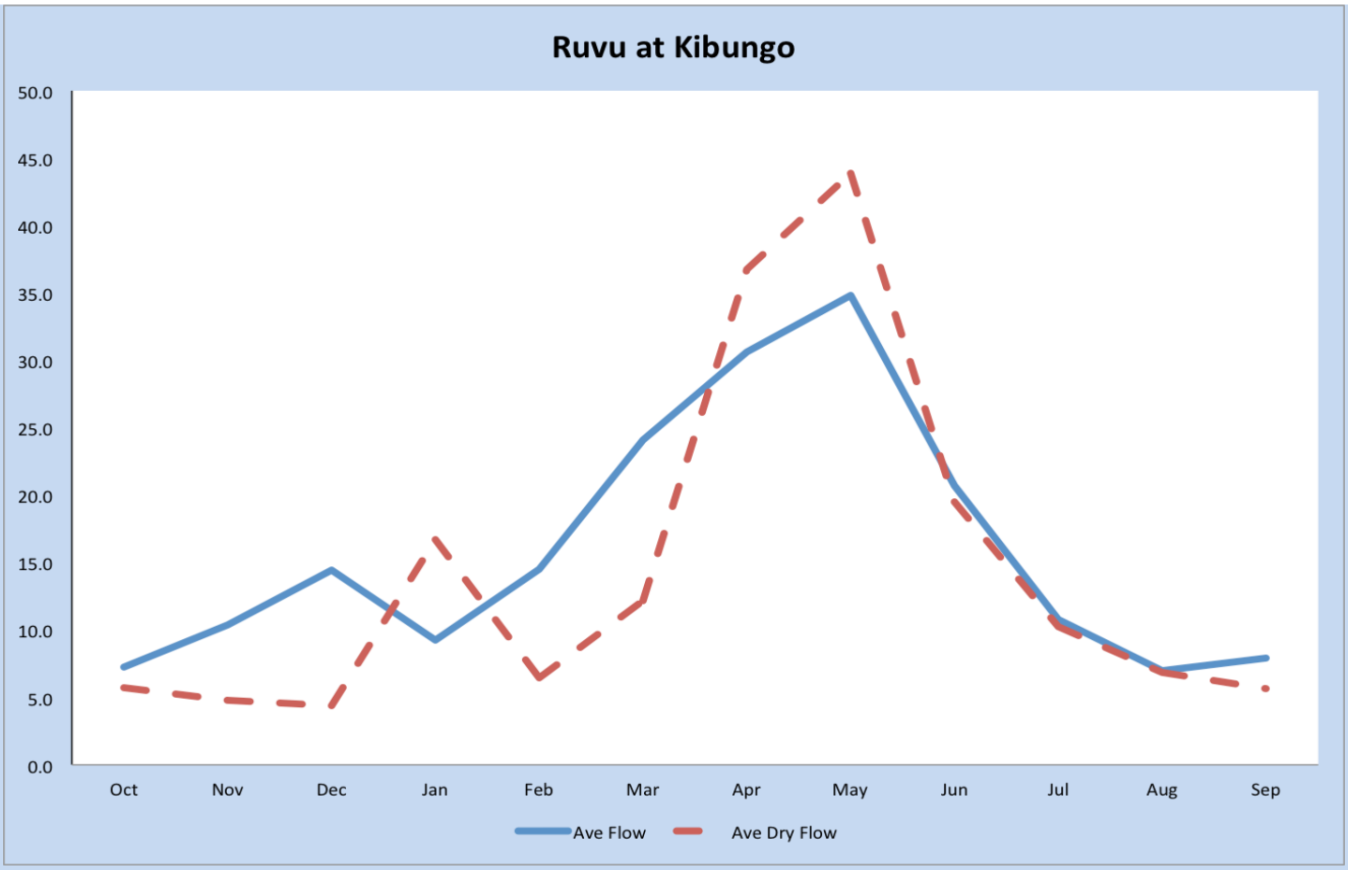
Location: Ruvu River, middle basin		
District: Morogoro	**Ward:** Kisemu	**Village:** Kibangile
Characteristics: Site has minimal human activities and influence. Steep banks with dense riparian forest give a mosaic of light and share conditions. Channel is dominated by boulders and cobbles, which produce many stony runs and well oxygenated riffle habitats. Water is relatively shallow.		

Physical Indicators

- Hydrologic record for analysis: 1952-1989
- Minimum recorded historical flow: 0.82 m^3/s on 24 Oct 1952
- Maximum recorded historical flow: 169.45 m^3/s on 6 May 1981
- Channel cross-section morphology of Ruvu River at Kibungo: Banks have limited erosion with no undermining. The riverbed at this site appears stable.

Biological Indicators

- Fish: 15 species, representing 8 families
- Vulnerable species: *Kneria uluguru*
- Flow-sensitive species: *Chiloglanis, Amphilius, Kneria, Opsaridium, Labeo, Barbus oxyrhynchus, Barbus macrolepis*
- Riparian plants: Dominated by riparian trees, with some bamboo.
- Flow sensitive species: *Ficus sur, Oryza longistaminata, Phragmites mauritianus, Pennisetum purpreum, Cyperus denudatus, Syzygium guineense, Leersia hexandra, Mimusops riparia* and *Ficus exasperata*.



Social Indicators
Dependence of local human populations on freshwater ecosystem services:
Fishing (limited), from August to March
Water for domestic uses
Small-scale irrigation for subsistence agriculture
Challenges:
Agricultural expansion for crops like maize, rice, and millet
Deforestation for agriculture and charcoal (limited)
Casual mining for gold, ruby and other minerals
Assets for water resources management:
Village leadership is strengthened by having sub-village leaders
Kibangile village has environmental and water committees that assist with conservation of reserved forest areas and water sources

Site 2: Mgeta River at Duthumi

Location: Mgeta River Basin

District: Morogoro **Ward:** Bwakila and Chimi **Village:** Bonye and Mbwade

Characteristics: River at this site is typical of a floodplain section, and is primarily a pool-run dominated channel with no riffle habitats. Dense riparian vegetation upstream and downstream of this site. Bed sediments are mainly fine materials.

Physical Indicators

Hydrologic record for analysis: 1953-1969

Minimum recorded historical flow: 0.001 m^3/s on 14 Jan 1961

Maximum recorded historical flow: 202.20 m^3/s on 27 Nov 1963

Channel cross section morphology for Mgeta River at Duthumi: Macro channel banks, the flood zone and the active channel banks are occupied by dense reeds. The river's bed sediments are primarily sand. Channel banks appeared unstable, with slumping and undermining.

Biological Indicators

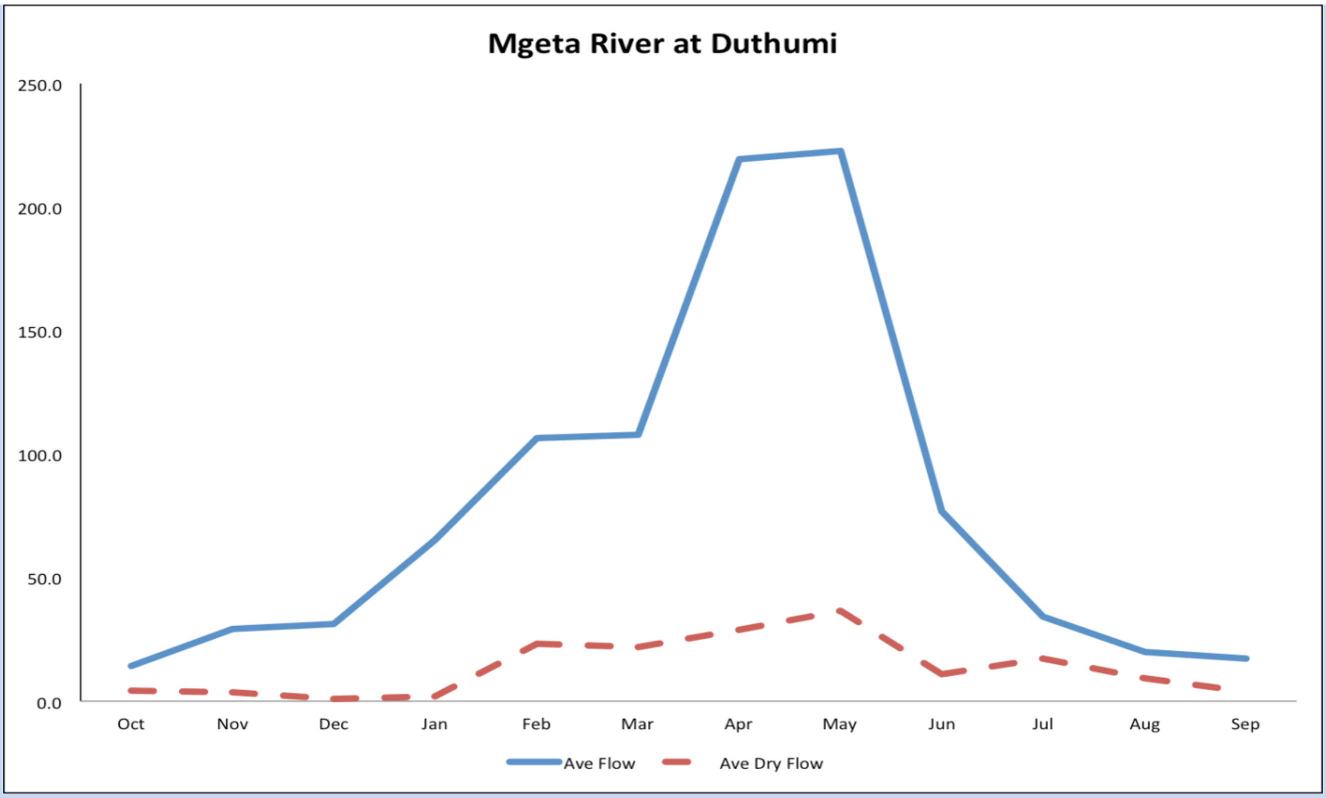
Fish: 10 species, representing 7 families

Vulnerable species: *Schilbe moebiusii*

Flow-sensitive species: *Schilbe moebiusii and Barbus oxyrhynchus*

Riparian plants: A combination of trees, shrubs and grasses

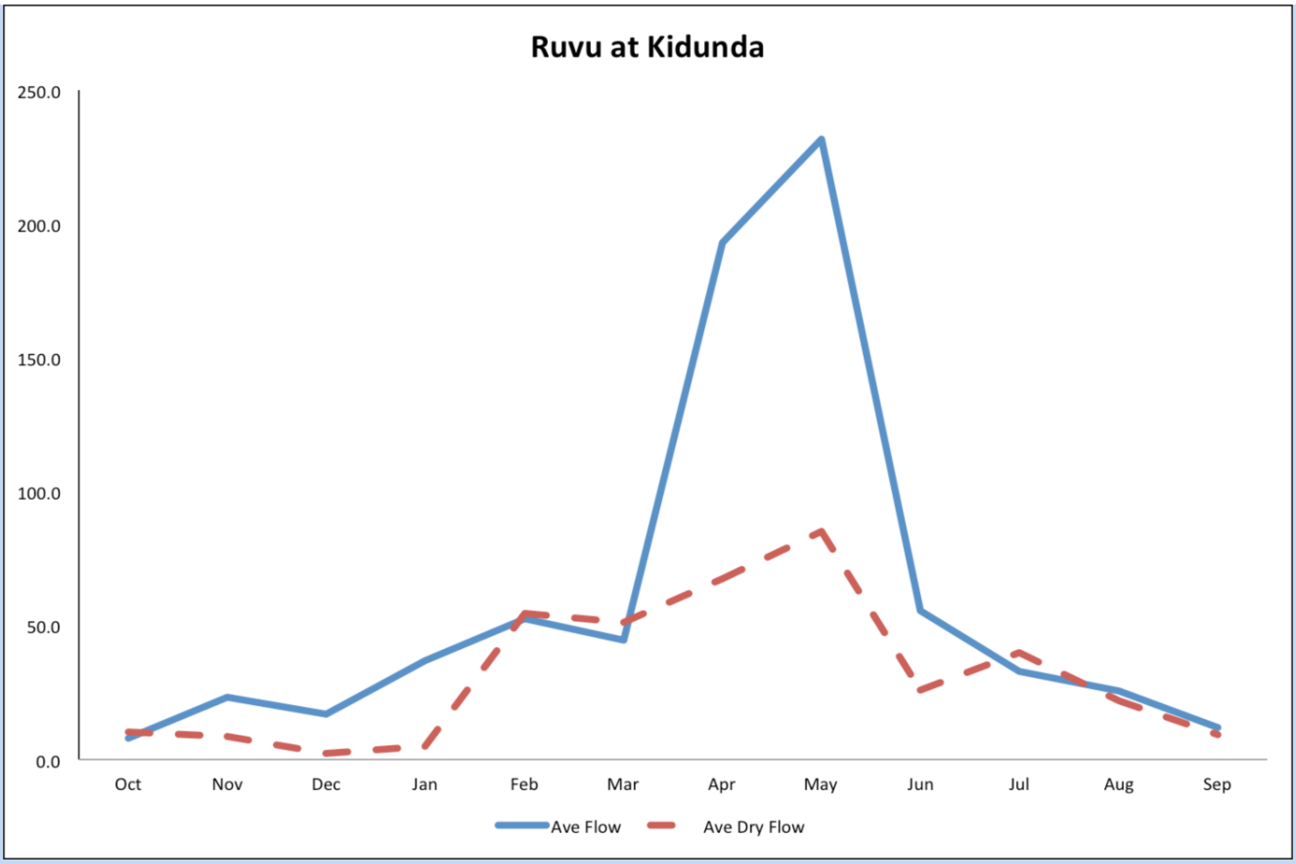
Flow sensitive species: *Ficus sur, Phragmites mauritianus, Pennisetum purpreum, Leersia hexandra, Mimosa pigra, Ficus exasperata, Combretum constrictum* and *Ludwigia stolonifer*



Social Indicators
Dependence of local human populations on freshwater ecosystem services:
Fishing from April to July
Water for domestic uses from Mgeta River
Small-scale irrigation for agriculture, using pump generators that pump water from Mgeta river
Livestock keeping and related water needs, primarily by pastoralists
Collection of sand and grasses from the river banks for building materials
Harvesting of medicinal plants from riparian areas
Challenges:
Agricultural expansion for crops like maize and rice
Deforestation for agriculture and charcoal
Low flows during dry periods and related crop failure because of lack of irrigation water or rainfall
Degrading water quality
Water borne diseases are sometimes reported
Conflicts
Assets for water resources management:
Selous Game Reserve is close by and provides incentive for ecosystem conservation
Forest conservation is a positively perceived practice
Co-ownership of a community forest between villages near the EFA site
Village environmental and water committees exist and guide management of resources
Village by-laws related to conservation of river and riparian resources exist

Site 3: Ruvu River at Kidunda

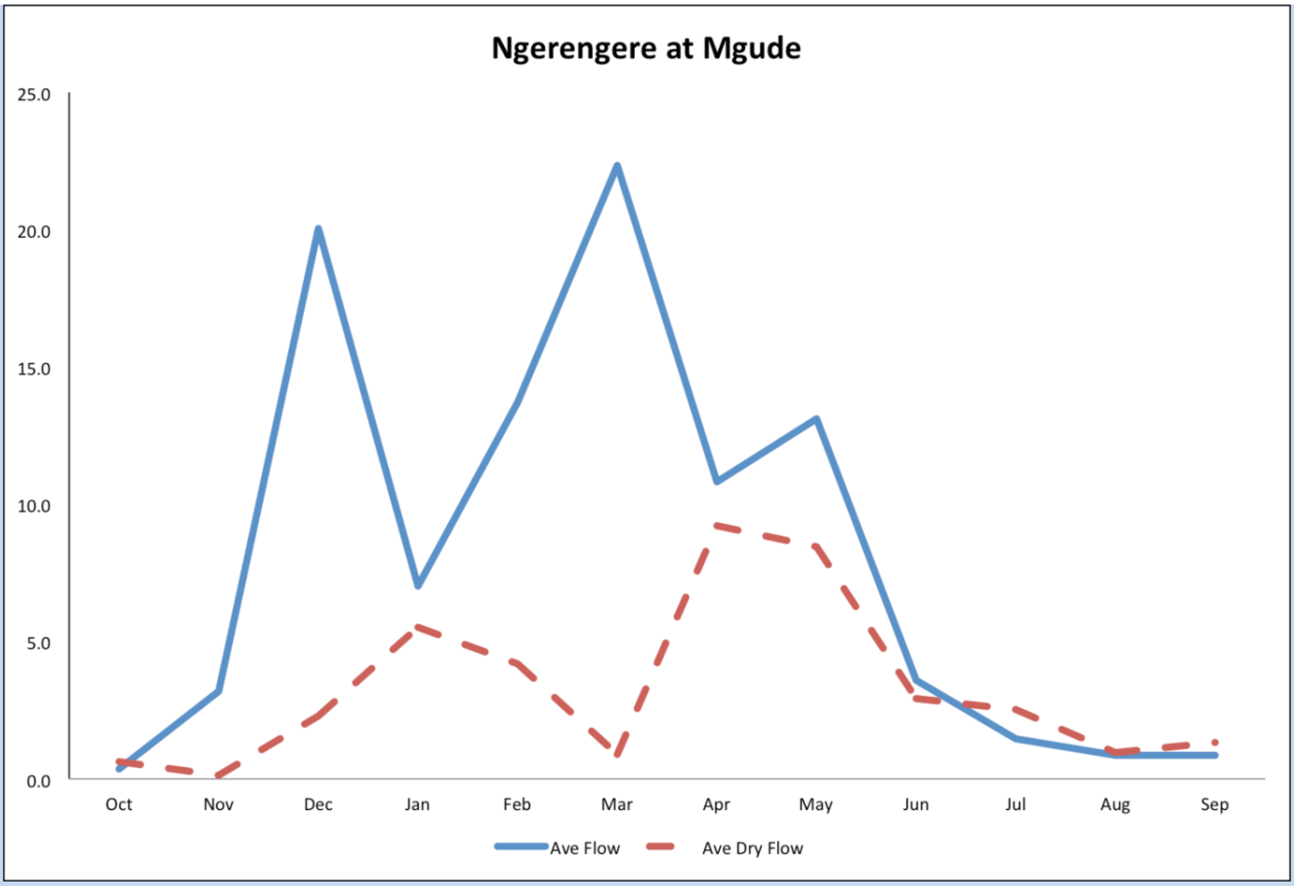
Location: Middle Ruvu Basin		
District: Morogoro	**Ward:** Mkurazi	**Village:** Kidunda
Characteristics: Typical floodplain section of the river with banks and river channel dominated by coarse and fine bed sediments, with some areas of silt and clay. This is a pool-run dominated channel. Most river banks have areas devoid of vegetation.		
Physical Indicators		
Hydrologic record for analysis: 1950-1968		
Minimum recorded historical flow: 0.01 m^3/s on 14 Jan 1961		
Maximum recorded historical flow: 472.24 m^3/s on 27 Nov 1963		
Channel cross section morphology for Ruvu River at Kidunda: The river reach at Kidunda has a moderately confined floodplain on the left bank and the channel is a single thread. Generally, banks have good vegetation cover and minor isolated erosion.		
Biological Indicators		
Fish: 12 species, representing 8 families		
Vulnerable species: *Distichodus petersii*		
Flow-sensitive species: *Chiloglanis deckenii* and *Barbus oxyrhynchus*		
Riparian plants: Heterogeneous community of shrubs and trees, and some riparian wetland habitats		
Flow sensitive species: *Ficus sur, Oryza longistaminata, Phragmites mauritianus, Pennisetum purpreum, Syzygium guineense, Leersia hexandra, Nymphaea caerulea, Mimosa pigra, Ficus exasperata* and *Combretum constrictum*.		



Social Indicators
Dependence of local human populations on freshwater ecosystem services:
Fishing from March to August, for a limited number of households
Nearly all households use Ruvu river as a main source of water
Small-scale irrigation for agriculture, particularly for vegetable crops, done using buckets
Challenges:
Degrading water quality from uses like washing
Water borne diseases are sometimes reported
Flows in Ruvu River may have been declining over the past decade, according to anecdotal evidence
Use of toxic plants and chemicals for fishing may be affecting fish assemblages
Assets for water resources management:
Kidunda is a remote village with poor road infrastructure, and people are very dependent on the river
Crocodiles and hippos may still be in the river, which could indicate good ecological status
Villages are involved in a Community Based Organization known as JUKUMU society
Village environmental and water committees exist and guide management of resources
Village by-laws related to conservation of river and riparian resources exist

Site 4: Ngerengere River at Mgude

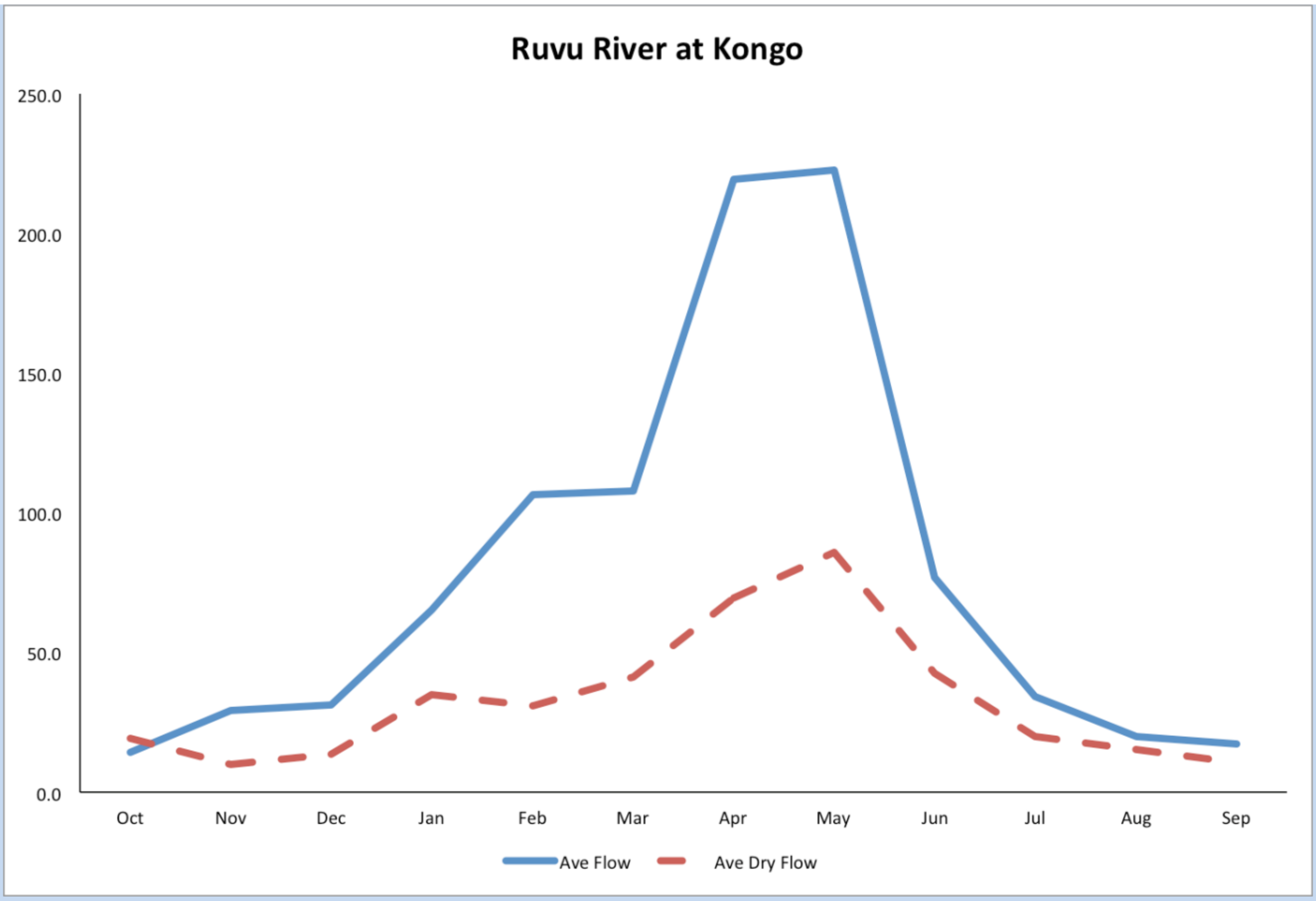
Location: Ngerengere Basin		
District: Morogoro	**Ward:** Ngerengere	**Village:** Ngerengere
Characteristics: Channel and bed sediments are dominated by fine material with some areas of silt and clay. This is a pool-run dominated area, with some areas of riffles. Channel has steep banks with riparian vegetation and few trees that provide shading. Close proximity to Ngerengere townshop means that people are often using this section of the river for various activities.		
Physical Indicators		
Hydrologic record for analysis: 1968-1990		
Minimum recorded historical flow: 0 m^3/s on 16 Mar 1976		
Maximum recorded historical flow: 155.79 on 7 May 1981		
Channel cross section morphology for Ngerengere River reach at Mgude: This is a narrow channel, entrenched in a sloping terrace, with low sinuosity and sand bars in low flow periods. At higher flows, the channel at this site contains rapids and fast runs near areas of bedrock. There is some evidence of channel erosion where livestock have accessed the channel.		
Biological Indicators		
Fish: 9 species, representing 7 families		
Vulnerable species: none		
Flow-sensitive species: *Chiloglanis, Amphilius uranoscorpus,* and *Labeo cylindricus*		
Riparian plants: Somewhat dense cover by riparian trees (50-75%), and other classes of vegetation, despite high levels of vegetation clearance for cultivation.		
Flow sensitive species: *Ficus sur, Phragmites mauritianus, Pennisetum purpreum, Cyperus denudatus, Leersia hexandra, Mimosa pigra, Sesbania sesban, Ludwigia stolonifer* and *Pistia stratiotes.*		



Social Indicators
Dependence of local human populations on freshwater ecosystem services:
Mindu Dam impounds river and provides water for agriculture and domestic uses
Fishing is practices from March to August by a limited number of households
Waste assimilation is a major use of the river
Challenges:
Water flows in the river have declined over the past decade
Deforestation in upstream areas
Expanding agricultural areas
River may be changing its course
Substantial degradation of water quality as a result of siltation, water pollution from industry, and uses of river for washing
Some evidence of water borne disease in local human populations
Assets for water resources management:
The villages have started the process for formulation of a Water Users Association (WUA), in collaboration with the WRBWO
Village environmental and water committees exist and guide management of resources
Village by-laws related to conservation of river and riparian resources exist

Site 5: Ruvu River at Kongo

Location: Lower Ruvu Basin		
District: Bagamoyo	**Ward:** Yombo	**Village:** Kongo
Characteristics: Major modifications have taken place upstream from this site. These include a water abstraction structure and a weir, which have resulted in both channel and flow alterations. This site is the closest to the Ruvu Estuary, and therefore estuarine conditions downstream should be considered in its plans for management. Extensive rice and maize plots are found on one side of the river, while the other side is covered by a dense wetland area.		
Physical Indicators		
Hydrologic record for analysis: 1950-1989		
Minimum recorded historical flow: 0.92 m^3/s on 18 Dec 1971		
Maximum recorded historical flow: 784.57 m^3/s on 9 May 1973		
Channel cross section morphology for Ruvu at Kongo: The Ruvu River channel at this site appears to have been modified recently by floods, and these modifications may occur frequently. The valley form at this site is an unconfined flood plain, approximately 6 km wide. The river is highly meandering, alluvial channel. Some erosion was observed in locations where farming is done on river margins.		
Biological Indicators		
Fish: 18 species, representing 13 families		
Endemic species: *Alestes stuhlmani*	Vulnerable species: *Distichodus petersii*	
Riparian plants:		
Flow sensitive species: *Ficus sur, Polygonum senegalense, Oryza longistaminata, Phragmites mauritianus, Pennisetum purpreum, Vosia cuspidate, Nymphaea caerulea, Mimosa pigra, Sesbania sesban, Combretum constrictum, Ludwigia stolonifer, Echnocloa scabra* and *Pistia stratiotes*		



Social Indicators
Dependence of local human populations on freshwater ecosystem services:
Nearly half of all households, at a minimum, are involved in fishing activities; fishing is practiced throughout the year and used for home consumption and sale
Harvesting of elephant grasses for building materials
Harvesting of medicinal plants from riparian areas
Challenges:
Conflicts between livestock keepers and farmers
Influences of upstream water withdrawals
Assets for water resources management:
Crocodiles and hippos may still be in the river, which could indicate good ecological status
Village environmental and water committees exist and guide management of resources
Village by-laws related to conservation of river and riparian resources exist

Environmental Flow Recommendations

The results presented here are the product of days of deliberation from a team of scientific experts, representatives from the WRWBO and Tanzanian Ministry of Water, and international freshwater resource scientists. They are backed by years of professional experience or scientific studies in Tanzania and in other tropical areas. Ecological management categories were set in accordance with conditions as of 2014, and flow recommendations are not without some degree of uncertainty. The results and specific flow recommendations should be revisited periodically, and especially after any major changes to the conditions in the Ruvu River basin that would affect the suggested EMC at any of the five sites. As is the case with other EFA studies, an adaptive management approach is also suggested in the Ruvu River basin, by which the WRBWO and scientists monitor the effectiveness of recommended environmental flows at sustaining species and ecosystem functional processes and accordingly make management adjustments.

Setting the Ecological Management Category

The suggested Ecological Management Category (EMC) for each of the five sites ranged from B (largely natural with few modifications) to C (moderately modified), on the basis of the present state, trajectory of change, and sensitivity (Table 6). Specific details about how the EMC was determined for each site are in the sections that follow.

Table 6: Results of discussion on Ecological Management Category for five EFA sites in the Ruvu Basin. The scores (A, F) are based on the South African system.

Site	Present State	Trajectory	Importance	Recommended EMC
Ruvu at Kibungo	B	Negative	Very high	B
Mgeta at Duthumi	C/D	Negative	Very high	C
Ruvu at Kidunda	C	Negative	High	C
Ngerengere at Mgude	C/D	Negative	Low	C
Ruvu at Kongo	C	Negative	Moderate	C

Site by Site Environmental Flow Recommendations

Environmental flow recommendations for each of the five Ruvu EFA sites are presented below. Each site has a table of summary data from the available hydrologic record and the actual environmental flow prescriptions for both maintenance and dry years.

Site: Ruvu River at Kibungo

The recommended EMC for the Ruvu River at Kibungo was determined to be a B, although much discussion went into this determination. The site's present ecological state is also a B, and it is considered to be of high to very high importance on the basis of some of the fish species that are found at the site, and because the site is close to a forest reserve. The trajectory of change was considered to be negative, as activities like mining and deforestation are altering upstream areas and influencing this site. Therefore, environmental flow recommendations should be set with the goal of halting current negative trajectories toward degradation and maintaining the site in the present condition.

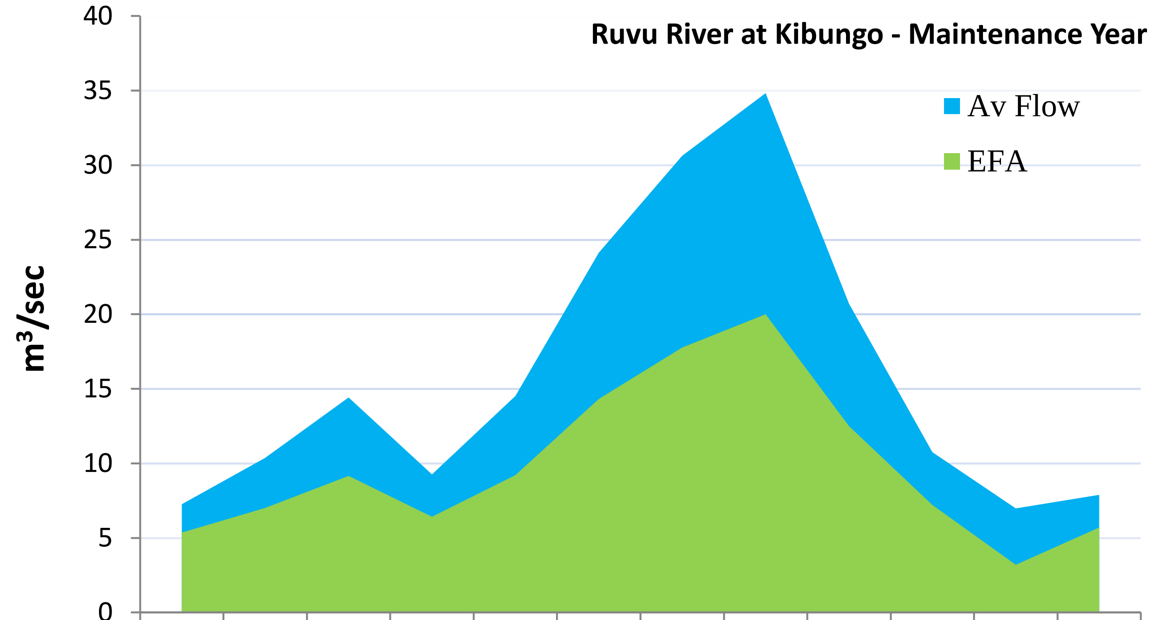
In terms of environmental flow recommendations for the dry years, the team opted to use the needs of fish as the strongest component of influence in the consensus decision-making process. This site was the one at which the fish expert caught the most flow sensitive species, and flow recommendations in dry conditions recognize the need to provide sufficient habitat for their survival in riffles. The level of certainty that the environmental flow recommendations proposed is moderate to good, given that fish species found at this site have been used in other parts of Africa to determine flow recommendations and therefore some literature on flow needs is available.

For the normal or maintenance years, again the team opted to use the needs of fish as the strongest component of influence in decision-making about environmental flow recommendations. In this case, recommended environmental flows should cover riffle areas and ensure adequate habitat availability. Fishes may also sometimes access smaller, possibly intermittent streams nearby, and more water in the channel during wet months can help facilitate this access.

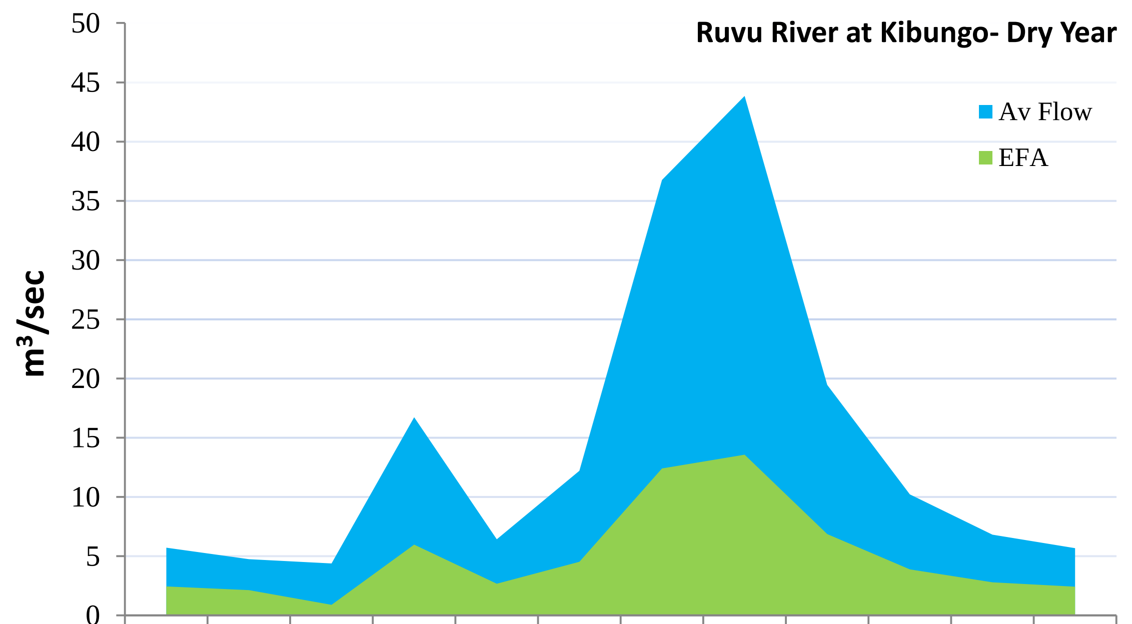
Floods were prescribed for the wet seasons of maintenance years. A flood of 44 m^3/s magnitude, which is similar in size to floods that historically have occurred on a 1-year return interval, is recommended on an annual basis. A goal of this flood is to ensure connectivity between the main Ruvu River channel and smaller streams, to provide access for species that use these habitats during their annual life cycle. Although not much information is available, it is thought that the spawning behavior of certain fish species may be linked to this annual flood.

Figure 8: Giant freshwater prawns in the Ruvu estuary depend upon an adequate seasonal freshwater flow regime in the Ruvu river reaching the estuary.

Figure 9: Recommended environmental flows for the Ruvu River at Kibungo. The area in blue represents the historical averages for maintenance years or for dry years. The area in green represents the recommended environmental flow across the year.



	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep
Av Flow	7.26	10.37	14.42	9.26	14.52	24.13	30.63	34.83	20.71	10.75	6.98	7.89
EFA	5.36	7.01	9.16	6.42	9.21	14.32	17.77	20	12.5	7.21	3.2	5.7



	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep
Av Flow	5.72	4.75	4.39	16.73	6.43	12.21	36.76	43.85	19.46	10.22	6.82	5.68
EFA	2.45	2.14	0.9	5.98	2.68	4.53	12.41	13.57	6.87	3.89	2.8	2.43

Site: Mgeta River at Duthumi

The recommended EMC for Mgeta River at Duthumi was determined to be a C. For this site, the present state was considered to be a C/D and the trajectory of change firmly negative. Results from a recent pilot study that examined sediment sources in the Ruvu Basin suggest that 70% of the sediment in the lower Ruvu River may be coming from areas near and upstream from this site (GLOWS-FIU Dutton, 2013). Additionally, there is a company that is evaluating the area around this site for mining, and a possible road may be constructed near here. However, this site borders the Selous Game Reserve and parts of the Selous also lie downstream, therefore the ecological importance and sensitivity of this site is high to very high. Further, this site faces another challenge as related to water resources management: the role and rights of pastoralists, and the impact of hundreds of animals drinking from the Mgeta River nearby. Given all these scenarios, environmental flow recommendations should be set with the goal of restoring the site to a desirable management class that is higher than the present state.

In terms of environmental flow recommendations for the dry years, the team opted to consider both water quality and fish as the priorities for decision-making on environmental flow recommendations. The team identified the need to maintain dissolved oxygen at sufficient levels, and to have a minimum flow during dry months that would keep the water flowing, at the least. During wetter months of a dry year, the team recommended that flow magnitudes should increase for flushing excess sediment from habitats, as a primary objective.

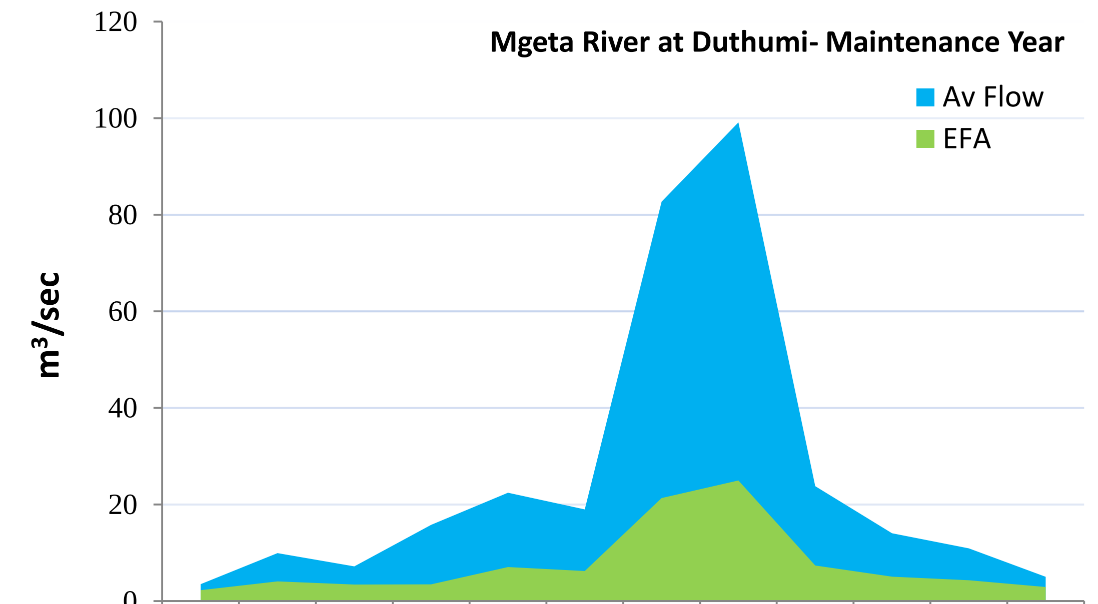
For the normal or maintenance years, recommended environmental flows first are focused on first stopping the negative trend as related to water quality. With less volume of water, water quality degrades. Because this site's management goals will require restoration to a half a class higher (e.g., from C/D to C), ensuring adequate flows is important particularly in dry months, as is the need to pursue direct management action as related to reducing pollution. During wetter months, higher flows are recommended to provide suitable habitat for fishes and for access to channel edges or floodplain areas.

Floods were prescribed for the wet seasons of maintenance years. A flood of 105 m^3/s magnitude, which has a return interval of 1.5 years, is recommended on an annual basis. A goal of this flood is to ensure lateral connectivity between the main Mgeta River channel and its floodplain and to flush sediments.

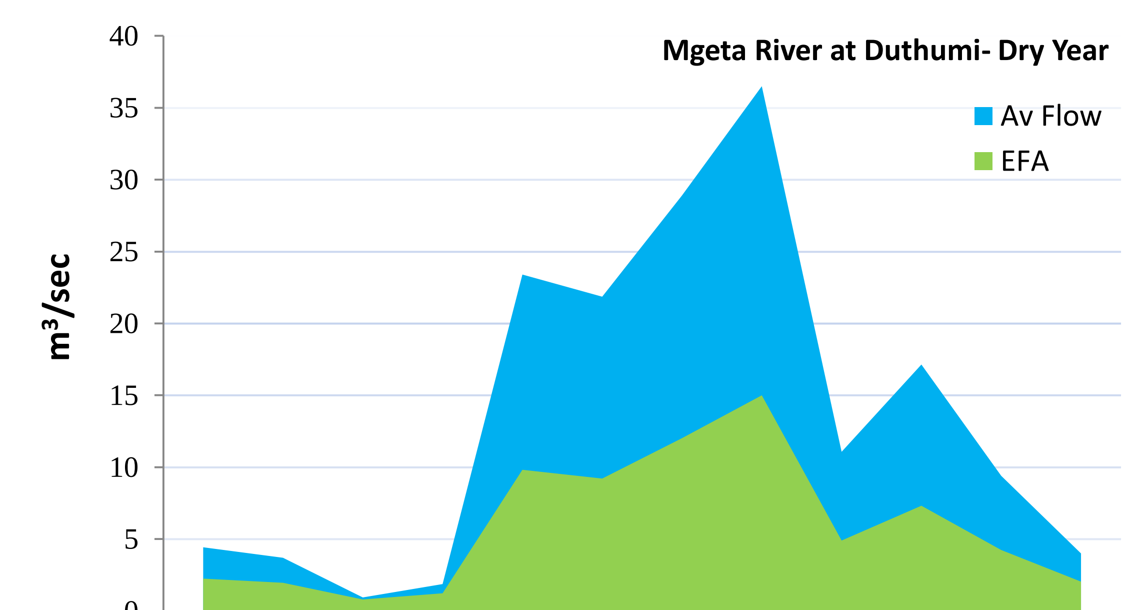
Table 8: Environmental flow prescriptions for the Mgeta River at Duthumi. Presented in the table are monthly average flows for dry and normal years and the recommended environmental flow expressed in magnitude and also as a percentage of the monthly average and mean annual runoff (MAR). Flood flows are recommended during normal years in the month of May.

Mgeta at Duthumi: Dry Year												
Index	**Oct**	**Nov**	**Dec**	**Jan**	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sep**
Average(m^3/s)	4.429	3.694	0.937	1.868	23.398	21.859	28.897	36.502	11.074	17.139	9.402	3.899
Recommended Environmental Flow												
Magnitude (m^3/s)	2.249	1.955	0.800	1.227	9.822	9.208	12.018	15.000	4.902	7.324	4.235	2.037
Magnitude (Mm^3)	6.023	5.068	2.143	3.285	23.762	24.663	31.150	40.176	12.706	19.616	11.342	5.281
% Average	51%	53%	85%	66%	42%	42%	42%	41%	44%	43%	45%	52%
% MAR	1%	1%	0%	1%	4%	4%	5%	6%	2%	3%	2%	1%
Mgeta at Duthumi: Normal Year												
Index	**Oct**	**Nov**	**Dec**	**Jan**	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sep**
Average(m^3/s)	3.353	9.961	7.206	15.806	22.458	19.012	82.730	99.145	23.822	14.074	10.944	5.045
Recommended Environmental Flow												
Magnitude (m^3/s)	2.280	4.102	3.448	5.488	7.066	6.249	21.361	25.000	7.389	5.077	4.335	2.936
Magnitude (Mm^3)	6.107	10.632	9.236	14.699	17.094	16.736	55.369	66.960	19.153	13.599	11.610	7.610
% Average	68%	41%	48%	35%	31%	33%	26%	25%	31%	36%	40%	58%
% MAR	1%	2%	1%	2%	3%	3%	9%	11%	3%	2%	2%	1%
Pulse (Normal Year)												
Magnitude (m^3/s)								105				
Magnitude (Mm^3)								9.07				
Return period (yrs)								1.5				
% MAR								1.4%				

Figure 10: Recommended environmental flows for the Mgeta River at Duthumi. The area in blue represents the historical averages for maintenance years or for dry years. The area in green represents the recommended environmental flow across the year.



	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep
Av Flow	3.53	9.96	7.21	15.81	22.46	19.01	82.73	99.15	23.82	14.07	10.94	5.05
EFA	2.28	4.1	3.45	3.49	7.07	6.25	21.36	25	7.39	5.08	4.34	2.94



	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep
Av Flow	4.43	3.7	0.94	1.87	23.4	21.86	28.9	36.5	11.07	17.14	9.4	4
EFA	2.25	1.96	0.8	1.23	9.82	9.21	12.02	15	4.9	7.32	4.24	2.04

Site: Ruvu River at Kidunda

The recommended EMC for Ruvu River at Kidunda was determined to be a C. For this site, the present state was considered to be a C and the trajectory of change to be negative. This site is likely to be transformed in the near future by the proposed Kidunda Dam, which is now entering its final phases of design and impact assessment. Additionally, this area may experience human population growth following the construction of the dam. However, the site is considered to be high to very high in terms of ecological importance and sensitivity, particularly from the aquatic ecology perspective and also because of the proximity of this site to the Selous Game Reserve. There is a wildlife corridor between the Selous and a forest reserve and there is interest in maintaining this corridor. In terms of aquatic ecology, there is an important annual flow that happens at this site, and the connectivity with the floodplain that this flood provides is critical to the life history of fish species. Environmental flow recommendations should be set with the goal of maintaining this site in a C class, although this will be a challenge given all of the impending changes. A buffer zone restoration program would also be of interest at this site.

In terms of environmental flow recommendations for the dry years, the team opted to consider strongly the needs of fish and riparian vegetation in making environmental flow recommendations. Flow recommendations were made with survival in mind for the driest months, so that just some water was flowing in the river. For wetter months, the team recommended that enough flow remain in the river to improve habitat conditions for fishes over drier months.

For the normal or maintenance years, again fishes were one of the main parameters for consideration during consensus decision-making on environmental flow recommendations. For drier months, flow recommendations are made to allow for fish species persistence through the dry season. For wetter months, it is necessary that the flow inundate appreciable areas of the banks, enough to cover some of the bank vegetation and provide access for fishes to these habitats. The species assemblage of fishes at this site includes several floodplain spawners, thus lateral connectivity is important.

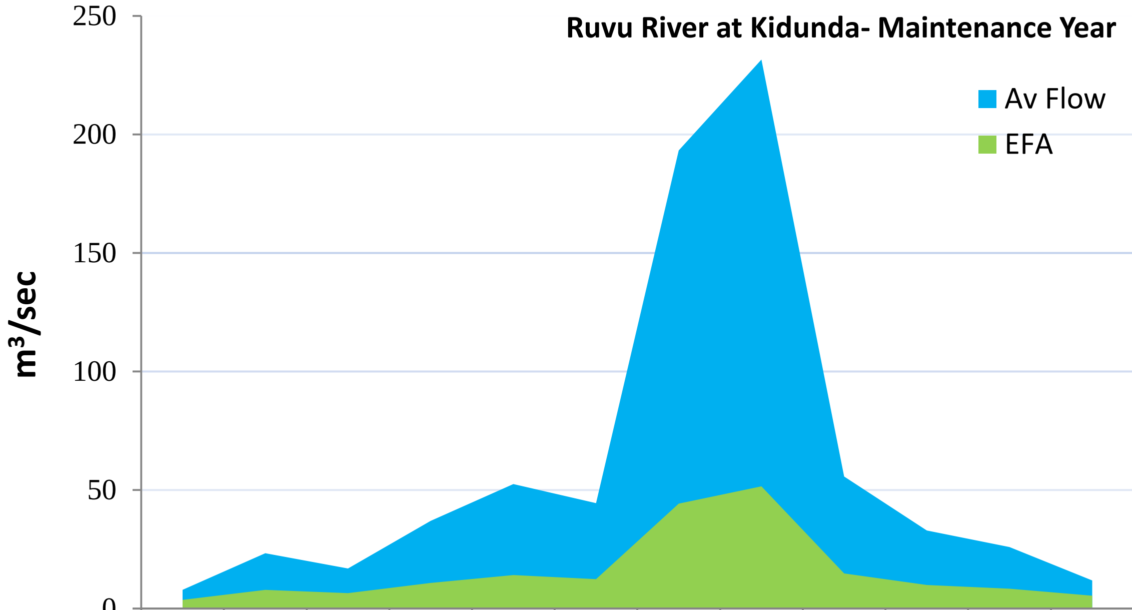
Floods were prescribed for the wet seasons of maintenance years. A flood of 104 m^3/s, with typically has a 1-year return, is recommended on an annual basis. A goal of this flood is to ensure lateral connectivity between the main Ruvu River channel and its floodplain, to provide access for species that use these habitats during their annual life cycle.

Noteworthy for this site is a rapid EFA that was conducted as a desktop study in 2011. This desktop study's conclusions and recommendations can be found in Kashaigili (2011).

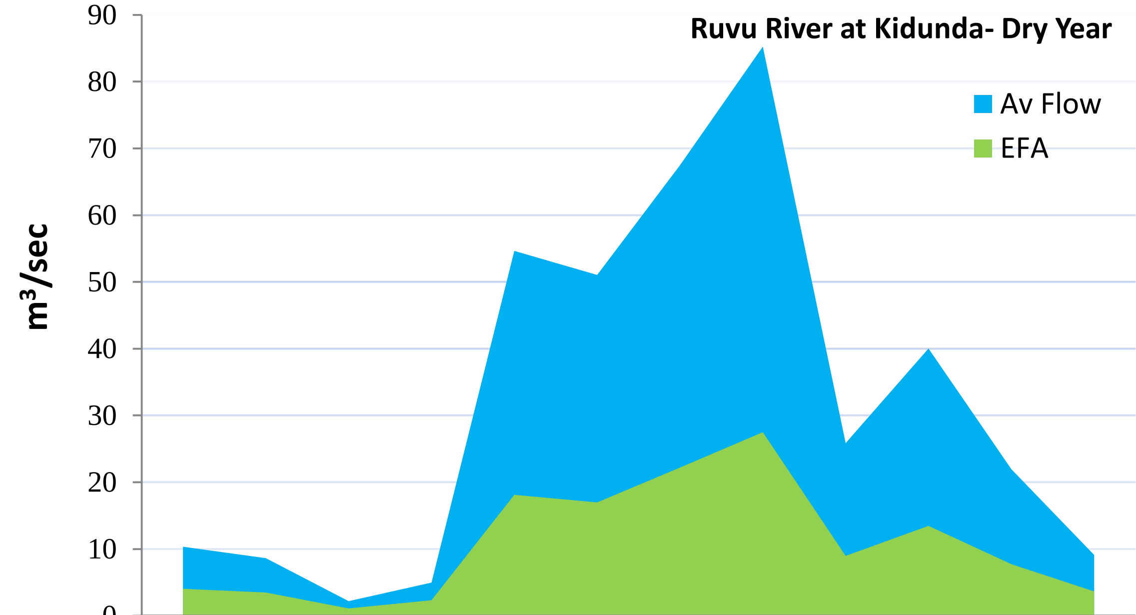
Table 9: Environmental flow prescriptions for the Ruvu River at Kidunda. Presented in the table are monthly average flows for dry and normal years and the recommended environmental flow, expressed in magnitude and also as a percentage of the monthly average and mean annual runoff (MAR). Flood flows are recommended during normal years in the month of May.

Ruvu at Kidunda: Dry Year												
Index	**Oct**	**Nov**	**Dec**	**Jan**	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sep**
Average(m^3/s)	10.344	8.627	2.187	4.970	54.646	51.054	67.489	85.252	25.863	40.030	21.959	9.106
Recommended Environmental Flow												
Magnitude (m^3/s)	4.038	3.492	1.100	2.330	18.118	16.976	22.200	27.500	8.970	13.473	7.730	3.645
Magnitude (Mm^3)	10.815	9.052	2.946	6.240	43.832	45.470	57.542	73.656	23.251	36.086	20.703	9.447
% Average	39%	40%	50%	47%	33%	33%	33%	32%	35%	34%	35%	40%
% MAR	1%	1%	0%	0%	3%	3%	4%	5%	2%	2%	1%	1%
Ruvu at Kidunda: Normal Year												
Index	**Oct**	**Nov**	**Dec**	**Jan**	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sep**
Average(m^3/s)	7.831	23.265	16.829	36.915	52.451	44.404	193.220	231.556	55.637	32.870	25.559	11.783
Recommended Environmental Flow												
Magnitude (m^3/s)	3.600	7.810	6.432	10.733	14.059	12.336	44.198	51.500	14.741	9.867	8.301	5.352
Magnitude (Mm^3)	9.642	20.245	17.229	28.747	34.012	33.041	114.561	137.938	38.209	26.427	22.235	13.873
% Average	46%	34%	38%	29%	27%	28%	23%	22%	26%	30%	32%	45%
% MAR	1%	1%	1%	2%	2%	2%	8%	9%	3%	2%	2%	1%
Pulse (Normal Year)												
Magnitude (m^3/s)								140				
Magnitude (Mm^3)								12.10				
Return period (yrs)								1				
% MAR								0.8%				

Figure 11: Recommended environmental flows for the Ruvu River at Kidunda. The area in blue represents the historical averages for maintenance years or for dry years. The area in green represents the recommended environmental flow across the year.



	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep
Av Flow	7.83	23.27	16.83	36.92	52.45	44.4	193.2	231.6	55.64	32.87	25.87	11.78
EFA	3.6	7.81	6.43	10.73	14.06	12.34	44.2	51.5	14.74	9.87	8.3	5.35



	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep
Av Flow	10.34	8.63	2.19	4.97	54.65	51.05	67.49	85.25	25.86	40.03	21.96	9.11
EFA	4.04	3.49	1.1	2.33	18.12	16.98	22.2	27.5	8.97	13.47	7.73	3.65

Site: Ngerengere River at Mgude

The recommended EMC for Ngerengere River at Mgude was determined to be a C. There was much debate over whether or not the Ngerengere at this site was a perennial river. Consultations with the WRBWO and elders in the region have led us to the idea that the Ngerengere was historically a perennial river, but has become more intermittent over time, most likely as a result of water withdrawals for human water use (R. Masikini, E. Lema, personal communications). The present state was classified as a C/D by the Ruvu EFA team, although other studies have considered it to be as low as E (GLOWS-FIU Mahay, 2013). The reason for the current effort's classification of the present state of this site as C/D was based on the fact that relatively sensitive species of macroinvertebrates were collected from the site during sampling, despite the fact that this site visually appears to be very degraded. Water quality data from the EFA site sampling and from other studies (Dutton, 2013) also paint a dim picture of the site's present state. In terms of ecological importance and sensitivity, this site was considered to be low or medium. Given these conditions, environmental flow recommendations should be set with the goal of restoration of this site and improvement to a higher class than the present state.

In terms of environmental flow recommendations for the dry years, the EFA expert team strongly suggested that any water flowing in the channel during the driest months be left to sustain ecosystems and ecological processes. During the wetter months of dry years, there is a need for sufficient pulse flows to flush sediments and help dilute pollutants. But the issue of water pollution deserves more attention from water resources managers. Environmental flows at this site should not be used to solve problems as related to water pollution; stricter controls on effluent are required.

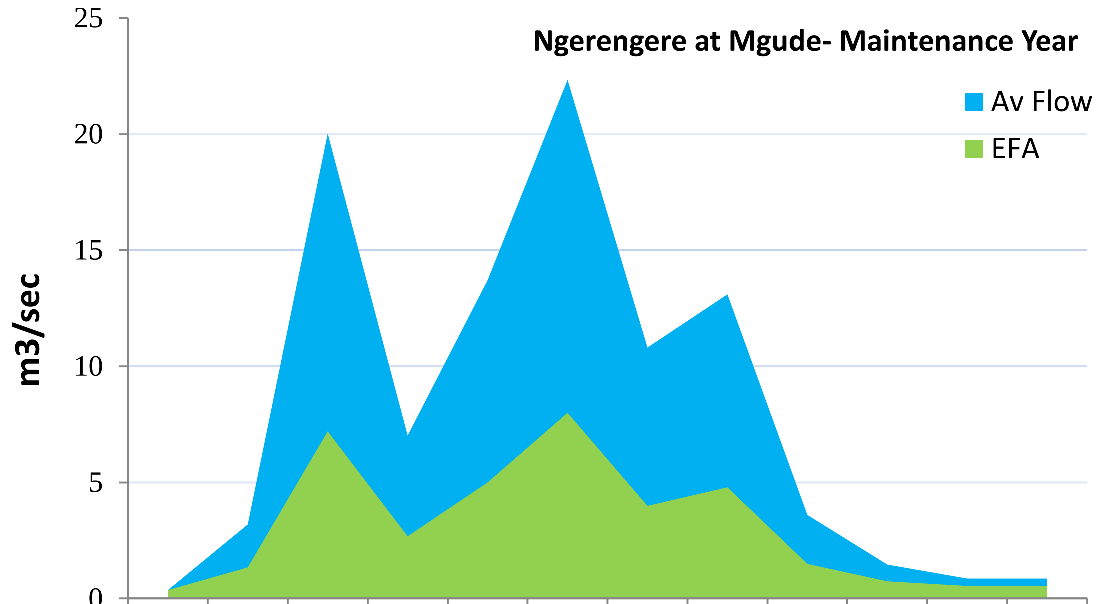
For the normal or maintenance years, again the recommendation is to leave as much of the natural flow in the river as possible during the dry season. There may be a little more water in normal years than in dry years, but as the goals of this site are restoration, there is a need to ensure enough flow for improvement over present conditions. During wetter months, sufficient water is needed to flush sediments and to provide additional habitat for aquatic biota. The actual confidence levels in the flow needs of species at this site are somewhat low. There has been limited sampling at this site, and a suite of other management concerns as related to the Mindu Dam and to degraded water quality. Therefore, how species and how the fluvial ecosystems will respond to improved flow management remains to be seen. Monitoring is suggested at this site.

Floods were prescribed for the wet seasons of maintenance years. A flood of 28 m^3/s magnitude, equivalent to that of roughly a 1.5-year return interval, is recommended on an annual basis. A goal of this flood is to ensure lateral connectivity between the main river channel and its floodplain and to flush out sediments and contaminants from the channel.

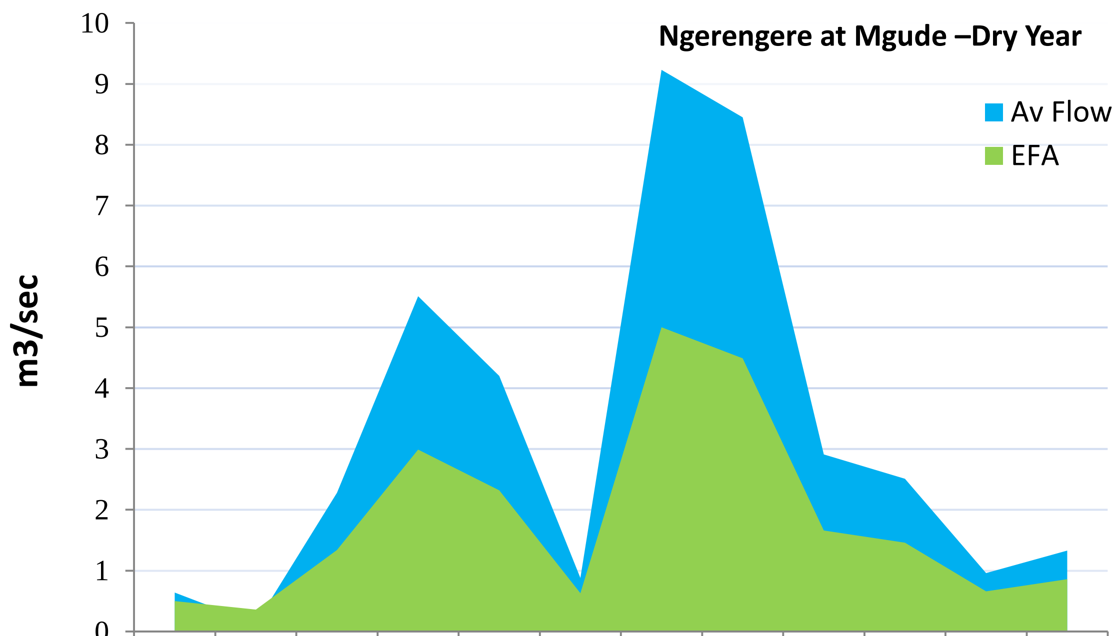
Table 10: Environmental flow prescriptions for the Ngerengere River at Mgude. Presented in the table are monthly average flows for dry and normal years and the recommended environmental flow, expressed in magnitude and also as a percentage of the monthly average and mean annual runoff (MAR). Flood flows are recommended during normal years in the month of March.

Ngerengere at Mgude: Dry Year												
Index	**Oct**	**Nov**	**Dec**	**Jan**	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sep**
Average(m^3/s)	0.639	0.133	2.281	5.510	4.196	0.883	9.234	8.450	2.912	2.509	0.955	1.333
Recommended Environmental Flow												
Magnitude (m^3/s)	0.502	0.360	1.339	2.986	2.316	0.626	5.000	4.485	1.661	1.456	0.664	0.856
Magnitude (Mm^3)	1.346	0.933	3.587	7.998	5.603	1.678	12.960	12.013	4.306	3.899	1.777	2.219
% Average	79%	270%	59%	54%	55%	71%	54%	53%	57%	58%	69%	64%
% MAR	1%	1%	2%	4%	3%	1%	7%	7%	2%	2%	1%	1%
Ngerengere at Mgude: Normal Year												
Index	**Oct**	**Nov**	**Dec**	**Jan**	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sep**
Average(m^3/s)	0.360	3.191	20.031	7.022	13.710	22.340	10.807	13.099	3.597	1.461	0.864	0.857
Recommended Environmental Flow												
Magnitude (m^3/s)	0.360	1.344	7.198	2.676	5.000	8.000	3.991	4.788	1.485	0.743	0.535	0.533
Magnitude (Mm^3)	0.964	3.484	19.278	7.166	12.097	21.427	10.345	12.824	3.849	1.989	1.434	1.381
% Average	100%	42%	36%	38%	36%	36%	37%	37%	41%	51%	62%	62%
% MAR	1%	2%	11%	4%	7%	12%	6%	7%	2%	1%	1%	1%
Pulse (Normal Year)												
Magnitude (m^3/s)						28.16						
Magnitude (Mm^3)						2.43						
Return period (yrs)						1.5						
% MAR						1.4%						

Figure 12 Recommended environmental flows for the Ngerengere River at Mgude. The area in blue represents the historical averages for maintenance years or for dry years. The area in green represents the recommended environmental flow across the year.



	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep
Av Flow	0.36	3.19	20	7.02	13.7	22.3	10.8	13.1	3.6	1.46	0.86	0.86
EFA	0.36	1.34	7.2	2.68	5	8	3.99	4.79	1.49	0.74	0.54	0.53



	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep
Av Flow	0.64	0.13	2.28	5.51	4.2	0.88	9.23	8.45	2.91	2.51	0.96	1.33
EFA	0.5	0.36	1.34	2.99	2.32	0.63	5	4.49	1.66	1.46	0.66	0.86

Site: Ruvu River at Kongo

The recommended EMC for Ruvu River at Kongo was determined to be C, and its present state considered to be C as well. This site is within the zone of influence of the Ruvu Estuary, from both up and downstream perspectives in that this site influences the estuary and in turn, the estuary also influences the Kongo site. The site was considered to have moderate importance or sensitivity from the perspective of aquatic and riparian species, but high importance in terms of geomorphology. The trajectory of change is solidly negative, with the main concern being water abstractions and the resultant hydrologic alterations. The upstream Kidunda Dam's flow regulation of the Ruvu River will influence this site, especially during the filling of the dam, but also during operation. Kidunda Dam is a single use dam for domestic water supply and there is concern about what its operation and management will mean for fishes and other biota, as well as sediment dynamics downstream. Given the present state and trajectory of change, environmental flow recommendations should be set with the goal of first stopping the negative trajectory and then maintaining the site.

In terms of environmental flow recommendations for the dry years, the team opted to use the needs of fish as the strongest component of influence in the consensus decision-making process. The flow recommendations recognized the need to keep some minimum flow in channel for survival conditions. Many of the fish species found at this site were either species with strong connections to the floodplain habitats or were estuarine species. Because of this site's proximity to the estuary, there was also some discussion on the need to understand better the patterns of saltwater intrusion into the Ruvu River channel. The EFA expert team advised that as additional information on the requirements of the estuary becomes available, these flow recommendations should be revisited.

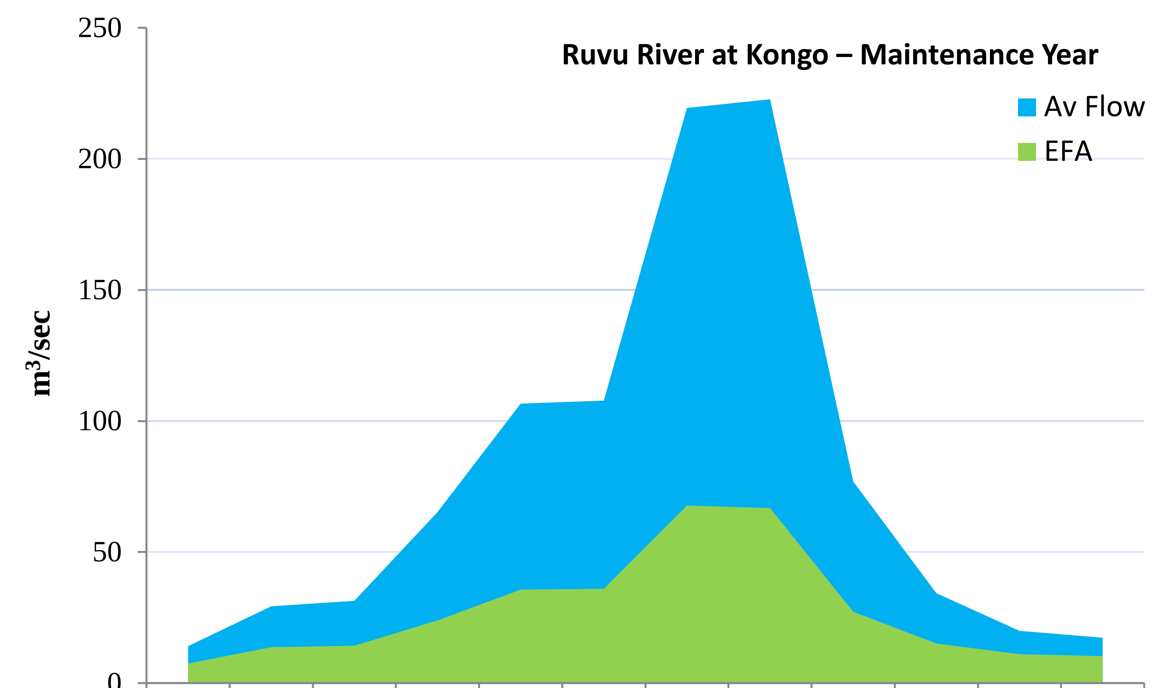
For the normal or maintenance years, the flow needs for channel processes and water quality conditions were considered to be of importance. The EFA expert team suggested that river flows be sufficient in dry months to move some of the fine sediments in the channel, but in the wettest months to flush deposited sediments. The team expressed need to consider these geomorphologic processes in more detail in future studies, as well as improve understanding of the needs of the estuary and coastal ecosystems for sediment input.

Floods were prescribed for the wet seasons of maintenance years. A flood of 92 m^3/s magnitude is recommended on an annual basis. A goal of this flood is to ensure lateral connectivity between the main Ruvu River channel and its floodplain, to provide access for species that use these habitats during their annual life cycle.

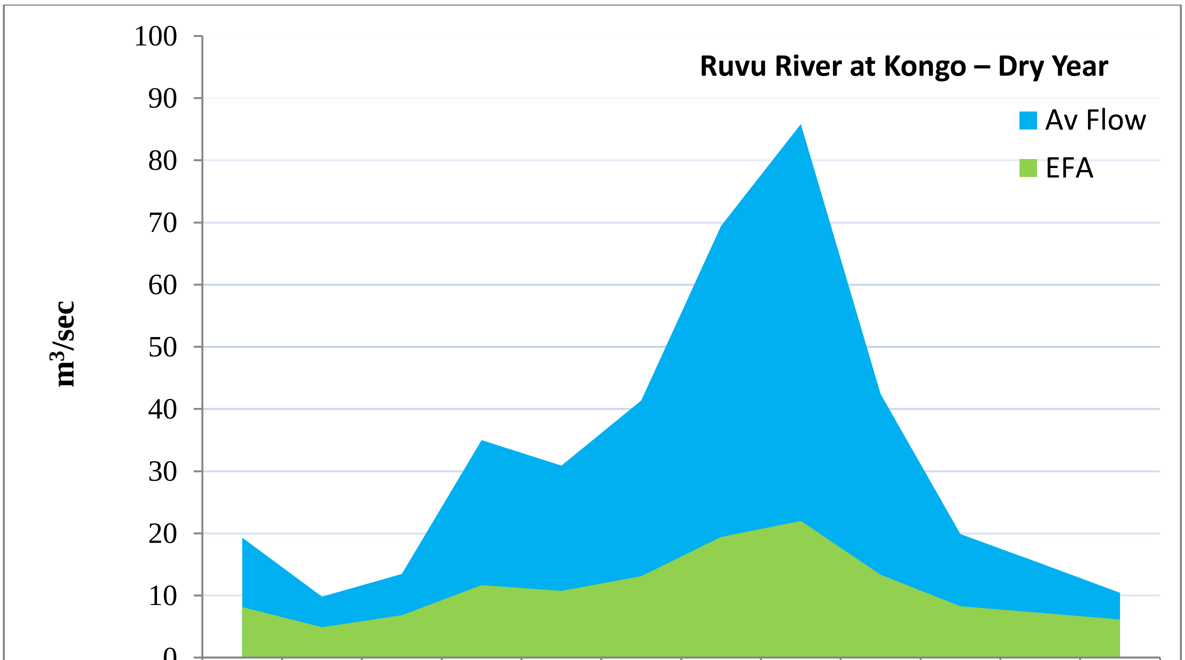
Table 11: Environmental flow prescriptions for the Ruvu River at Kongo. Presented in the table are monthly average flows for dry and normal years and the recommended environmental flow, expressed in magnitude and also as a percentage of the monthly average and mean annual runoff (MAR). Flood flows are recommended during normal years in the month of May.

Ruvu at Kongo: Dry Year												
Index	**Oct**	**Nov**	**Dec**	**Jan**	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sep**
Average(m^3/s)	19.317	9.815	13.468	35.001	30.897	41.367	69.444	85.833	42.424	19.884	15.201	10.433
Recommended Environmental Flow												
Magnitude (m^3/s)	8.143	4.900	6.827	11.671	10.748	13.103	19.419	22.000	13.341	8.271	7.217	6.145
Magnitude (Mm^3)	21.810	12.701	18.286	31.260	26.001	35.095	50.334	58.925	34.579	22.152	19.330	15.927
% Average	42%	50%	51%	33%	35%	32%	28%	26%	31%	42%	47%	59%
% MAR	1%	1%	1%	2%	1%	2%	3%	3%	2%	1%	1%	1%
Ruvu at Kongo: Normal Year												
Index	**Oct**	**Nov**	**Dec**	**Jan**	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sep**
Average(m^3/s)	14.114	29.306	31.397	65.249	106.637	107.766	219.456	222.762	76.931	34.298	19.935	17.329
Recommended Environmental Flow												
Magnitude (m^3/s)	7.500	13.697	14.292	23.913	35.676	35.997	67.740	66.800	27.233	15.116	11.034	10.294
Magnitude (Mm^3)	20.088	35.504	38.279	64.048	86.307	96.413	175.583	178.917	70.588	40.487	29.554	26.681
% Average	53%	47%	46%	37%	33%	33%	31%	30%	35%	44%	55%	59%
% MAR	1%	2%	2%	4%	5%	5%	10%	10%	4%	2%	2%	2%
Pulse (Normal Year)												
Magnitude (m^3/s)								92				
Magnitude (Mm^3)								7.95				
Return period (yrs)								< 1				
% MAR								0.5%				

Figure 13: Recommended environmental flows for the Ruvu River at Kongo. The area in blue represents the historical averages for maintenance years or for dry years. The area in green represents the recommended environmental flow across the year.



	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep
Av Flow	14.11	29.31	31.4	65.25	106.6	107.8	219.5	222.8	76.93	34.3	19.94	17.33
EFA	7.5	13.7	14.29	23.91	35.68	36	67.74	66.8	27.23	15.12	11.03	10.29



	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep
Av Flow	19.32	9.82	13.47	35.00	30.90	41.37	69.44	85.83	42.42	19.88	15.20	10.43
EFA	8.14	4.90	6.83	11.67	10.75	13.10	19.42	22.00	13.34	8.27	7.22	6.15

The Way Forward

The Ruvu EFA represents a first attempt to establish environmental flow recommendations for five sites in the Ruvu River Basin, in accordance with current legal and institutional frameworks for water resources management in Tanzania. The five sites considered by the Ruvu EFA team covered a range of scenarios that present management challenges for the WRBWO, from the case of the Ruvu River at Kidunda, a site which is scheduled for construction of a new dam in the next few years; to the case of the Ngerengere River, where a substantial restoration effort is needed to bring the river back to acceptable ecological condition; to the case of the Ruvu River at Kongo, where the cumulative effects of multiple upstream users of freshwater on the river must be contemplated in environmental flow recommendations. As with many previous EFA efforts in Tanzania, the Ruvu EFA involved an interdisciplinary team of scientific experts and leadership from the Tanzanian Ministry of Water, particularly the WRBWO.

The recommendations made by the Ruvu EFA are intended to be revisited periodically, either as conditions of the landscape or of rivers in the basin change, or as new management challenges arise. The recommendations of the Ruvu EFA should also be revisited as more scientific data become available for the basin. Hydrological data are particularly important; much of the present historical hydrologic record contains gaps in information, or data were collected manually. Automated gauges and more consistent data collection in the future will help improve understanding of flow tendencies in the Ruvu Basin. Similarly only limited scientific information on ecology, geomorphology, or water quality is available for the Ruvu Basin. The Ruvu EFA sponsored two field campaigns—one in the dry season and one in the wet season—which represent one of the only attempts to actually link flow and ecology or flow and geomorphology. Apart from these brief field studies, a limited assortment of historical information is available on fishes, on the Ruvu Estuary, and on biological species richness in the Ruvu's mountain blocks. Therefore, relationships between flow and ecology that form the basis of the flow recommendations for the Ruvu River were heavily based on experience from other rivers and on professional judgment of respected Tanzanian scientists.

The Ruvu EFA would have benefited from the inclusion of a stronger social science component. A few socially-oriented studies were commissioned as part of the Ruvu EFA effort, and these studies helped to provide information about the socioeconomic context and human population trends in the Ruvu Basin. But there is a noted absence of information that links human uses of rivers to flow. For example, how are the availability and quality of freshwater ecosystem goods and services in Tanzania—such as use of rivers for transportation, for waste assimilation, for building materials—influenced by river flows? This information would strengthen the discussions around environmental flow recommendations, as it would allow for more quantitative estimates of the flow needs for protection of key freshwater ecosystem services.

For each of the five sites in the Ruvu Basin, environmental flow recommendations that have resulted from this effort should be considered during decision-making about water allocation. At each of the sites, when new concessions for water are being considered, or when existing concessions are being re-evaluated, the flow needs of ecosystems should be taken into account and given second priority in decision-making about allocation of water, as per the Tanzanian Water Resources Management Act (2009). The constant involvement of the WRBWO in the Ruvu EFA process means that staff from the WRBWO participated in the formulation of environmental flow recommendations, and that they are aware of the reasons why certain flows are important to leave in rivers for ecosystems. The WRBWO also provided leadership during the process of setting management objectives for each site, whether the goal was to maintain, restore, or accept certain amounts of ecological degradation. This integral involvement of the WRBWO in all aspects of the Ruvu EFA, and the deep understanding of the WRBWO of the process, will hopefully facilitate higher likelihood of implementation of the environmental flow recommendations that have emerged from this effort.

At this close of this current Ruvu EFA effort, a list of future research areas has been identified (Table 12). The goal of this list is to assist Tanzanian and international scientists in targeting efforts to better understand flow-ecology relationships, and to pursue collection of data that will help refine the environmental flow recommendations for rivers of the Ruvu Basin in the future.

Conclusion

The Ruvu River is now the fifth major river basin in Tanzania for which there exists a comprehensive EFA study. The realization of the Ruvu EFA has helped to continue the process of capacity building around EFA in Tanzania, and has helped to solidify the advances that the East Africa region has made in recognizing the importance of freshwater flows for ecosystems and allocating water accordingly. The future growth of EFA in Tanzania depends on the continued support of the Tanzanian Ministry of Water for EFA and the Tanzanian government's commitment to implementing the Tanzanian Water Resources Management Act (2009), which provides the necessary legal backing for EFA. The expertise of Tanzanian scientists is an essential component of the EFA process as well, providing valuable data and scientific insight into understanding of the flow needs of ecosystems in Tanzania. This collaboration between water managers and scientists is a cornerstone of the EFA process in Tanzania.

Tropical rivers worldwide are undergoing rapid transformation, as a consequence of new hydropower development, agricultural expansion, mining, and urbanization, among other factors. As is the case for the Ruvu River, often only limited scientific data is available about tropical rivers subjected to these changes. The future of tropical rivers depends on increased appreciation and knowledge of the remarkable ecosystems that they harbor, and the vital resources rivers provide to human populations. And the future of tropical rivers depends on solid legal and institutional backing for management tools like environmental flows, which explicitly recognize ecosystem's needs for water and can provide a strategy for river protection in the context of rapid development. For this, it is hoped that Tanzania and the Ruvu EFA provide an example for other tropical rivers in East Africa and beyond.

Table 10: Research recommendations for the Ruvu River Basin to improve environmental flow recommendations.

Basin-wide	• Understanding flow-response curves for important biota and ecosystem processes. • Linking environmental flow recommendations from the five sites, particularly in terms of their influence on the Ruvu at Kongo site. Potential use of MikeBasin or similar program to model flow changes and their effects on different parts of the basin. • Use of bio-monitoring in assessment of river conditions, and therefore increasing scientific knowledge of macroinvertebrate assemblages, particularly in smaller rivers and upper basin areas. • Assessment and monitoring of river conditions once environmental flow recommendations are implemented. Are environmental flow achieving the expected / hoped outcomes for maintenance or restoration? • Improved understanding of flow needs of Saadani National Park ecosystems. • Water quality profiles and monitoring in both the Ruvu and Wami basins.
Research recommendations for specific sites	
Ruvu River at Kongo	• Increased scientific understanding of the estuary, especially flow needs and sediment needs, as well as importance of freshwater flows of different magnitude. • Increased scientific understanding of the links between sediment transport and river discharge. • Development of flow-ecology response curves for estuarine biota. • Mapping / understanding of the salt / freshwater boundary waters and their seasonal movement. • Examination of saltwater intrusion into groundwater; possible drilling of shallow wells. • Distributions of mangrove species and their zonation along the estuary.
Ruvu River at Kidunda	• Development of flow-ecology response curves for freshwater biota and for key ecosystem processes. • Review of studies from other places that examine effects of increased flows in dry periods; could be a consequence of operation of Kidunda Dam. • Review scenarios of fish productivity in the reservoir of proposed Kidunda Dam • Understand and model effects of controlled or regulated flows of Ruvu River by Kidunda Dam on downstream areas and human populations.
Ngerengere River	• Improved understanding of extent of water pollution in the Ngerengere River • Understanding of tolerance levels or thresholds for survival of native biota. How is it possible that biota, such as macroinvertebrates, appear to be surviving in what seems to be a very contaminated river? • Toxicology studies of aquatic biota • Water quality assessments, with spatial and temporal components • Assessment of sediments in Mindo Dam reservoir • Review of historical perspectives on the Ngerengere River, through interviews with elders, sediment cores, and paleontology.

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