Wami River Basin, Tanzania

Environmental Flow Assessment Phase II

Tanzania Integrated Water, Sanitation and Hygiene (iWASH) program

Wami River Sub-Basin, Tanzania
Environmental Flow Assessment Phase II

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Table of Contents

Institutional Collaborators ix

Acknowledgments x

Executive Summary 1

Introduction 3

Phase I EFA 3

Objectives of Phase II EFA 4

Background to the EFA Studies 5

Wami River Basin 5

Selection of Five EFA Sites 6

River Flows 6

Fieldwork Methodologies 8

Geomorphology 8

Hydrology 9

Water Quality 10

Macroinvertebrates and Fish Fauna 11

Riparian Vegetation 13

Socio-Economic Conditions 13

Fieldwork Results 16

Geomorphology 16

Kinyasungwe River at Kongwa (EFA Site 1) 16

Mkondoa River at Kilosa (EFA Site 2) 17

Wami River at Mtibwa (EFA Site 3) 18

Wami River at Mandera (EFA Site 4) 19

Wami River at Matipwili (EFA Site 5) 19

Hydrology 20

Kinyasungwe River at Kongwa (EFA Site 1) 20

Mkondoa River at Kilosa (EFA Site 2) 21

Wami River at Mtibwa (EFA Site 3) 22

Wami River at Mandera (EFA Site 4) 23

Wami River at Matipwili (EFA Site 5) 26

Water Quality 28

Ambient water quality 28

Chemical analysis 29

Heavy metals (Chromium, Lead) 30

Macroinvertebrates and Fish Fauna 31

Macroinvertebrates 31

Fish Fauna 33

Riparian Vegetation 37
Vegetation Communities 38
Invasive Species 39
Keystone and Indicator Species 40
Diversity and Human Influence 41
Plant's Flow Dependence 43
Socio-Economic Conditions 44
Domestic Use 44
Productive Subsistence Uses 45
Riparian and Instream Resources 45
Environmental Flow Considerations 47
Ecological Considerations 47
Geomorphology 47
Water Quality and Aquatic Species 47
Macroinvertebrates and Fish Fauna 48
Riparian Vegetation 49
Socio-economics 49
Site-by-Site Analysis 50
Kinyasungwe River at Kongwa (EFA Site 1) 50
Mkondoa River at Kilosa (EFA Site 2) 50
Wami River at Mtibwa (EFA Site 3) 50
Wami River at Mandera (EFA Site 4) 50
Wami River at Matipwili (EFA Site 5) 50
Additional Hydrological Records 51
New Discharge Data Sets 51
Modification of Routing Model 52
Flow Availability 53
Environmental Flow Recommendations 55
Kinyasungwe River at Kongwa (EFA Site 1) 55
Mkondoa River at Kilosa (EFA Site 2) 56
Wami River at Mtibwa (EFA Site 3) 56
Wami River at Mandera (EFA Site 4) 57
Wami River at Matipwili (EFA Site 5) 58
All sites: water quality considerations 59
Conclusion 60
References 62

List of Acronyms

AAD	Available Average Discharge
ADC	Acoustic Digital Current (meter)
ASPT	Average Score per Taxon
BBM	Building Blocks Methodology
DBH	Diameter at Breast Height
DO	Dissolved Oxygen
EC	Electrical Conductivity
EF	Environmental Flows
EFA	Environmental Flow Assessment
FFA	Flood Frequency Analysis
FIU	Florida International University
GEV	General Extreme Value
GPS	Global Positioning System
IEFA	Initial Environmental Flow Assessment
IFIM	Instream Flow Incremental Methodology
IUCN	International Union for Conservation of Nature
MML	Method of Maximum Likelihood
iWASH	Integrated Water, Sanitation and Hygiene
SASS	South African Scoring System
SRP	Soluble Reactive Phosphate
SS	Sample Size
TAL	Total Alkalinity
TCMP	Tanzania Coastal Management Project
TDS	Total Dissolved Solids
TKN	Total Kjeldah Nitrogen
TN	Total Nitrogen
TOC	Total Organic Carbon
TP	Total Phosphorus
TSS	Total Suspended Solids
UDSM	University of Dar es Salaam
WADA	Water and Development Alliance
WQ	Water Quality
WRBWO	Wami/Ruvu Basin Water Office

List of Tables

Table 1: Population sample sizes in study villages......15
Table 2: Average flow velocities and discharges of the Kinyasungwe River......21
Table 3: Average flow velocities and discharges of the Mkondoa River. 22
Table 4: Average flow velocity and estimated discharges of the Wami River at Mtibwa. 23
Table 5: Average flow velocities of the Wami River at Mandera by Float Method. 24
Table 6: Average flow velocities and discharges of the Wami River at Mandera. 25
Table 7: Average flow velocities of the Wami River at Matipwili EFA site by the Float method......27
Table 8: Average flow velocities and discharges of the Wami River at Matipwili. 28
Table 9: Physical water quality parameters at EFA sites. 28
Table 10: TSS, sulphates and sodium at EFA sites 29
Table 11: Calcium and Magnesium concentrations at EFA sites. 29
Table 12: Nutrients concentrations at EFA sites......30
Table 13: Heavy metals concentrations at EFA sites......31
Table 14: Benthic macroinvertebrate species at EFA 1, 2 and 5......32
Table 15: Macroinvertebrates tolerance to pollution in EFA 1, 2 and 5......33
Table 16: Shannon-Weaner diversity index of macroinvertebrates in EFA 1, 2 and 5......33
Table 17: Fish species collected in the EFA sites during 2007 and 2011 EFA field surveys......34
Table 18: Shannon Weaner fish diversity index for the five EFA sites......35
Table 19: Conservation status of fish species at EFA sites in the Wami River Basin......36
Table 20: Representative fish species in major environmental guilds in the Wami River......36
Table 21: Moderate, high and critical sensitive fish species at EFA sites in the Wami River Basin 37
Table 22: Vegetation communities at EFA sites in the Wami River Basin 38
Table 23: Invasive species in various areas along the channel 39
Table 24: Endangered, threatened and endemic species around EFA sites......40
Table 25: Keystone species around EFA sites in the Wami River Basin......40
Table 26: Indicator vegetation species around EFA sites in the Wami River Basin......41
Table 27: River resource use in the Wami River Basin (Initial EFA 2008) 44
Table 28: Dominant household family sizes around EFA sites......45
Table 29: Dominant livelihood activities around EFA sites......45
Table 30: Instream and riparian resources around EFA sites 46
Table 31: Flow dependence of social services and livelihood activities around EFA sites. 46
Table 32: Guidelines of key water quality parameters for protection of aquatic organisms including most sensitive fish species in tropical rivers......48
Table 33: Estimation of village water consumptions at EFA sites......49
Table 34: Additional discharge information in the Wami River Basin......52
Table 35: Assessment of flow availability at 1GD16 from revised flow requirements at EFA Site......53

Table 36: Estimated flood discharges at EFA study sites 54
Table 37: Recommended EFs (m3/s) at EFA site 1 (the Kinyasungwe River at Kongwa) 55
Table 38: Recommended EFs (m3/s) at EFA site 2 (the Mkondoa River at Kilosa)....56
Table 39: Recommended EFs (m3/s) at EFA site 3 (the Wami River at Mtibwa) 57
Table 40: Recommended EFs (m3/s) at EFA site 4 (the Wami River at Mandera) 58
Table 41: Recommended EFs (m^3/s) at EFA site 5 (the Wami River at Matipwili) 58
Table 42: Recommended maximum water quality levels at all 5 EFA sites 59

List of Figures

Figure 1: Location map Wami/Ruvu River Basin (orange boundaries) in Tanzania. 5

Figure 2: Location map showing the 5 EFA Sites for Phase I and II. 6

Figure 3: Spatial location of five selected EFA sites and conditions in April 2011. 8

Figure 4: Flow condition of the Kinyasungwe River at Kongwa (EFA site 1) on 12th April 2011. 20

Figure 5: Flow condition of the Mkondoa River at Kilosa (EFA site 2) on 13th April 2011. 21

Figure 6: Flow condition of the Wami River at Mtibwa (EFA site 3) on 14th April 2011. 22

Figure 7: Flow condition of the Wami River at Mandera (EFA site 4) on 15th April 2011. 23

Figure 8: River cross-section at study location where the float method was used. 24

Figure 9: Rating curve data of the Wami River at Mandera (1G2). 26

Figure 10: Flow condition of the Wami River at Matipwili (EFA site 5) on 16th April 2011. 26

Figure 11: Plant species diversity during (a) wet and (b) dry season 41

Figure 12: Population structure and DBH size class distribution among the EFA sites. 43

Figure 13: Biomass distribution among EFA sites. 43

List of Images

Image 1: Man fishing in the Wami River near the Mandera River. These shoals provide important habitat for aquatic biota 7

Image 2: Typical fisherman house in Sadaani Village with fish nets strung outside..14

Image 3: Many wild animals still inhabit the Wami River Basin 15

Image 4: River flow gauge visited by WRBWO staff 27

Image 5: Fish diversity in the Wami River Basin is understudied..37

Image 6: The Diwale River (left) is a tributary of the Wami River whose headwaters drain the Nguru mountains(right)..43

Image 7: The Wami estuary has both socioeconomic and ecological importance 51

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 (Figure 1). 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 Wami EFA 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

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 we make in developing countries has long-term benefits for America and the American people.

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Funding for the Wami River Environmental Flow Assessment (EFA) was provided by the people of the United States of America through the U.S. Agency for International Development (USAID) and The Coca-Cola Company, as a component of the Water and Development Alliance (WADA).

The views and opinions of the authors expressed herein do not necessarily state or reflect those of the United States Agency for International Development, the United States Government, The Coca-Cola Company or Florida International University.

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In Phase I, logistical and administrative support in Tanzania was provided by the Wami/Ruvu Basin Water Office, together with the Tanzania Coastal Management Partnership (TCMP). The staff members of TCMP, especially Jeremiah Daffa, Appa Mandari, Esther Kapinga, and Baraka Kalangahe, deserve acknowledgements for their efforts to offer guidance on the Wami River EFA Phase I. We are grateful to the Coastal Resources Center at the University of Rhode Island, in particular Cathy McNally, Don Robadue, and Jim Tobey for the initial invitation extended to FIU to work with the Tanzania WADA I Program, and for continued support throughout Phase I. Special thanks go to Andrea Lamelas and Dr. Michael McClain, both previously at Florida International University. Dr. Jay O'Keeffe of the UNESCO-IHE was helpful with ideas on how to approach the Wami River project during its planning phases. Amanda Subalusky and John Stiefel provided valuable editorial assistance in the preparation of Phase I documents.

In Phase II, logistical and administrative support in Tanzania was provided by the Wami/Ruvu Basin, together with the Integrated Water Sanitation and Hygiene (iWASH) Program being implemented as part of the Global Water for Sustainability (GLOWS) led by Florida International University (FIU). The staff members of the iWASH Program deserve acknowledgement, especially Leodgard Haule in his role as Manager of the WADA II Project, Asha Mercy Mohamed for her support to field coordination, and Lorna Davey for her efforts in editing this final report. A very special thanks to Appa Mandari, who coordinated the Wami EFA in both Phase I under TCMP, and in Phase II under the iWASH Program.

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Within GLOWS/FIU, Dr. Elizabeth Anderson provided guidance and participated actively in the second phase of the Wami River EFA and the production of the present document. Vivienne Abbot, Marwan Noorani, Amartya Saha and Maria Donoso contributed in the publication of this report.

It is hoped that this project and the lessons learned from the Wami River EFA provide an example for other basin water offices in Tanzania.

Executive Summary

Tanzania's National Water Policy of 2002 and Water Resources Management Act of 2009 establish an order of priority in decision-making as related to allocation of surface water resources. According to these frameworks, basic human needs for water use are afforded first priority, and then water for the long-term sustainability of ecosystems is given second priority in decision-making about water. Implementation of this legislation means that water managers in Tanzania must understand the needs of ecosystems in terms of quantity, quality and timing of freshwater flows. Environmental flow assessment (EFA) is a process by which these ecosystem needs are identified and quantified to the best degree possible. More than 200 approaches have been employed worldwide for EFA, but the general consensus to which many people are arriving is that EFA should be a holistic process that considers the flow needs of ecosystems and the flow linkages to the availability and quality of freshwater ecosystem services upon which humans depend. Further, ideally EFA should be conducted with input from scientists, water managers, and those with a stake in resource management decisions.

In 2007, the Wami/Ruvu Basin Water Office (WRBWO), in collaboration with scientists from the University of Dar es Salaam (UDSM) and Florida International University (FIU) began a process of EFA for the Wami River Basin in order to better understand the flow needs of ecosystems. This work has been supported by the Tanzania Water and Development Alliance project (WADA), Phases I and II. A first round of EFA studies for the Wami River was carried out in April – December 2007.

This report summarizes the results of a second round of data collection as related to EFA in the Wami River Basin, and a review of the original flow recommendations. The aims of this second round were to fill gaps in understanding that were identified in the 2007 studies, to update analyses of the hydrologic record, and to revisit the original environmental flow recommendations. A limitation of the first round of EFA studies was that field data were only collected during the dry season, because of the short timeframe of the study and the absence of a rainy season in early 2008. The present study addressed this need through a wet season sampling event, which took place in April 2011. The same team of scientific experts that had participated in the first round of EFA again worked together, and this time a water quality expert joined the team.

The timing of the wet season fieldwork was arranged to coincide with flood flow conditions at most EFA sites following good rains in the Basin. This enabled field sampling of fish, macroinvertebrates, riparian vegetation, geomorphology, socio-economics and hydrology. However, high flow conditions with high flow velocities prevented direct discharge measurements during sampling at three of the study sites along the main Wami River (Mtibwa, Mandera, Matipwili) due to safety reasons. In terms of ecology, the fieldwork indicated existence of some fish and macroinvertebrate species that were not collected during the November 2007 fieldwork, and absence of some vegetation species that were observed during the 2007 fieldwork. The only water quality data now available at the five study sites was collected during the wet season fieldwork, and these data suggested that most parameters are still within the permissible values under Tanzanian guidelines. More information on socioeconomic parameters and further interviews with residents in the Wami River Basin were also gathered, allowing for increased understanding of the links between flow and availability of freshwater ecosystem services.

On the basis of the additional wet season data, the original environmental flow recommendations that were suggested in 2007 were revisited and, in some cases, revised. The recommendations were as follows:

i. Interpretation of environmental flow needs with consideration of the new wet season data led to a proposed adjustment of the recommended environmental flow regime at the Kinyasungwe River at Kongwa site (EFA Site 1) to support wet season ecological and geomorphological flow. During the 2007

dry season sampling, this site had been completely dry and therefore the 2011 wet season data were an important contribution to the understanding of the river's dynamics.

ii. The recommended environmental flow regimes for the EFA Site 2 - 5 (the Mkondoa River at Kilosa, the Wami River at Mtibwa, the Wami River at Mandera, and the Wami River at Matipwili) were left unchanged, as the wet season data upheld those original recommendations.

iii. Although water quality measurements indicate good quality of water within the Wami River Basin, minimum water quality standards have been recommended for the Wami River Basin to support the continued conservation of aquatic ecology.

It is also recommended that the following further research be conducted to support these EFAs:

ii. Additional fieldwork be undertaken to continue increasing the scientific understanding of the Wami River and its tributaries, and particularly the flow dependence of ecosystems and ecosystem services.

iii. More in-depth study of ecologically important areas of the basin, such as the shoals at the Wami River at Mandera and the estuary of the Wami River at Saadani National Park.

iv. More study and inventory of aquatic and riparian biodiversity is needed to complete species lists for the basin; these studies should be accompanied by social research into human uses of aquatic and riparian resources.

v. Hydrologic models for the basin should be updated continually as more data become available and to provide longitudinal linkages between the sites within the Basin's hydrographic network for practical applications in basin water allocation.

vi. Finally, given that EFA should be viewed as a process, the WRBWO and the scientific experts' team should periodically revisit the recommended environmental flows for the five sites as more scientific information on the Wami River Basin becomes available.

Introduction

This Report broadens the Environmental Flow information available for water resources management in the Wami River Basin, and acts as a companion to the first round of the Wami River Basin environmental flow assessments documented in the Initial Environmental Flow Assessment (EFA) Synthesis Report (Hyera *et al.,* 2008). Specifically, it summarizes the results of EFA fieldwork carried out during the wet season of 2011 and provides suggestions for updating the Phase I EFA and environmental flow recommendations in the Initial EFA Report (Hyera *et al.*, 2008).

Phase I EFA

The EFA processes undertaken are designed to meet the goals for surface water resources management as laid out in Tanzania's National Water Policy of 2002, the National Water Sector Development Strategy for 2006-2015, and the Water Resources Management Act No. 11 of 2009. The National Water Policy of 2002 recognizes the flow needs of ecosystems as the second priority in allocation of water resources, following freshwater requirements for basic human needs and domestic activities. A detailed description of the institutional and legal frameworks for water management in Tanzania is set out in the Initial Environmental Flow Assessment Synthesis Report (Hyera *et al.*, 2008).

In order to best make water resource allocation decisions within this order of priority, Environmental Flow Assessments (EFAs)—which identify the quantity, quality and timing of flows needed for ecosystems and ecosystem services—are needed for all major rivers in Tanzania, including the Wami River. As set out in the Environmental Flow Assessments, Wami River Sub-Basin (Hyera, 2007), an EFA is a management tool that can assist the institutions tasked with managing water resources to meet the challenges of balancing the diverse needs for water in a rapidly changing landscape. Accordingly, the Wami/Ruvu Basin Water Office (WRBWO), in collaboration with scientists from Florida International University (FIU) and the University of Dar es Salaam (UDSM), began an initiative in 2007 to conduct an initial EFA for the Wami River Basin, through the Tanzania Water and Development Alliance (WADA) project.

As set out in the EFA Synthesis Report, the first round of EFA studies was realized between April – December 2007 and included:

i. a review of the literature on the Wami River Basin;
ii. field data collection during the dry season; and
iii. a flow-setting workshop to articulate the management goals for the Wami River and to identify, by consensus, the recommended environmental flows.

For the EFA process and ultimately to improve information for decision-making, the following five key sites in the Wami River Basin were selected for data collection and EFA recommendations:

- *Kinyasungwe River at Kongwa (EFA Site 1);*
- *Mkondoa River at Kilosa (EFA Site 2);*
- *Wami River at Mtibwa (EFA Site 3);*
- *Wami River at Mandera (EFA Site 4);*
- *Wami River at Matipwili (EFA Site 5)*

Initially eight key sites were identified for the EFA. However, only these five key sites satisfied the requirements and captured the length and diversity of the Wami River network.

These sites were selected on the basis of hydraulic and geomorphological criteria and because they represented critical and varied habitats for fish, aquatic invertebrate and riparian vegetation (Ndomba, 2007; Mwanukuzi, 2007).

The steps undertaken during the Wami River EFA process included: (1) literature reviews of available information for the Wami River Basin; (2) analysis of the hydrologic record and use of modeling approaches to fill in gaps in this record; and (3) field data collection during the dry season. The team followed guidelines from several well-established EFA approaches (e.g., Building Block Methodology, Savannah Process). On the basis of the information that was gathered, quantitative estimates for environmental flows were made for five EFA sites in the Wami River Basin; these estimates were arrived at by consensus of the scientific team, the WRBWO, and other representatives from the Tanzanian Ministry of Water. These recommended environmental flows were then subsequently used by the WRBWO as a simple tool for decision-making about water allocations in the Wami River Basin. The first round of EFA for the Wami River also served as a capacity building exercise for the WRBWO and for scientific experts from UDSM, improving the WRBWO capacity in assessing and implementing environmental flow recommendations and resulted in the formation of a solid Tanzanian team that has since assisted with EFAs in other Tanzanian Basins (Mara, Ruaha, Pangani, and Ruvu). This team includes scientific experts in the following disciplines: hydrology, hydraulic engineering, aquatic ecology, riparian botany, geomorphology, and social sciences. It also created a process for EFAs that can be replicated with relative ease by other basin water offices in Tanzania.

Nevertheless, it was recognized from the start that the report produced during this Phase I EFA (ref), often referred as the Phase I EFA Synthesis Report, would need to be complemented with additional data collection and analysis, particularly as one of the main limitations of the first round of EFA was the absence of field data collection during the wet season. Additionally, the Wami River is subject to dynamic river flow variations, and there was need to better capture these variations in the EFA.

Objectives of Phase II EFA

In 2011, with new support from the Phase II of the Tanzania WADA project, which forms part of the Global Water for Sustainability (GLOWS) Tanzania Integrated Water Sanitation and Hygiene (iWASH) Program, a second round of sampling was conducted during a period of wet weather, when flows were high in the Wami River and its tributaries. Data were collected and analyzed on flow, hydraulic parameters, physical and chemical characteristics of river water, ecological characteristics of aquatic and riparian biota, and channel geomorphology. Further, information on the human relationships with the Wami River and its tributaries was collected and analyzed, including dependence of human populations on freshwater ecosystem services (e.g., freshwater, food, fibre, navigation, among others), and how those ecosystem services are influenced by flow. This report sets out the results, recommendations and conclusions for environmental flows in the Wami River Basin from this second round of sampling to compliment the EFA in Phase I. This Report should therefore be read in conjunction with the Initial EFA Synthesis Report (Hyera *et al.*, 2008), to ensure a complete picture of the Wami River Basin.

Background to the EFA Studies

Wami River Basin

As set out in the introductory sections of the Ndomba (2007) dry season study, the Wami River drainage basin is located on the eastern side of Tanzania. Figure 1 shows the Wami/Ruvu basin which comprises of the catchments of Wami, Ruvu and coastal rivers that are jointly administered as a unit by the Ministry of Water. The Wami basin extends between 5° and 7° Latitudes, South and between 36° and 39° Longitudes, East.

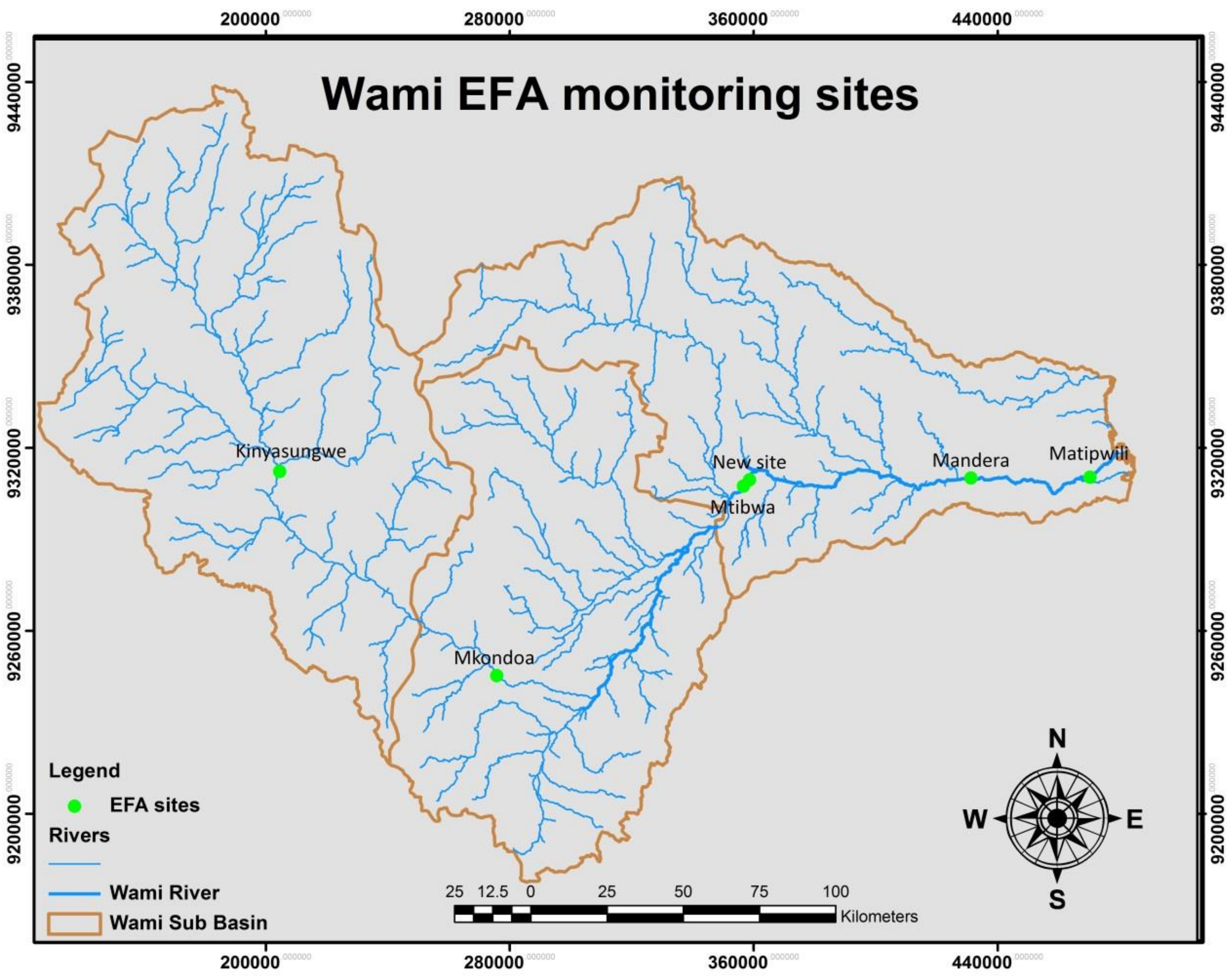
Figure 1: Location map showing the Wami/Ruvu River Basin (orange boundaries) in Tanzania.

The Wami River system covers an area of about 40,000 km^2 with 1G2 as an outmost downstream gauging station. The Wami River has its water sources in the Kaguru Mountains in Morogoro Region. The river flows into the Indian Ocean and contains the Wami Delta, which is about 90 km north of Dar es Salaam around Matipwili village (Madulu, 2005). The importance of the Wami River basin originates from its diversified use, which benefits a multiplicity of stakeholders including species in natural habitats, agriculture (both large and small scale), pastoralism, wildlife conservation, and domestic and industrial activities (Madulu, 2005).

Selection of Five EFA Sites

The selection process for the five EFA Sites is set out in the Initial EFA Synthesis Report (Hyera *et al.*, 2008). A map showing the final sites selected is shown below (Figure 2). The site at Mtibwa is proposed to be moved a bit further downstream.

Figure 2: Location map showing the 5 EFA Sites for Phase I and II. For the Wami River at Mtibwa site, both old and new locations are shown.



River Flows

The natural hydrologic variability and dynamic character of the Wami River has an ecological importance. The life histories of species that inhabit the Wami River and adjacent riparian zones are adapted to seasonal changes in flows; these changes, for instance from low to high flows, can be biological cues for species migrations or can help with habitat maintenance. Therefore, water allocation for the ecosystems and recommendations for environmental flows should follow this natural flow seasonality. Field data to support EFA studies needs to provide information on the ecology and related characteristics of rivers during both low and high flow periods. From the start therefore, there would be a need to complement the data from the first round of EFA studies in the Wami River Basin detailed in the initial EFA.

The Wami River Basin seasonality consists of a transition pattern of intra-annual (within year) flow variation between a bimodal (double peaks) regime in the north and a unimodal (single peak) regime in the south. The bimodal pattern has two peaks, a slight peak during and following the *vuli* (short) rains in October-January and a major peak during and following the *masika* (long) rains in March-May. The unimodal pattern is experienced in the largest part of the Wami River Basin and is characterized by a well-defined flow peak in March-June/July. The seasonal flow patterns further indicate that low flows in rivers in the Wami River Basin are experienced during the dry period, particularly February-March and July-October/November, with the lowest flows observed normally in October/November. In certain drought years, some smaller rivers do completely dry up during dry periods. For graphic representations of the seasonal river flows please refer to the IEFA Synthesis Report (Hyera *et al.*, 2008). The initial EFA fieldwork for Phase I was undertaken in the five key sites during November 2007, during typically the lowest flow period.

Beyond the annual extremes of low and high flows, five main types of hydrologic years can be identified: drought, dry, normal, wet and flood years. Valimba (2007), using all record average daily flow annual hydrographs, indicated the typical period of low flows in the Wami River Basin to extend between 14 August and 2 December. The typical high flows period during and following *masika* (long) rains extends between 11 March and 20 June (see IEFA Synthesis Report (Hyera *et al.*, 2008) for graphic representations).

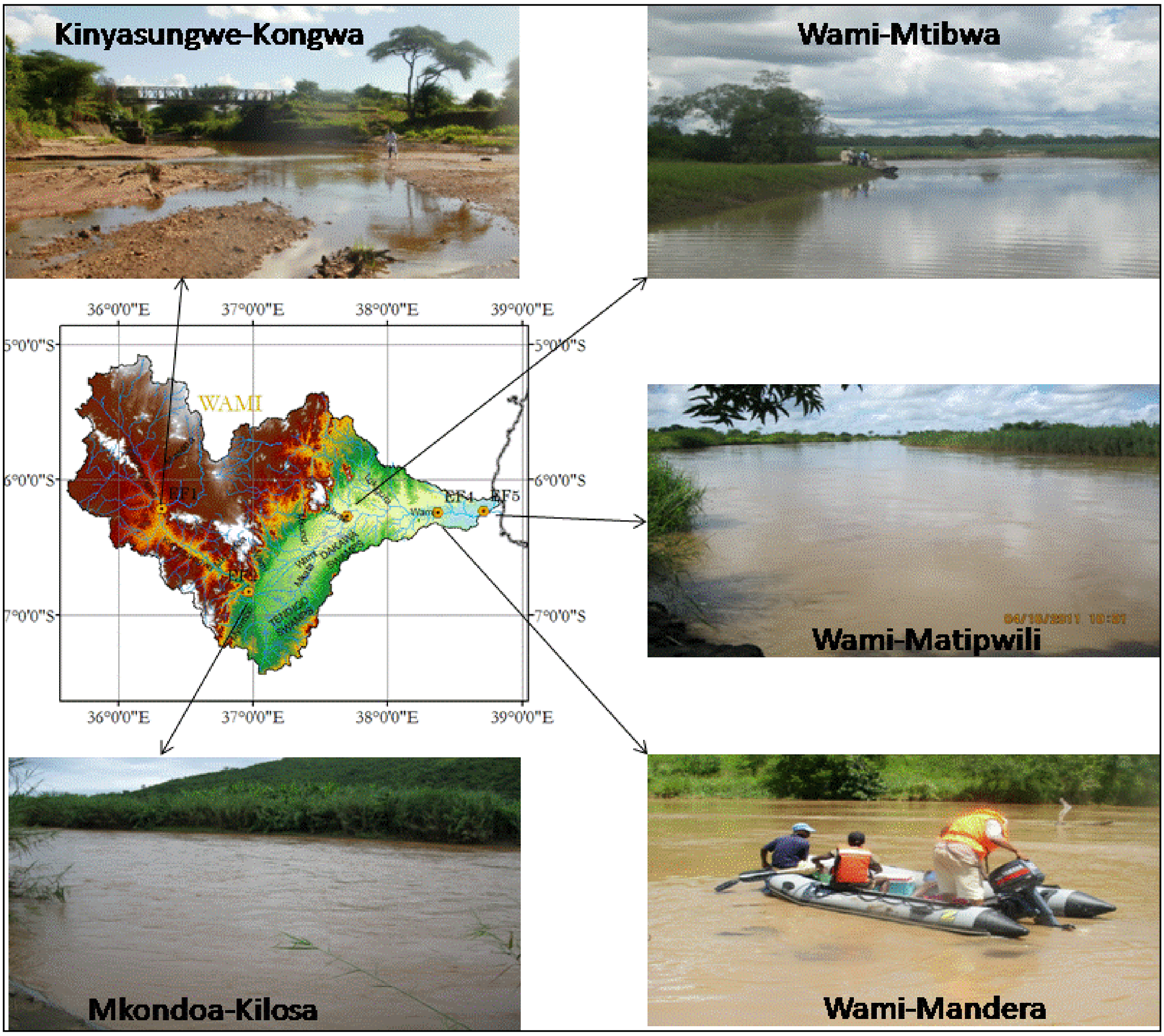
Image 1: Man fishing in the Wami River near Mandera. These shoals provide important habitat for aquatic biota.

Fieldwork Methodologies

The wet season fieldwork was initially planned for 2008, however, the rains were scant that year and we determined that conditions were therefore not appropriate for sampling. Follow up EFA studies in the Wami River were then postponed until the second phase of the Tanzania WADA project, which began in late 2010.

The five key sites were sampled in early 2011 (April 11 – 16), and were the same five sites sampled during the initial EFA sampling in 2007 (*Kinyasungwe at Kongwa, Kilosa, Mtibwa, Mandera and Matipwili*), shown in Figure 3 below.

Figure 3: Spatial location of five selected EFA sites and conditions in April 2011.



Geomorphology

A river's channel is strongly influenced by flow, and therefore geomorphologic field data collection is a key component of an EFA study.

During the 2011 fieldwork, geomorphological conditions were determined using:

i. Direct observation based on the site assessment form for the geomorphologic component of the Building Block Methodology (Rowntree and Wadeson, 1999). This resulted in identification of characteristics of riparian and channel vegetation, channel cross section geomorphologic units, the nature of flows and general channel conditions. Where present, processes occurring in the river reach, such as deposition, erosion, incision, meandering and braiding of the channel, were also observed
ii. Collection of 'grab samples' of sediments from each geomorphologic unit, particularly riverbanks, riverbed, pools and riffles, and sand bars. At low flows, the surface material was scooped using the bed load sampler. At high flows, the sampler was mounted on a graduated metal load and surface material scooped from the riverbed. The suspended sediment was not collected but assessed based on the turbidity of water.

This geomorphologic information was then assessed to describe the nature of water flows and their effect on channel adjustment. Processes occurring on the river channel were used to infer the nature of channel adjustment. The sediment size from grab samples found on different geomorphological units was used to identify the competence of the river conveyance of material supplied and its implication in maintenance of the channel. Sieve analysis was performed in the laboratory on the grab samples to obtain the dominant grain size in the scoop sample collected. The source of the sediments was speculated on the basis of the nature of the catchment at the EFA site and characteristics of the channel banks. The catchment characteristics were identified further by interpretation of satellite images and topographic maps of the study site. The images were used to identify, for example, erosion scars or land use. In addition, the source of sediments was inferred from analysis of the nature of the catchment from the topographic maps. This information was integrated to derive a narrative report of the river channel characteristics during wet season flows.

Hydrology

During the first round of EFA studies in the Wami River Basin in 2007, an extensive desktop analysis of available historic hydrologic records and studies was conducted (Valimba, 2007) and therefore this was not repeated for this report. Wet season field data collection and analysis of river discharges corresponding to various water depths and velocities were, however, carried out in 2011 to mirror data collection and analysis undertaken in 2007 for the dry season.

Measurements of river flows were carried out using three discharge measurement methods: Propeller Type Current Meter; Acoustic Digital Current (ADC) Meter; and Float Methods: The Propeller Type Current Meter is the most direct discharge measurement method. The ADC method requires a deep knowledge of numerous input variables that are used in the automatic computation of sectional discharges and is subject to observer experience on river conditions. The Float Methods only measure surface velocities while water flow width and depth are average across the section, being a process which might introduce some errors. However, the Float Methods can be of use in some situations where river wading is difficult. Flow factors were determined as ratios between Propeller Type Current Meter discharges and float/ADC discharges to estimate propeller discharges when only Float discharges are estimated.

Something important to note about the hydrology component is that the historical hydrologic records for all of the sites on the Wami River have gaps, and also there is some concern about consistencies in data collection and hydraulic rating curves. Therefore, through desktop analyses, field data collection, and hydraulic modeling, this effort has aimed to provide the best estimates possible for the hydrologic regime at each of the five EFA sites in the Wami River Basin.

Water Quality

EFAs aim to provide information on the quantity and timing of river flows as well as on the quality of water, another important factor for the persistence of species and the maintenance of ecosystem services. In 2007, limited Water Quality (WQ) sampling was conducted and summarized (Tamatamah, 2007). For this round of EFA studies, the choice of WQ parameters to be sampled was made following the data suites proposed in King *et al.* (2008) and on the basis of cost of analysis.

The suites of variables for which data for EFA studies are required are listed below. Those underlined are essential (the data on the other variables provides useful additional information). Those variables in bold are the WQ parameters that have been analyzed in this study.

i. System variables: <u>**pH; water temperature; dissolved oxygen (DO)**</u>.
ii. Non-toxic constituents: <u>**electrical conductivity (EC)**</u> or <u>**total dissolved solids**</u> **(TDS)**; **TSS**; base cations (**sodium**, potassium, **calcium, magnesium**); other constituents such as **sulphat**e, silica and total alkalinity (TAL).
iii. Nutrients: <u>**total phosphorus** (TP); **soluble reactive phosphate (SRP); total nitrogen (TN); nitrate; ammonia (proportion of ionized to unionized); nitrite;**</u> total organic carbon (TOC).
iv. Toxic constituents: <u>metal pollutants</u> **(Pb, Cr)**; pesticides; any other toxins likely to occur in the system.

As noted in the Initial EFA Summary Report (Hyera *et al.*, 2008), although currently the Wami River Basin is considered ecologically sound, water pollution from industrial sources, large-scale agriculture, or domestic wastes is becoming an emerging concern. Treatment of wastewaters is not currently widespread, thus it is important to consider WQ in the parameters from grab water samples. The parameters selected were based on the following criteria or concerns:

i. Total Phosphorus: an indicator of runoff from agriculture and is typically found at very low concentrations in unpolluted waters. This parameter is of interest since the availability of phosphorus is responsible for stimulating algae blooms.
ii. Ortho-Phosphorus: the dissolved form of phosphorus that is readily available for utilization by plants and algae.
iii. Total Nitrogen (TN): a common indicator of water quality and the relative concentrations of both nitrogen and phosphorus can be indicative of human impacts on a water body.
iv. Nitrate: highly soluble in water and is commonly used as an indicator of water quality. Nitrate is a component of fertilizers, sewage, and manure. The Wami River Basin is full of agricultural activities and cattle breeding, especially in the upper catchment. Due to low vegetation land cover, especially in the semi dry areas of Dodoma, erosion is imminent. Potential for transportation of nutrients during perennial flash floods is high.
v. Ammonia: highly soluble in water and is commonly used as an indicator of water quality. Ammonia is a component of fertilizers, sewage, and manure and it is an indicator of nutrient loading from agricultural activities upstream. High pH in combination with high water temperature converts ammonium ions to dissolved ammonia, which is highly toxic to fish at relatively low levels.
vi. Total Suspended Solids: can impact aquatic life by clogging fish gills, decreasing foraging success, and ultimately can result in decreasing growth rates of fish inhabiting water with high levels of suspended solids. High concentrations of suspended solids can also decrease light penetration through the water column, which indirectly affects other parameters such as temperature and dissolved oxygen concentrations (by decreasing photosynthesis).
vii. Total Dissolved Solids: a measure of inorganic salts and dissolved organic matter.

viii. Calcium and Magnesium: both contribute to water hardness and may provide a buffer that moderates pH fluctuation.
ix. Lead and Chromium: toxic heavy metals that can result from human activities in the basin. There are textiles and leather tanning industries in the basin with potential of releasing these heavy metals into the water system.

Standard WQ grab sample procedures for nutrients and heavy metals were followed in the sampling locations as described in the Standard Method for the Examination of Water & Wastewater (APHA/AWWA/WEF, as reported in Lenore *et al.*, 1999): using a water sampler with extendable arm to enable taking samples away from the river bank; following an appropriate regimen of blanks, duplicate samples (taken as field splits) with a target of less than 20% relative percent difference to assure quality; and use of a boat to get samples from free flowing areas of the river. All samples for nutrients and heavy metals were appropriately fixed and stored in cool boxes before being shipped to the laboratory for analysis. Samples for heavy metals were fixed using 5 drops of concentrated HNO_3 in one liter sample while samples for nutrients were fixed using 5 drops of concentrated H_2SO_4 in one liter sample as described in the standard methods (Lenore *et al.*, 1999). Before taking samples, the sampler was rinsed with distilled water then with the sample. A waterproof portable meter kit type OAKTON PCD 650, was used to capture ambient water quality parameters (Temperature, pH, DO, TDS, NaCl and conductivity).

All WQ analyses were done according to Lenore *et al.* (1999). For TN, the Kjeldahl Method was used; NO_3 was analyzed by the cadmium reduction method and NH_3 was analyzed by the Nessler method. Ca and Mg were analyzed by the Titrimetric method, Pb was analysed by Dithizone method, Cr was analyzed by colorimetric method using Diphenylcarbadize, Na was analyzed using the Atomic Absorption Spectrometric method, and TP and SRP were analyzed using the Ascorbic Acid Method. Two different laboratories were involved in the analysis of the samples. Analysis for TSS, NO_3, NH_3-N, Ca, Pb, Cr, and Mg were carried out by Water Laboratory Services at Maji-Ubungo in Dar es Salaam. The analyses for TKN, TP, SRP and Na were carried out by the Chemical and Mining Engineering Chemical Laboratory of the University of Dar es Salaam.

Macroinvertebrates and Fish Fauna

From the ecological standpoint of on-going EFA studies, fish and macroinvertebrates are two representative kinds of aquatic fauna often chosen for use in determining environmental flow requirements. The procedures used in fieldwork for this study loosely followed those of the Instream Flow Incremental Methodology (Stalnaker *et al.*, 1995) in which flow/habitat relationships for fauna of the river are used to identify their flow requirements.

During the first round of EFA for the Wami River Basin in (Hyera, 2007), an extensive literature review on all information relevant to ecology and freshwater species of the Wami River Basin was conducted, and then field data on fish, macroinvertebrates, and their habitat were collected at the five EFA sampling sites (Tamatamah, 2007). During this round, these earlier reports were reviewed to identify data gaps and propose the further research required. The major gap identified was the paucity of information regarding fish and macroinvertebrate fauna of the Wami River. The list of fish species reported in the Wami River, first established using historical literature and collections from 2007 (Tamatamah 2007), was updated following review of additional published literature and inclusion of new information on fish species in the Wami River Basin. Despite searches to locate additional published literature and inclusion of new information on macroinvertebrates since 2007, it appears that there have been no further studies in the Wami River Basin reported in the scientific or grey literature.

Field sampling involved the collection of fish and macroinvertebrates from selected transects at each of the five key sites in April 2011. Flood flows experienced at Mtibwa and Mandera made it unsafe to operate sampling equipment for collection of benthic macroinvertebrate samples. Thus, macroinvertebrate samples were only collected from Kinyasungwe, Kilosa, and Matipwili. The range of meso and microhabitats present for fish and macroinvertebrates at the sites, including riffles and pools, were recorded. Site data on other stream habitat characteristics such as width, depth, velocity, substrate characteristics, instream cover and bank cover, riparian vegetation, and selected physico-chemical water quality parameters were obtained from relevant specialists working in the EFA team.

As with the 2007 survey, due to the presence of benthic macroinvertebrate (small aquatic insects, oligochaetes, molluscs and crustaceans and other organisms without backbones that inhabit the substrate surface for all or part of their lifecycles) the macroinvertebrate sampling method employed was the use of a Surber sampler with 243 µm mesh size. At each site where the sampler was used, the field crew randomly selected three sub-sampling locations within each aquatic habitat type present (i.e., riffle, pool and run). If only one or two of the habitat types were present only those habitat types were sampled. The metal frame of the sampler was laid on the substrate and a heavy stick was used to disturb the substrate within the frame. The organisms that were dislodged from the substrate were allowed to drift freely into the net downstream. The net contents were emptied into a white tray where large objects were removed, water was added and invertebrates were sorted from material in the tray. The invertebrates were then transferred into glass specimen jars and preserved in a 70% alcohol solution until delivered to UDSM for analysis.

All the macroinvertebrate samples collected were sorted and identified using general invertebrate textbooks and manuals (Ruppert and Barnes, 1994; and Gerber and Gabriel, 2002) at the UDSM. Specimens were assigned only to the lowest taxon within which they could be placed with certainty. Due to a paucity of published literature and taxonomic keys of the Tanzanian stream fauna, the specimens were identified only to family level.

As with the 2007 survey, the fish sampling method employed was a combination of gill netting, seine net pulls and electroshocking:

i. The seine net consisted of 8 m long by 1 m wide net panel with 5 mm mesh and attached to holding rods at either end. Two people, one at each end, were needed to operate the net. The net was set across the shallow parts of the river (< 1 m) then pulled towards the banks. Fish were then trapped and encircled. A single seine net sweep lasted for a period of 5 minutes and two sweeps were deployed at each sampling site where the gear was operated;
ii. A battery powered SAMUS (Model 725G) electroshocker with variable voltage regulator and electronic digital timer was used to produce a voltage on the electrode placed in the water. Fish coming into contact with the electrical field were stunned and then captured with dip nets. Stunned fish typically regain consciousness within several minutes after capture. Sampling was conducted while moving upstream to ensure that fish were not disturbed, prior to being sampled, by disturbances to the streambed and material dislodged by the sampling team that then moved downstream with the flow. A single electroshocking event lasted for about 20 minutes;
iii. A set of 100 m by 2 m multimesh gill net panel was used and at each site the net was allowed to stay in water for the period of 3 hours.

The electroshocking and seine net pulls were limited to those areas where members of the sampling team could enter the water, primarily along the banks and in shallow reaches. Unlike the 2007 survey, the electroshocker was operated only at Kinyasungwe at Kongwa, the only site where the flow of water in the river was moderately low to allow members of the sampling team to safely wade through and operate the equipment. For similar reasons, the seine net pull was only used at Kinyasungwe at Kongwa and Kilosa. In the remaining sites, flows were relatively high or wider sections, which made it unsafe to operate the electroshocker and seine net so gill nets were used as human access by wading was not possible.

Fish caught at each site were identified in the field according to the taxonomic guides (Bernacsek, 1980; Eccles, 1992; Skelton, 1993; and Witte & van Densen, 1995). Total lengths and wet weight measurements were taken to the nearest 0.1 mm and 0.1 g, respectively. Sex of each individual fish was determined from gonad inspection following anatomical dissection and/or using external characters for larger specimens. Gonad state was assessed using a five-point scale modified after Bagenal (1978) as given in the Wami River Basin aquatic ecology report produced during a previous EFA exercise (Tamatamah, 2007). Voucher specimens of fish species were photographed using a digital camera.

Riparian Vegetation

Vegetation in the riparian zone of a river is strongly influenced by river flow: high flows can help prevent encroachment of riparian vegetation in the river channel or establishment of exotic species; low flows can allow for recruitment of seedlings. For riparian vegetation sampling, on the basis of heterogeneity in habitat conditions in riparian areas, both qualitative and quantitative methods were employed so as to obtain basic information at each of the sampling sites.

Riparian vegetation was sampled using the standard Nested Quadrat Sampling Technique (Stohlgren *et al.*, 1995). This method entails the use of rectangular quadrats, combining the advantage of minimizing edge effect as well as increasing the chances of including most species in the study area. Three level sampling was done where trees were sampled in 20m × 25m quadrants. Shrubs and saplings were sampled in 5m × 2m quadrants nested in the bigger quadrant and finally grasses and herbs were sampled in smaller quadrants measuring 2m × 0.5m nested in the 5m × 2m quadrants. The information collected included number of trees and DBH, shrubs and juvenile trees including species identification. In order to come up with exhaustive checklist of plant species from Wami River Basin, all associated species occurring in the big quadrant were recorded in the field.

During this study, some plant specimens were identified in the field and those species that proved difficult to identify in the field were collected and transported to the Dar es Salaam herbarium. They were then identified using the available floras, manuals, or matched with preserved dried herbarium specimens. Information generated from this data includes composition and biomass, population structure of the keystone species, species of conservation significance, invasive or introduced alien species and the flow dependence of riparian vegetation and aquatic macrophytes at the field study sites.

Socio-Economic Conditions

Humans receive multiple goods and services from freshwater ecosystems, and the availability and quality of these services is influenced by river flow. The EFA process aims to understand this linkage. In addition, water use for domestic water supplies is given the first priority in the new Tanzania Water Resources Management Act of 2009. It is therefore necessary to identify the current level of water use in the villages for i) consumption (drinking and cooking), ii) hygiene (bathing, washing, cleaning), iii) amenities (watering, non-essential tasks) and iv) productive subsistence use (livestock watering, kitchen garden, local brewing, etc.).

Before field data collection, a review of available literature was done to get an insight of some useful information including livelihoods, economic values of river, population, riparian resources, economic activities, and socio-economic characteristic in the Wami River Basin.

The selection of study villages was initially done during the first round of EFA studies in 2007 (Hyera, 2007) at the five selected EFA sites. The process involved identification of villages closest to each EFA site and the criterion for a target village was to be located within 10 km from rivers in the Wami River Basin, near the five study sites. Initially, several villages were identified to satisfy this criterion but on further screening selecting only villages closest to EFA sites for comparison with information from other disciplines (ecology and geomorphology), only the following five villages, closest to each EFA site, were targeted for sampling:

- *Ng'ambi in Kongwa District (Kinyasungwe at Kongwa),*
- *Kibaoni in Kilosa District (Mkondoa at Kilosa),*
- *Lukenge in Mvomero District (Wami River at Mtibwa),*
- *Mandera (Wami River at Mandera) and*
- *Matipwili (Wami River at Matipwili) in Bagamoyo District.*

For population sampling, sample sizes were initially estimated according to methods from Utah State University Extension (2006), however, based on the village demographic characteristics and activities carried out in the village, the actual sample sizes were smaller. Efforts were made to have large sample sizes for interviewees and this was successful in most villages with sample sizes exceeding 30. As set out in Table 1, 200 household interviews were conducted for this study and between 30 and 50 households were interviewed in each village. Simple random sampling was used in selecting respondents in order to get reliable information (see Utah, 2006 for a detailed breakdown of the sampling approach applied).

Image 2: House in Sadaani Village. Many fishermen inhabit the village and nets are typically strung outside homes.

Table 1: Population sample sizes in study villages.

Village	Population	Theoretical household sample size (SS)	Corrected theoretical sample size (SS_{cor})	Actual sample size
Ng'ambi	8,377	96	95	50
Kibaoni	2,100	96	92	40
Lukenge	1,960	96	92	30
Mandera	2878	96	93	40
Matipwili	1995	96	92	40
Total	**17,310**	**480**	**463**	**200**

Primary data on communities and households were collected using mainly two techniques: focus group discussions and household questionnaires. Both open and closed ended questions were administered to selected respondents representing a certain household. The structure of information collected from both techniques aimed at assessing the following: (1) the type and diversity of in stream and riparian resources used by rural communities; (2) the extent and seasonality of in stream and riparian resources that are being used by rural communities; (3) livelihood dependency on river resources; and (4) major environmental problems that may have arisen since the previous study in 2007 (Hyera, 2007). Walking around villages to observe, document and photograph resources was another strategy used during the field trip in order to collect more data.

Image 3: Many wild animals still inhabit the Wami River Basin.

Fieldwork Results

Geomorphology

Kinyasungwe River at Kongwa (EFA Site 1)

Area

The site is located at an entrenched channel with no floodplain. The pattern of the channel reach is a wandering type with low sinuosity. The high terrace is rarely inundated and is covered by shrubs with isolated trees. Shrubs and trees occur on the banks but they are undermined by lateral erosion of the meandering river. The channel has little modification by existence of a bridge in vicinity of data collection sites, while footpaths and livestock that are brought to the river for water have severe impact on riverbanks. The riparian and channel vegetation, morphologic units and channel physical conditions are described in detail in Mwanukuzi (2007).

River flow was low during the April 2011 wet season data collection with isolated plain beds, sand waves, shallow pools, runs, and riffles. The side pools were dry, dominated by clay and silt material and with no or barely perceptible flow water depth in pools was barely 1 cm deep. Runs have smooth boundary turbulence flows of about 7 cm depth. Materials on runs were essentially sand. Rippled flows occurred on shallow water depth about 3 cm thick. The water was clear, although may have low pH because of salts mobilized by the salinization process, a pedological process in the semi-arid catchment. Fine gravel mixed with sand was the dominant bed material.

Channel Impacts

The shape and pattern that the river adopts is another manifestation of channel adjustment to prevailing flows and sediment load. Channel adjustment may lead to a changing lateral profile (cross section size: deep/shallow, narrow/wide) and/or longitudinal profile (flow pattern: straight, meandering or braiding/anastomosing). High flows can widen cross-sections while limited load tends to scour and deepen the channel. During the wet season fieldwork at Kinyasungwe, river flow was low while the channel cross section area was wide implying that water flows were at low side of the wet season flows indicating short lived high discharges (1-3 days) occurring normally as flushing flows. An anatomizing kind of channel occurs at Kinyasungwe, which is a manifestation of increasing bed load that may result due to accumulation of gravel.

Sediments

The active channel is alluvial and dominated by sand bars (70-80% of the channel). Lateral, point and mid-channel bars were widespread with limited lee bars. The grain sizes of sediments range from silt to gravel. Point bars are dominated by sand size sediments. The mid-channel bar and lee bars were composed of unsorted gravel to sand size sediments. A narrow flood bench shows signs of being inundated by annual floods and was dominated by sand size sediments. The banks were asymmetrical. The left bank is deeply incised and dominated by clayey materials. The right bank is shallow with isolated terraces of sand deposits. There is no sign of flood deposits on high terrace. Also, the bank is composed of in-situ weathered clayey material.

The source of sediments in the channel includes riverbank materials that are removed through lateral erosion during the high flows and slumping. Erosion of the bank is exemplified by the wandering behavior of the river channel. Much of the bed load is part of colluvial material on the foot of inselbergs[1]. Sand and gravel materials which are mobilized from the inselbergs and sediments are transported by flash floods and deposited in river channels when the flash flood water disappears. Winnowing and sorting occur during the medium and low flows. Bed sediments along runs are made up mostly of sand. Sands continue to be transported by low flows, only to be deposited as sand dunes on point bars or when surface flows stop as lateral bars. Clay and silt deposit on the riverbed occur as slumping material of highly incised banks.

Suspended sediments depend on or relate more to supply, while bed load transportation depends on river flows. Course material consisting of gravel to pebble size sediments was observed at Kinyasungwe implying that the critical shear stress at Kinyasungwe during the wet season flows is too low to remove material supplied in the channel. Consequently the channel is aggrading and affecting pools. This is exemplified by low 0.316 m/s flow velocity and shallow flow depth. Low shear stress is a function of low hydraulic radius and slope. In turn hydraulic radius is a function of water supply and materials that maintain the surface material. Therefore, the combination of low rainfalls, high permeability of the substrate and low slope can affect the river.

Mkondoa River at Kilosa (EFA Site 2)

Area

The valley is moderately confined with a narrow floodplain on the left bank. Along the reach the valley is confined with no floodplains. The channel is a single thread and straight and dominated by plain bed, mobile waves of sand and runs. The channel type is alluvial with no observable sand bars. Dominant perimeter material is sand with localized silt to clay material on the right bank. Localized pools and riffles are present. Bed materials are essentially sands derived from the upper catchment, loosely packed, and they move with flows forming a moving bed.

Channel Impacts

The channel is modified by the existence of a combined vehicles-locomotives bridge. The right bank floodplain is highly cultivated and flood deposits are loosened during cultivation. The left bank and its floodplain are covered by reeds and sugarcane. The bank condition is stable with no sign of erosion or slumping. Reed cover stabilizes the bank. Limited erosion occurs on the right bank on the footpath where reeds were destroyed. There is a tendency toward the flatbed of sand. Overbank deposition is widespread on the right bank.

Straight reaches that result due to high gradient occur at this Kilosa site. However, the pattern changes from straight channels at this site to a meandering channel occurring within the Kilosa-Mtibwa section. Meandering is a result of reduced shear stress with the subsequent deposition, especially of bed load carried from upper catchments through upstream reaches. Meandering is therefore a characteristic within the Mkata-Dakawa-Turiani plains extending from Kilosa to Dakawa.

Sediments

The bed material is largely sand size deposits derived in the dry upper catchment. Silt and clay size sediments occur on riverbanks and floodplain and are mostly deposited during flooding. They are mobilized by flash

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[1] Inselbergs (translated from the German: Insel, “island,” and Berg, “mountain”) are isolated hill that stands above well-developed plains and appears not unlike an island rising from the sea (http://www.britannica.com, last accessed 15th August 2013)

floods in the drier upper catchments. Some of the sediments are from the weathered rock and soils. Much of wet season flow conveys suspended load materials downstream. There are no large size sediments within the reach. Much of the deposition occurs upstream of the channel and in the old river impoundment, which is clogged with sand deposits. Since there are high depositions upstream of the site, the river tends to braid due to heavy load. The section of Mkondoa is bounded by woodlands over isolated hills. At this study site, there was no in-channel deposition of sediments during both the dry season and wet seasons. Consequently wet season flows are considered sufficient maintenance flows.

Wami River at Mtibwa (EFA Site 3)

Area

The floodplain is unconfined, being an extension of the Mkata-Turiani plains. The river channel is entrenched in this plain and channelized for about 130 m length. The main channel and the constructed channel are separated by isolated islands that form between the main channel and the flood zone. The top active channel bank and the active channel bank were inundated during wet season field work. All riparian and in-channel vegetation on these geomorphologic units that existed during the dry season flow was submerged during this high flow, with the exception of large trees.

Morphological units observed on this site include a localized plunge pool occurring on a rocky gabion used for river crossing during the low flows. Plain beds and deep pools of alluvial deposits and runs are dominant. Backwater flows are localized while the channel is mainly straight with extensive overflows in the floodplains. Vegetated stable islands exist in the middle of the channel resulting from channelization, not due to deposition. Perimeter material is basically silt-clay dominating the pools and bed materials are largely silt-clays. Riffles occur on localized boulders in the channel. The reach type is mainly a plain-bed with localized pools.

Channel Impacts

The channel is being modified by a new bridge, culvert and rock gabion constructions. The channel has been channelized and crossed by road on the rock gabion. Through channelization processes, vegetation has been removed and the channel has been made unstable and is likely to undergo further lateral erosion. Currently, the left hand bank is stable without any fluvial bank erosion while limited erosion occurs on the right hand bank. Sub-areal erosion is limited on sparsely vegetated banks. Silt and clay deposition occur in limited amounts in pools, therefore there is moderate tendency towards the flat bed. The bank condition is stable, and the bed showed sign of degradation and aggradations.

Sediments

Suspended sediments are significant at this site. These sediments originate from the farming activities occurring in the Mkata-Turiani plains. The bed load is largely silt-clays that are removed during the high flows. Therefore, the bed is stable. The course materials are usually deposed in the upstream part of the Mkata plain and therefore are limited at this site. Bank erosion, avulsion and slumping are limited because banks are stabilized by vegetation. The removal of vegetation could lead to bank erosion. At this study site, there was no in-channel deposition of sediments and consequently wet season flows are considered sufficient maintenance flows. Much of the load at Mtibwa is suspended sediments resulting from human disturbance from agricultural activities. A major contribution of wet season flows is to supply sediments in the floodplain and maintain the ecological integrity of the floodplain. The meandering channel pattern occurring within the Kilosa-Mtibwa section characterizes this reach lying within the Mkata-Dakawa-Turiani plains extending from Kilosa to Dakawa.

Wami River at Mandera (EFA Site 4)

Area

The valley at this site is a confined type, while the channel is a bifurcated type with stable banks and also stabilized by vegetation in different sections of the river. The active channel bank has patchy reeds, grasses and shrubs. Middle channel islands contain reeds. Since the river is confined type, there are no top active channel banks. The site has sections of rocky bed and alluvial type while the reach has number of geomorphologic units including the bedrock pavement, rapids on bedrock and boulders, plunge pools, riffles and runs. The nature of bars occurring at the site is island type, which are stable and vegetated and bedrock core bars on which sand accumulates and there is vegetation. Generally the channel is a mixed type and the reach is composed of bedrock, pool-rapids, step-pools and pool-riffles. The perimeter materials are bedrock, boulder, and cobble, with localized silt clays.

Channel Impacts

The channel within 100 m of the study sites shows no signs of modification, although vegetation removal on the access footpath is observed in few locations on the riverbank. The footpath impact is moderate. Severe vegetation removal is due to trampling by livestock that affects some portions of the bank. There is no observable bank erosion and overbank deposition is minor. The general assessment is that the bank condition is stable and there is no bed degradation or aggradations.

Sediments

Suspended load is an important sediment type that is passing through the Wami-Mandera site. The bed deposit occurs in pools and low energy environments, such that materials in these areas are essentially silt-clays. The channel is stable and consequently there are little supplies of sediments from the channel suggesting that most of the sediments are derived from land through erosion. The catchment at this site is composed of undulating hills with few tributaries while the lowland is occupied by woodlands that leave the land bare most of the year. Sheet wash with erosion is an important process supplying sediments in the river and therefore the first rains carry loose soil material found on the land to constitute the river sediments. No gravel or pebbles are found in this area, signifying the thick soil deposits on the Wami plain. At this study site, there was no in-channel deposition of sediments and consequently wet season flows are considered sufficient maintenance flows. Some reaches in the Wami-Mandera area are bifurcating type.

Wami River at Matipwili (EFA Site 5)

Area

The banks are stabilized by reeds, while the floodplain is characterized by dense reeds, patchy grasses, bushes, farms and bare surface. Bank toe and bars were not observable since the water was at bank full. The valley is generally an unconfined floodplain that is flooded annually while morphological units observed are plain bed with sand, run, and backwater. There were no bars that were observed during the dry season flow suggesting that they have been removed by high flows. The channel type is alluvial, composed of sand and silt as perimeter material.

Channel Impacts

We observed no direct modification of the channel, but the channel tends to erode on bare sections of the bank due to removal of reeds by trampling during the water intake for domestic use. Vegetation removal is moderate on banks. There is not yet a feeling of the impact of the water pump house currently established but its impact may occur later. The channel appears active, shifting laterally through lateral erosion attributed to riverbank undercutting. The bank condition can be rated as limited erosion with bank erosion ranging 0-10%. The bed condition shows no sign of aggrading as bed material (well sorted sand) accumulated during the low flows are removed during the high flows. There is good vegetation cover of the back. Minor isolated erosion occurs, but no continuous damage of banks or vegetation.

Sediments

Suspended load is important sediment passing through Matipwili, as exemplified by observed high water turbidity during the wet season fieldwork. The river section between Mandera and Matipwili is a winding channel type, wandering in the coastal plain. The coastal plain consists of thick deposit of silt-clays, which form an important source of suspended sediments in the lower Wami River. The suspended sediments are also supplied by bank erosion while there are limited supplies of bed load materials at Matipwili. Therefore, channel scouring and lateral erosion are among the processes that remobilize the fine particle carried as suspended load. The bed deposit is largely sand, derived after long conveyance of sediments that pass through Mandera, with Mandera site catchment being a source. Owing to limited supply of sediments, an estuary forms at the river mouth.

At this EFA site, there was no in-channel deposition of sediments and consequently wet season flows are considered sufficient maintenance flows. River channel meandering with low sinuosity is common at Matipwili, which leads to periodic shifting of channel from one location to another. High flows of the wet season are enough to act as the maintenance flows as they are capable of removing indecisive species and sand bars in the channel, thus maintain the channel integrity.

Hydrology

Kinyasungwe River at Kongwa (EFA Site 1)

Figure 4: Flow conditions of the Kinyasungwe River at Kongwa (EFA site 1) on 12th April 2011.

The Kinyasungwe River at Kongwa was visited during the wet season data collection on 12th April 2011. The river was flowing at shallow water depth below the knee level and the flow covered only a portion of river width, while elsewhere wet riverbed was exposed (Figure 4).

Field measurement of discharge involved the use of all three methods: the float method, ADC and propeller type current meter method and the results are shown in Table 2. The propeller type current meter method gave a discharge of 0.415 m^3/s while the other two methods measured large discharges. The discharges measured by the manual propeller type and automatic ADC are close with ADC discharge being only 9% higher. Discharge by the float method is, however, excessively higher than propeller type discharge by 41%. This was attributed by the estimation of average flow velocity and wetted area over the river cross-section. The method estimates velocity of the water surface, which was multiplied by a factor of 0.82 to obtain average velocity for the river section. Cross-section area was estimated as a product of average flow depth and width of the section assuming rectangular cross-section of water flow. It is therefore included in grey in Table 2 below to be ignored for the purposes of further analysis.

Table 2: Average flow velocities and discharges of the Kinyasungwe River.

Measurement method	Velocity (m/s)	Discharge (m^3/s)	Flow ratio
Propeller type Current Meter	0.316	0.415	-
ADC	0.328	0.454	1.094
Float Method	0.532	0.585	1.410

Mkondoa River at Kilosa (EFA Site 2)

Figure 5: Flow conditions of the Mkondoa River at Kilosa (EFA site 2) on 13th April 2011.


The Mkondoa River at Kilosa was visited on 13th April 2011. The river was flowing at high water depth at hip level (Figure 5). Flow was smooth (laminar) throughout the EFA reach with water flowing a bit faster near the right bank than elsewhere and slowest near the left bank.

Measurement of discharge involved the use of the float method and the propeller type current meter method. The results are shown in Table 3. The discharge measured by the two methods was similar. The float method gave a discharge of 14.802 m3/s that is only 1.7% less than the discharge estimated using the propeller type current meter of 15.059 m^3/s. This suggests that the river cross-section at Kilosa can adequately be represented by a rectangular shape (see Ndomba, 2007), and the correction factor of 0.82 is adequate to correct surface flow velocity to average flow velocity for the entire river width. Moreover, estimated discharge from rating curve at 1GD2 of 15.503 m^3/s is comparable to measured discharges by the two methods.

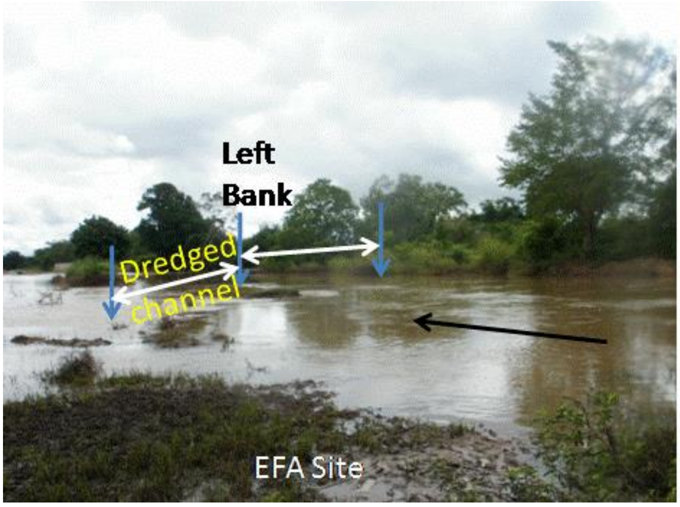
Table 3: Average flow velocities and discharges of the Mkondoa River.

Measurement method	Velocity (m/s)	Discharge (m^3/s)	Flow ratio
Propeller Type Current Meter	0.927	15.059	
Float Method	1.095	14.802	0.983
Rating at 1GD2*		4.713	
Rating at 1GD2**	-	63.251	
Rating at 1GD2***		15.503	

**From sounded depth of 0.358 m (gauge height of 0.858 m) during Propeller Type measurements.*
*** From a gauge height of 1.604 m.*
**** From gauge height of 1.10 m suggesting additional sedimentation of 0.504 m above H_o of 0.5m.*

Wami River at Mtibwa (EFA Site 3)

Figure 6: Flow conditions of the Wami River at Mtibwa (EFA site 3) on 14th April 2011.



The Wami River at Mtibwa was visited on 14th April 2011. The Wami River is joined by the Mkindo River tributary at Mtibwa Sugarcane Plantations, just upstream (~ 200 m) of the original study site. The site has been significantly modified by a bridge construction downstream (< 100 m) and the channel has been dredged to distribute river flow from the main channel to side culverts (Figure 6). These are changes that have taken place since the original 2007 sampling during the first round of EFA studies. This dredging and river training make this section no longer suitable as a study or reference site. The most preferable new site would be located downstream to still account for effects of the Mtibwa River area on the Wami River flow conditions.

During our field visit, the river was flowing overbank over much of the river section from the upstream reach (before the Wami-Mkindo confluence) through the study site to the downstream reach. The flow was sub-divided into three flowing channels, two natural and one dredged, just downstream of the Wami-Mkindo confluence extending past the study site. Flows were fastest in the middle channel, which is the normal main river channel, and slow on the other two channels.

The risk of being swept away by fast moving flood water and wide overbank flow prevented discharge measurements by the propeller type current meter and ADC methods and river width and cross-sectional area measurement. Only the float method was applied to measure surface flow velocities, which were corrected to obtain average flow velocity of the central river channel and the results set out in Table 4. Due to the difficulties in measuring discharge at this site a hydraulic model was developed.

The hydraulic model developed for this site (from historical flows and dry season EFA measurements, coupled with estimated average flow velocities, and allowed estimation of the discharge that could be passing across the original cross-section. The 1G1 discharge of 79.724 m^3/s was derived from the recorded average river stage of 4.30 m (1300: 4.35 m; 1800: 4.25 m) on 14th April 2011. The existing rating curve (Ministry of Water) and stage readings at Mkindo gave a discharge of 24.141 m^3/s on 14th April 2011, which was used to estimate a discharge of 31.118 m^3/s at 1GB1A giving a total of 55.259 m^3/s from the Mkindo River. These discharges of the Wami River at 1G1 and Mkindo River were routed downstream to the Mtibwa study site by the developed routing model (Valimba, 2007) to obtain an equivalent discharge of 140.856 m^3/s, which is almost twice the estimated average discharge of 75.0 m^3/s obtained with the developed hydraulic model (Ndomba, 2007). This led to improvement of the hydraulic model simulation at Wami-Mtibwa for high flood flows. The best estimate for the actual discharge is therefore 140.9 m^3/s.

Table 4: Average flow velocity and estimated discharges of the Wami River at Mtibwa.

Measurement method	Depth (m)	Velocity (m/s)	Discharge (m^3/s)
Float Method		1.269	-
Hydraulic model		-	75.000
Rating curve Wami-Dakawa (1G1)	4.30	-	79.724
Rating curve Mkindo-Mkindo (1GB2)	4.01	-	24.141
1GB1A*			31.118

** estimated from Mkindo discharge*

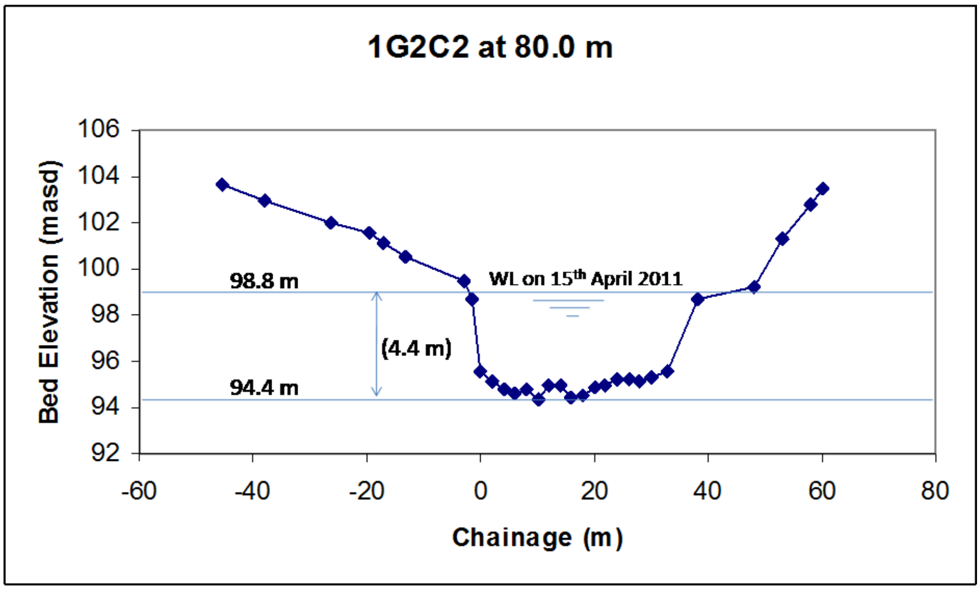
Wami River at Mandera (EFA Site 4)

Figure 7: Flow conditions of the Wami River at Mandera (EFA site 4) on 15th April 2011.

The Wami River at Mandera was visited on 15th April 2011. The river was flowing as a single channel at bank full level along the reach upstream to the study site (Figure 7). The flow was laminar (smooth) up to a point just downstream of the study site where turbulent river flow on the rocky bed occurred, a characteristic to a location just upstream of the 1G2 gauging station at the Mandera Bridge. Surface water flow was fastest near the right bank, with flow velocity decreasing towards the left bank.

Measurements using the float method were undertaken at the original study site. The results are set out in Table 5. A rope was stretched across the river width to measure the river width. Owing to strong flow current and long width, the rope was straightened with difficulties to measure a width of 48 m. As the location where the float method was used to estimate surface water flow velocity coincides with a cross-section established during the November 2007 fieldwork (Ndomba, 2007), the water level situation on 15 April 2011 was plotted onto this cross-section to establish a water depth of 4.4m and confirm the river cross-section width measurement (Figure 8) This results in a flow area of 211.2 m^2.

Figure 8: River cross-section at study location where the float method was used.



Measurements of surface flow velocities across the river width confirmed the observation of variable flow velocities. The slowest waters were near the left bank, where average velocity was about 0.54 m/s while the fastest waters were near the right bank with average flow velocities exceeding 1.0 m/s (Table 5). With a 2-metre measuring rod used, the rod could not touch the riverbed at the middle of the river indicating that water depth exceeded 2 m.

Table 5: Average flow velocities of the Wami River at Mandera by Float Method.

Distance (m)	Time (s)	Velocity (m/s)	Adjusted Velocity (m/s)	Width (m)	Depth (m)	Area (m^2)
70.8	108	0.655	0.537	48	4.4	211.2
70.8	91.26	0.776	0.636	48	4.4	211.2
70.8	83.16	0.851	0.698	48	4.4	211.2
70.8	84	0.843	0.691	48	4.4	211.2
70.8	47.56	1.487	1.219	48	4.4	211.2
70.8	54.81	1.292	1.059	48	4.4	211.2

The risk of being swept away by fast moving floodwater prevented discharge measurements by the propeller type and ADC methods at this study site. An alternative location for measurements where these methods could be used was chosen: the flow gauge at the Mandera Bridge and the measurements taken on 15th April 2011. The results are set out in Table 6. Average measured discharge by the propeller type current meter method at the Mandera Bridge (1G2) was 81.763 m^3/s corresponding to an average depth of 1.484 m at 1G2. This average measured flow depth was significantly lower than river stages at 1G2, which were 2.42 m (1002 hours) and 2.50 m (1825 hours); the latter follows an increase of water level since 1630 hours from rainfall received between 1330 and 1500 hours. The triangular distribution of flow velocity across the river width gave an average velocity of 0.878 (0.537 + ½(1.219-0.537)) m/s for the river section. This flow velocity across a 211.2 m^2 flow section gives a river discharge of 185.434 m^3/s.

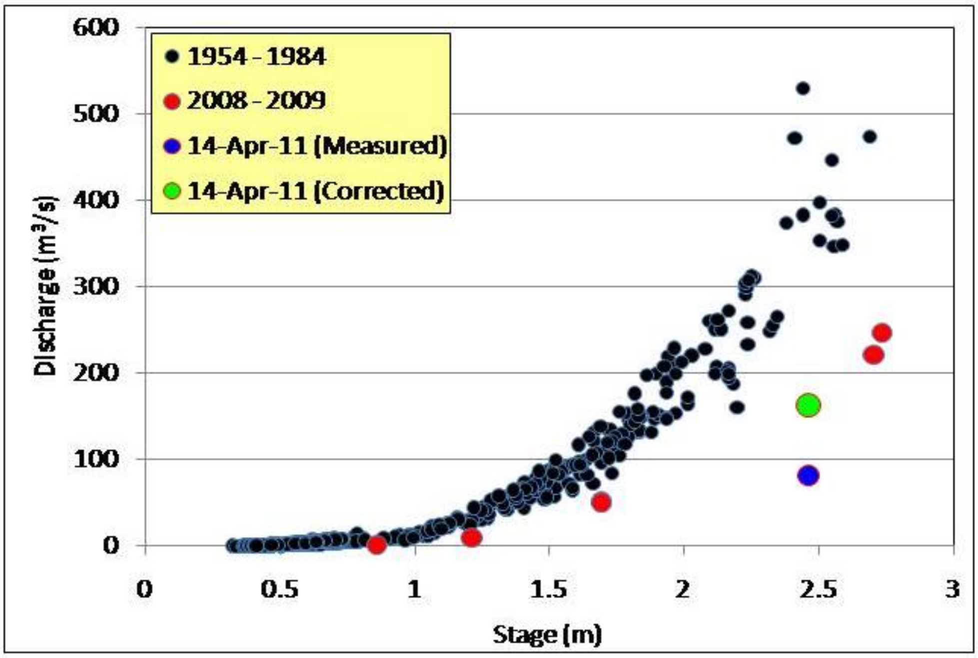
Rating flow measurement on 17 April 2008 indicated a discharge of 246.5 m^3/s at a gauge height of 2.73 m (Table 6). The measured discharge of 81.763 m^3/s on 15 April 2011 appears well outside other measurements while recent measurements indicate a downward shifting rating curve (Figure 9). A discharge of 162.663 m^3/s would fit into the curve reflected by the recent measured discharges and was therefore considered the corrected measured discharge at 1G2. However, the developed flow routing model (Valimba, 2011), which takes into consideration long-term observations, gives a discharge of 145.153 m^3/s upstream discharges of the Wami and Mkindo rivers. This discharge is used at 1G2 and EFA site 4, the Wami River at Mandera, for analysis, but it should be clear that the rating curves need to be updated. The hydraulic model developed for this study site (Ndomba, 2007) could be underestimating the discharge as it gives a discharge of 104.0 m^3/s, well below the estimated 145.153 m^3/s (Table 6). This led to re-calibration of the hydraulic model at this site to better simulate the high flows. As Mtibwa to 1G2, only the Lukigura River with small discharge joins the Wami River and therefore only a slight increase of discharge is anticipated, between 145 - 185 m^3/s, and therefore the discharge of 145 m3/s is the best estimate. Therefore for the purposes of the table below it is assumed that the routing model is more accurate and therefore the hydraulic model and rating curve 1G2 have been shown in grey scale in Table 6.

Table 6: Average flow velocities and discharges of the Wami River at Mandera.

Measurement method	Depth (m)	Velocity (m/s)	Discharge (m^3/s)
Propeller Type Current Meter	1.484	1.004	81.763
Float Method	-	0.878	185.434
Hydraulic model	-	-	104.000
Rating curve 1G2[1]	2.420[a]	-	330.899
Rating measurement[2]	2.730	1.264	246.499
Routing model	-	-	145.153

[1] *gauge reading at 10:02 am on 15th April 2011*
[2] *rating field measurements on 17th April 2008 by WRBWO*

Figure 9: Rating curve data of the Wami River at Mandera (1G2).



Wami River at Matipwili (EFA Site 5)

Figure 10: Flow conditions of the Wami River at Matipwili (EFA site 5) on 16th April 2011.

The Wami River at Matipwili was visited on 16 April 2011. The Wami River at the Matipwili study site was flowing as a single channel at bank full level (Figure 10). The flow was laminar (smooth) throughout EFA site and the surface water flow was fast and uniform across the river width between the right and left banks.

The risk of being swept away by fast moving floodwater prevented discharge measurements by propeller type and ADC methods at the study site. Flow velocity measurements using the float method were carried out at this site. The results are set out in Table 7. The float method gave average flow velocity exceeding 1.0 m/s (and averaging at 1.367 m/s. This was rather uniform across the river width. This velocity is approximately close to estimated peak velocity of 1.40 m/s at Matipwili (Ndomba, 2007).

The earlier measurements of river channel cross-sections at several locations at this site in 2007 (Ndomba, 2007) were used to indicate a river width of 44.743 m corresponding to an average bank full depth of 3.90 m. The relatively rectangular shape of the river cross-section gives a total area of 174.5 m^2. Estimates of the corresponding discharge on 16 April were made and set out in Table 7. This discharge could have therefore been 238.538 m^3/which is closely comparable to a discharge of 220 m^3/s estimated by the hydraulic model developed for this site (Ndomba, 2007). The routing model estimates the discharge of 145.223 m^3/s for the Wami River at Matipwili, which is lower than estimates from the float method and hydraulic model (Table 8). Consequently, this required re-calibration of the hydraulic model to closely reproduce measured discharge. This process reproduced water levels and flow velocity distribution and hence river discharge.

Table 7: Average flow velocities of the Wami River at Matipwili EFA site by the Float method.

Distance (m)	Time (s)	Velocity (m/s)	Adjusted Velocity (m/s)	Width (m)*	Depth (m)*
133	82	1.622	1.330	44.743	3.90
113	77.70	1.712	1.404	44.743	3.90

** From Ndomba (2007).*

Image 4: River flow gauge visited by WRBWO staff.

Table 8: Average flow velocities and discharges of the Wami River at Matipwili.

Measurement method	Velocity (m/s)	Discharge (m^3/s)
Float Method	1.367	238.538
Hydraulic model	-	220.000
Routing model*	-	145.223

Water Quality

Ambient water quality

Table 9 summarizes spatial trends of the ambient water quality parameters that were measured in situ during sampling: Electrical Conductivity (EC), Total Dissolved Solids (TDS), Dissolved Oxygen (DO), Temperature and pH.

Table 9: Physical water quality parameters at EFA sites.

Sampling Site	Date (d/m/y)	Time	Water Temp (C)	DO % (mg/l)	EC (µS) **	pH *	Na Cl (mg/l)	TDS (ppm)
Kinyasungwe-Kongwa (EFA 1)	12.04.2011	9.30	24.0	95.2%	**2,760**	**11.7**	n.m	2,930
Mkondoa –Kilosa (EFA 2)	13.04.2011	9.25	28.0	77.8%	375.0	**10.2**	n.m	408.0
Wami-Mtibwa (EFA 3)	14.04.2011	14.35	31.0	53.9% (4.66)	180.9	**8.9**	116.0	140.6
Wami –Mandera (EFA 4)	15.04.2011	12.45	30.0	91.4% (6.48)	212.0	**9.8**	112.0	133.0
Wami-Matipwili (EFA 5)	16.04.2011	13.15	28.1	94.2% (7.11)	210.0	**8.8**	111.3	128.9
River WQ (From fair to very good) (TBS)				60-70%				
Receiving water standards-Category 1 (TBS)				> (6 mg/l)		6.5-8.5	< 200	< 2000
Quality domestic water standards (Tz) (TBS)						6.5-8.5	< 200	

** The pH readings for all the EFA sites are high because the geology in this area contributes to alkalinity in these waters as it is most likely saline ground water in this area. Saline water sources are characterized by high concentrations of carbonate salts, typically sodium carbonate and related salt complexes giving rise to alkalinity. The presence of fish is surprising.*

*** As with the explanation above, the EC reading for EFA 1 is high because there was very little water in the upper river catchment at the time of sampling and due to the high salinity of the water (see explanation on locals using water for cooking).*

The Kinyasungwe-Kongwa station indicated the highest values of TDS, EC, DO and pH compared to other sites. This is partly explainable from the fact that all the other stations were experiencing flooding situations while Kinyasungwe was not. Parameters in other stations were lower partly because of dilution factors. TDS, EC and pH were particularly high. Water temperature showed a very different trend: a progressive increase downstream to a high at the Wami-Mtibwa site and subsequent continuous decrease towards the Wami-Matipwili site, while DO and pH showed exactly the opposite trends to those of water temperature. The increase of pH after the Wami-Mtibwa was not as significant as that of DO. The DO levels in a stream depend on factors such as organic content, degree of aeration. With turbulent flow especially at the Wami-Mandera site, high DO is expected.

Chemical analysis

Table 10 shows the chemical results of the water samples taken. Total Suspended Solids (TSS) showed the highest value in the sample taken from the Mkondoa-Kilosa site whilst Suphate (SO_4) showed a continually decreasing trend from the upper catchment (Kinyasungwe-Kongwa) down to the Wami-Matwipili site. Sodium (Na) is more unpredictable as it showed high concentrations at the Kinyasungwe-Kongwa and the Wami-Mtibwa sampling points, while at all the other points the concentration was 50 mg/*l* or lower.

Table 10: TSS, sulphates and sodium at EFA sites.

Sampling Site	Date	Time	Water Temp (C)	TSS (mg/*l*)	SO_4 (mg/*l*)	Na (mg/*l*)
Kinyasungwe-Kongwa (EFA 1)	12.04.2011	9:30	24	45	470	266.96
Mkondoa –Kilosa (EFA 2)	13.04.2011	9:25	28	730	63	50
Wami-Mtibwa (EFA 3)	14.04.2011	14:35	31	86.7	13	368.42
Wami –Mandera (EFA 4)	15.04.2011	12:45	30	146.7	17	35.38
Wami-Matipwili (EFA 5)	16.04.2011	13:15	28.1	300	12	34.5
River WQ (From fair to very good) (TBS)						
Receiving water standards-Category 1 (TBS)					< 600	
Quality domestic water standards (Tz) (TBS)				1500	< 400	

Table 11 shows the Calcium (Ca) and Magnesium (Mg) concentrations. The two Ca and Mg ions showed very similar orders of magnitude at most of the stations except Wami-Matwipili, which had higher levels in magnitude of Ca than Mg. Mg ion levels decreased continuously from the upper sampling station at Kinyasungwe-Kongwa down to Wami-Matwipili. The concentrations of Ca on the other hand behaved differently as they showed a minimum at Wami-Mtibwa sampling point and thereafter increasing all the way to Wami-Matipwili. The Ca trend closely followed the pH trend while the Mg trend closely followed the TDS trends (Table 11). Calcium and Magnesium both contribute to water hardness and may provide a buffer that moderates pH fluctuation.

Table 11: Calcium and Magnesium concentrations at EFA sites.

Sampling Site	Date	Time	Water Temp (C)	Ca (Mg/l)	Mg (mg/l)
Kinyasungwe-Kongwa (EFA 1)	12.04.2011	9:30	24	100.00	87.50
Mkondoa –Kilosa (EFA 2)	13.04.2011	9:25	28	36.00	32.80
Wami-Mtibwa (EFA 3)	14.04.2011	14:35	31	16.80	17.50
Wami –Mandera (EFA 4)	15.04.2011	12:45	30	17.60	11.60
Wami-Matipwili (EFA 5)	16.04.2011	13:15	28.1	37.60	8.70
River WQ (From fair to very good) (TBS)					
Receiving water standards-Category 1 (TBS)					
Quality domestic water standards (Tz) (TBS)				< 200	< 150

Table 12 sets out the nutrient concentrations. These nutrients showed highest concentrations at the Mkondoa-Kilosa site followed by the Wami-Matwipili station. Soluble Reactive Phosphorus (SRP) concentrations showed an increasing trend from Kinyasungwe down to the Matwipili sampling stations. Whilst NO_3 was observed to be at low levels in all sampling points, NH_3-N (ammonia) was observed to be relatively high, above the allowed levels for receiving waters at the Mkondoa, Mtibwa and Matipwili sampling stations. Normally ammonia is converted to Nitrate via a nitrification process; however this process is favored by high DO while disfavored by high pH values greater than 8.5. The predominance of nitrate indicates stabilized conditions with respect to oxygen demand (Metcalf and Eddy, 2003). The pH of the water at all sampling points was greater than 8.5. Ammonia in its unionized form (NH_3) is known to be toxic to fish. The toxicity is reported to increase with increasing pH while increasing the environmental calcium concentration is reported to significantly decreased NH_3 toxicity to golden shiners at pH 8.0 (Sink, 2010). Generally, concentrations of all the nutrient species except NH_3-N were within the allowed limits under Tanzanian standards.

Table 12: Nutrients concentrations at EFA sites.

Sampling site	Date	Time	Water Temp (°C)	NO3 (Mg/l)	NH3-N (mg/l)	TKN (mg/l)	TP (mg/l)	SRP (mg/l)
Kinyasungwe-Kongwa (EFA 1)	12.04.2011	9:30	24	0.00	0.17	12.32	0.348	0.107
Mkondoa –Kilosa (EFA 2)	13.04.2011	9:25	28	0.30	1.62	12.04	1.164	0.135
Wami-Mtibwa (EFA 3)	14.04.2011	14:35	31	0.00	1.18	11.2	0.475	0.23
Wami –Mandera (EFA 4)	15.04.2011	12:45	30	0.00	0.51	5.04	0.455	0.226
Wami-Matipwili (EFA 5)	16.04.2011	13:15	28.1	0.30	1.30	10.08	0.594	0.467
River WQ (From fair to very good) (TBS)					< 0.2 - 1.3			
Receiving water standards-Category 1 (TBS)				≤ 50	< 0.5			
Quality domestic water standards (Tz) (TBS)				≤ 30	< 0.5			

The major factors affecting the nutrient levels in the basin are nutrient sources and natural variations in stream flow. During rainy seasons nutrients can be easily washed from land and human settlements into rivers. The dominant source of nitrogen and phosphorus in the Wami River Basin is most likely agriculture in which agricultural nutrient sources such as manure and fertilizer, combined with agricultural acreage, would have the greatest impact on the trends in flow-adjusted nutrient concentrations. The low levels of nutrients can be attributed to dilution due to the flooding situation during wet season sampling. However, even the upper point of Kinyasungwe-Kongwa, which had very little water in the stream, showed low levels of nutrients.

The trend of concentrations of Total Phosphorus (TP) along the sampling points closely followed the trend of TSS indicating that most of the TP is contained in the suspended matter. The Total Kjeldahl Nitrogen (TKN) showed a decreasing trend from the upstream sampling point at Kinyasungwe-Kongwa to Wami-Matipwili. However, the Wami-Mandera point showed the lowest levels.

Heavy metals (Chromium, Lead)

The levels of Chromium (Cr) and Lead (Pb) in the different sampling points along the Wami River Basin (Table 13) indicate generally that levels of these two toxic substances are within the allowed limit. The highest level of Cr was obtained at Wami-Mandera while for lead the highest was obtained at Wami-Matipwili. The levels of Pb were very similar in magnitude except for Wami-Mandera sampling point, which showed the lowest concentration of Pb.

Table 13: Heavy metals concentrations at EFA sites.

Sampling Site	Date	Time	Water Temp (C)	Cr (Mg/l)	Pb (mg/l)
Kinyasungwe-Kongwa (EFA 1)	12.04.2011	9:30	24	0.01	0.042
Mkondoa –Kilosa (EFA 2)	13.04.2011	9:25	28	0.00	0.032
Wami-Mtibwa (EFA 3)	14.04.2011	14:35	31	0.01	0.040
Wami –Mandera (EFA 4)	15.04.2011	12:45	30	0.05	0.005
Wami-Matipwili (EFA 5)	16.04.2011	13:15	28.1	0.00	0.047
River WQ (From fair to very good) (TBS)					
Receiving water standards-Category 1 (TBS)				< 0.10	< 0.10
Quality domestic water standards (Tz) (TBS)					

Macroinvertebrates and Fish Fauna

Macroinvertebrates

Macroinvertebrates were collected at the Kinyasungwe River at Kongwa (EFA Site 1), the Mkondoa River at Kilosa (EFA Site 2) and the Wami River at Matipwili (EFA Site 5). There was an inability to sample at the Wami-Mtibwa (EFA Site 3) and the Wami-Mandera (EFA Site 4) sites due to high flood flows.

Eighteen (18) benthic macroinvertebrate families belonging to nine (9) orders (*Gastropoda, Decapoda, Plecoptera, Ephemeroptera, Odonata, Hemiptera, Trichoptera, Coleoptera* and *Diptera*) were encountered in the samples collected from the Wami River during the wet season (Table 14). This is in contrast to the twenty-seven (27) families belonging to eleven (11) orders of macroinvertebrates that were collected in the Wami River during the dry season sampling. This decrease in number of benthic macroinvertebrate families observed during the wet season sampling is most likely due to the inability to sample at EFA Site 3 and 4. The benthic macroinvertebrate species composition, sensitivity score and average score per taxon (ASPT) at EFA sites 1, 2 and 5 are set out in Table 14 below.

A macroinvertebrate index of the South African Scoring System (SASS) (Chutter, 1998; Dickens and Graham, 2002) was used to assess the health of various sampling sites and the general indication of quality of the environment at those sites. SASS uses the average macroinvertebrate scores computed from sensitivity of the various animals to water quality to measure the health of the site. Based on SASS index, average scores of 0-2 signify a highly impacted site, 2-4 an impacted site, 4-6 a slightly impacted site and >6 a good quality/healthy site. The average SASS scores computed at EFA sites (Table 15) indicate that EFA 1 is a healthy river site with EFA 2 and EFA 5 being slightly impacted but having scores that nearly matches those of a health site. This study also identified seven (7) macroinvertebrates as being highly tolerant to pollution, six (6) moderately tolerant and four (4) with very low tolerance to pollution of the nineteen (19) macroinvertebrate taxa collected. Two (2) of the four (4) most sensitive macroinvertebrate families were collected at EFA Site 1, while EFA Site 2 and EFA Site 5 registered one each for the remaining two families.

Table 14: Benthic macroinvertebrate species at EFA 1, 2 and 5.

Taxonomic group	Kongwa (EFA Site 1)		Kilosa (EFA Site 2)		Matipwili (EFA Site 5)	
	Number	Sensitivity Score	Number	Sensitivity Score	Number	Sensitivity Score
Gastropoda						
Thiaridae	0	0	1	3	0	0
Decapoda						
Atyidae	0	0	1	8	2	8
Plecoptera						
Perlidae	0	0	1	12	0	0
Ephemeroptera						
Baetidae 1 sp	5	4	1	4	5	4
Baetidae 2 sp	1	6	0	0	4	6
Caenidae	0	0	0	0	3	6
Teloganodidae	1	12	0	0	0	0
Odonata						
Gomphidae	2	6	1	6	0	0
Libellulidae	3	4	0	0	0	0
Calopterygidae	0	0	0	0	1	10
Hemiptera						
Naucoridae	3	7	0	0	0	0
Trichoptera						
Hydropsychidae	7	4	0	0	0	0
Leptoceridae	1	6	0	0	2	6
Coleoptera						
Psephenidae	1	10	0	0	0	0
Dytiscidae	7	5	0	0	1	5
Diptera						
Tipulidae	3	5	0	0	0	0
Simuliidae	2	5	0	0	2	5
Chironomidae	0	0	1	2	1	2
Total individuals	36		6		21	
Total taxa	12		6		9	
Total score		74		35		52
ASPT	**6.17**		**5.83**		**5.78**	

The presence of the four (4) most sensitive families (*Perlidae, Teloganodidae, Calopterygidae and Psephenidae*) which have a very low tolerance to pollution is subsequently used in considering environmental flows that will aid protection of the ecological values of the Wami River in the environmental flow considerations and recommendations (such as Water Quality) given in this Report.

Applying the Shannon-Weaner diversity index (H') for all of the macroinvertebrates found in the wet sampling generally indicated that the Wami River Basin has a good diversity of macroinvertebrates (Table 16). EFA Site 1 has a relatively higher macroinvertebrate species diversity index followed by EFA Site 5, possibly indicating better river health status than EFA Site 2.

Table 15: Macroinvertebrates and tolerance to pollution in EFA sites 1, 2 and 5.

Taxa	Highly tolerant	Moderately tolerant	Very low tolerance
Thiaridae			
Atyidae		✓	
Perlidae			✓
Baetidae 1 sp	✓		
Baetidae 2 sp		✓	
Caenidae		✓	
Teloganodidae			✓
Gomphidae		✓	
Libellulidae	✓		
Calopterygidae			✓
Naucoridae		✓	
Hydropsychidae	✓		
Leptoceridae		✓	
Psephenidae			✓
Dytiscidae	✓		
Tipulidae	✓		
Simuliidae	✓		
Chironomidae	✓		
18	**7**	**6**	**4**

Table 16: Shannon-Weaner diversity index of macroinvertebrates in EFA 1, 2 and 5.

Sampling Site	Species Diversity Index	Species Evenness
Kinyasungwe at Kongwa (EFA 1)	2.25	0.91
Mkondoa at Kilosa (EFA 2)	1.79	0.99
Wami at Matipwili (EFA 5)	2.04	0.93

Fish Fauna

Fish fauna of the Wami River Basin is one of the least known in the eastern flowing rivers of East Africa. Approximately sixty five (65) species have been reported in the Wami River. Much of this knowledge is based only on the works of Bernacsek (1980), Eccles (1992), Anderson *et al.* (2007) and the present study (i.e. EFA fish sampling survey conducted in November 2007 and April 2011). The thirty one (31) species of fish recorded during the two EFA fish sampling surveys at the five EFA sites are set out in Table 17, being 51% of the sixty five (65) species reported overall.

Five additional species (highlighted in black in Table 17 - *Barbus oxyrhyinchus*, *Atopochilus vogti*, *Petrocephalus catostoma*, *Macrobrachium* sp *and Distichodus rufijiensis*) were encountered in the wet season sampling. Conversely, due to the high volume of freshwater flow during the wet season pushing the estuarine wedge further towards the sea mouth, estuarine fishes (*Glossogobius giuris*, *Eleotris fusca*, *Liza macrolepis* and *Microphis fluviatilis*) which were caught at Matipwili site during the dry season sampling were not recorded during the wet season sampling. Several other fish species caught during the dry season sampling were not encountered during the wet season sampling

Table 17: Fish species collected in the Wami EFA sites during 2007 and 2011 EFA field surveys.

Family	Species	Kongwa (EFA 1)	Kilosa (EFA 2)		Matibwa (EFA 3)		Mandera (EFA 4)		Matipwili (EFA 5)	
		2011	2007	2011	2007	2011	2007	2011	2007	2011
Cyprindiadae	*Barbus leticeps*				✓			✓		
	Barbus usambarae						✓			
	Barbus amphigramma									
	Barbus kerstenii		✓							
	Barbus paludinosus	✓	✓	✓						
	Barbus oxyrhyinchus							✓		
	Labeo victorianus(*)									
	Labeo cylindricus	✓				✓	✓	✓	✓	
	Labeo coubie				✓	✓		✓		
	Raiamas sp									
	Opsaridium microlepis (E)						✓			
Characidae	*Brycinus affinis*						✓	✓	✓	
	Brycinus imberi				✓		✓		✓	
	Micralestes acutidens				✓					
Cichlidae	*Astatotilapia bloyeti*						✓			
	Tilapia zillii	✓					✓			
	Oreochromis niloticus(*)	✓								
	Oreochromis Pangani*(*)* (CE)							✓		
Clariidae	*Clarias gariepinus*	✓				✓				
Mochokidae	*Chiloglanis deckenii*			✓						
	Synodontis wamiensis				✓		✓	✓		✓
	Synodontis maculipinna					✓	✓	✓		✓
	Atopochilus vogti							✓		
Bagridae	*Bagrus orientalis*				✓	✓		✓		✓
Mormyridae	*Petrocephalus catostoma*					✓				
Amphiliidae	*Amphilius ur anoscopus*						✓			
Gobiidae	*Glossogobius giuris*								✓	
Electridae	*Eleotris fusca*								✓	
Mugilidae	*Liza macrolepis*								✓	
	Schilbe moebiusii					✓				
Caridae	***Macrobrachium sp***	✓						✓		
Syngnathidae	*Microphis fluviatilis*								✓	
Distichodontidae	***Distichodus rufijiensis***					✓				✓
		5	**2**	**2**	**6**	**7**	**10**	**10**	**7**	**4**

(Status description: * Introduced or Endemic; V Vulnerable; E Endangered; CE Critically endangered; NT Near threatened)..

Species Diversity

Catches were dominated by members of the family Cyprinidae, which comprised 63% of the total number of fishes collected in all sampling sites. The small species of *Barbus* (*B. paludinosus)* were the most abundant species contributing 58% of the total catch. The freshwater prawns (*Macrobrachium* sp) were the second most dominant groups comprising about 14% of the total catch. The remaining fish species made less than 4% contribution to the catch. With regards to fish distribution, *Labeo cylindricus* and *Synodontis maculipinna* were the two widely distributed fish species during the wet season (caught in three out of the five EFA sites). *Synodontis wamiensis*, *Clarias gariepinus*, *Labeo coubie*, and *Distichodus rufijiensis* were the second widely distributed species encountered in two of the five sampling sites.

Applying the Shannon-Weaner fish diversity index (H') resulted in a range from zero at EFA Site 2 (where only one species of fish was recorded) to 2.32 at EFA 4 (where twelve different species were recorded) (Table 18). These results are similar to those reported during the dry season sampling (note EFA Site 1 was completely dry and therefore was not sampled in the dry season visit, while EFA Site 4 had the most spectacular riffle-pool habitats during the dry season sampling, which may help to explain high fish diversity recorded at this site).

Table 18: Shannon Weaner fish diversity index for the five EFA sites.

Sampling Site	Species Diversity Index	Species Evenness
Kinyasungwe at Kongwa (EFA 1)	0.69	0.48
Mkondoa at Kilosa (EFA 2)	-	-
Wami at Mtibwa (EFA 3)	1.93	0.93
Wami at Mandera (EFA 4)	2.32	0.93
Wami at Matipwili (EFA 5)	1.37	0.85

Gender

Maturing ovaries and testes (stage 3 and above) were considered mature for determination of sexually active individuals. Overall, about 42% of the adult individuals of the fish species during the wet season sampling were carrying ripe gonads, reaching 51% in adult *Barbus paludinosus*. The occurrence of a relatively large number of spent adult males and females in the populations potentially indicates that the main fish spawning activity in the Wami River Basin takes place during the short rains in December/January or the beginning of the major long rains in March. The onset of breeding activity for the majority of tropical fish species is associated with rising water levels at the beginning of the rainy seasons (Welcomme *et al.*, 1988; Lowe-McConnell, 1975).

Biodiversity and Environmental Conservation

The list of fishes reported in the Wami River Basin as against the IUCN Red List of categories (IUCN, 2010) are set out in Table 19.

Based on the scheme of Welcomme *et al.* (2006), fish fauna of the upper, middle and lower sections of the Wami River Basin fall into three major environmental guilds (Table 20):

i. rhithronic or main channel communities (comprising guilds inhabiting riffles and pools);
ii. the potamonic guild which includes lotic (longitudinal migrants), lentic (floodplain dwellers), and eurytopic (low dissolved oxygen tolerant) communities; and
iii. guilds in estuarine and coastal lagoon communities which include freshwater, brackish water, and marine estuarine guilds as well as opportunistic marine fishes.

Their dependence on river flow varies from low to critical and spatial distribution is highly variable between sites (Table 21).

Table 19: Conservation status of fish species at EFA sites in the Wami River Basin.

Fish		Kongwa (EFA 1)	Kilosa (EFA 2)	Matibwa (EFA 3)	Mandera (EFA 4)	Matipwili (EFA 5)
Status	**Species**					
Exotic or Introduced to the Wami River	*Labeo victorianus**			✓		
	Oreochromis niloticus	✓				
	*Oreochromis urolepis hornorum**	Reported in literature				
	*Oreochromis pangani**				✓	
Vulnerable	*Sarotherodon macrochir*	Reported in literature				
	Nothobranchius steinforti	Reported in literature				
Near Threatened	*Barbus macrolepis*	Reported in literature				
Endangered	*Opsaridium microlepis*				✓	
Critically Endangered	*Oreochromis Pangani*				✓	

(**Oreochromis pangani* is a regionally endemic species, the *Oreochromis urolepis hornorum* is a regionally endemic species, and *Labeo victorianus* has a similar status in the Lake Victoria basin.)

Table 20: Representative fish species in environmental guilds in the Wami River.

Fish community type	Ecological guild	Representative fish genera/species in the Wami River	Sensitivity to flow
Rhithronic communities	Riffle guild	*Chiloglanis, Amphilius, Salmo truta*	Critical
	Pool guild	*Barbus, Brycinus*	Moderate
Potamonic communities	Lotic guild	*Labeo, Schilbe*	high
	Lentic guild	*Annual fish (Nothobranchius)*	Low
	Eurytopic guild	*Clarias gariepinus, Tilapia, Oreochromis,* Mormyrids (*Petrocephalus*)	Low
Guilds in estuarine and coastal lagoon communities	Freshwater estuarine guild	*Eleotris fusca* and *Glossogobius giuris*	Low
	Brackish water estuarine guild	Milkfish *(Chanos chanos*), Mugilidae (*Mugil cephalus*)	Moderate
	Marine estuarine guilds	Crustaceans (Penaeid prawns, crabs), Sea catfishes (*Arius* sp).	Moderate
	Opportunistic marine guild	*Scarus, Terapon, Gerres*	Moderate

Table 21: Moderate, high and critical sensitive fish species at EFA sites in the Wami River Basin.

Fish		Kongwa (EFA 1)	Kilosa (EFA 2)	Matibwa (EFA 3)	Mandera (EFA 4)	Matipwili (EFA 5)
Community	**Species**					
Rhithronic communities	*Chiloglanis*		✓			
	Amphilius				✓	
	Salmo truta	Reported in literature				
	Barbus oxyrhyinchus				✓	
	Brycinus			✓	✓	✓
Potamonic communities	*Labeo*	✓		✓	✓	✓
	Schilbe			✓		
Guilds in estuarine and coastal lagoon communities	Milkfish *(Chanos chanos*)	Restricted to the estuarine section of the Wami River at Saadani				
	Mugilidae (*Mugic cephalus*)					
	Crustaceans (Penaeid prawns, crabs)					
	Sea catfishes (*Arius* sp).					
	Scarus					
	Terapon					
	Gerres					

Image 5: Fish diversity in the Wami River Basin is understudied.

Riparian Vegetation

There is no clear demarcation of terrestrial and riparian vegetation in the Wami River Basin. There is a wide heterogeneity of distribution, a mosaic with patchy distribution, recurring without any defined pattern in some areas due to habitat variation. Since many of the streams and major tributaries of the Wami River are perennial, there is sufficient cover of riparian vegetation throughout the Basin, including the permanent wetlands in the system. Riparian communities are continuously linked to terrestrial communities with undefined transitional zone in some sites.

Vegetation Communities

In general, there are six vegetation communities within and closest to EFA sites and their distribution varies between EFA sites with some communities occurring at some sites while missing in other sites (Table 22). This shows that the terrestrial community around EFA sites is occupied by the heterogeneous vegetation types to include riverine vegetation in seasonal flows; seasonally inundated (waterlogged) grassland; wooded grassland; bush land; thicket-like vegetation confined to termite mounds, woodland, and bushed grassland.

Table 22: Vegetation communities at EFA sites in the Wami River Basin.

Vegetation		Kongwa (EFA 1)	Kilosa (EFA 2)	Matibwa (EFA 3)	Mandera (EFA 4)	Matipwili (EFA 5)
Community	**Species**					
Phragmites mauritianus	*Phragmites mauritianus*					✓
Mimosa - Combretum	*Combretum apiculata*	✓	✓	✓	✓	✓
	Mimosa pigra	✓	✓	✓	✓	✓
Syzygium-Ficus	*Ficus sur*		✓	✓		✓
	Ficus sycomorus					
	Garcinia livingstonia			✓		
	Syzygium guineense			✓		
Acacia-Phragmites	*Acacia polyacantha*		✓			
Cyperus-Equisetum	*Equisetum ramossismum*		✓			
	Cyperus denudatus		✓			
	Cyperus exaltatus		✓			
	Cyperus mundtii		✓			
	Cyperus spp		✓			
	Scoenoplectus nodiflorum		✓			
	Lersia hexandra		✓			
	Ipomoaea aqautica		✓			
	Oryza longistaminata		✓			
	Sorghustrum sp		✓			
Typha – Pennisetum	*Typha capensis*		✓			
	Pennisetum purpreum		✓			

The common plant species in the terrestrial community included *Acacia tortilis, Acacia nilotica, Commiphora africana, Brachystergia speciformis, Combretum apiculata, Acacia nigriscens, Hyphaen compressa,* and *Dalbergia melanoxylon*. The vegetation of the seasonally inundated grassland was commonly dominated by *Panicum heterostachys, Pennisetum purpureum,* and *Digitaria macroblephara* as grass species, while the dry areas were dominated by *Hyparrhenia filipendula*.

Acacia –Terminalia is a woodland community that occurs just after the riparian zone in the basin forming continuity between riparian and terrestrial vegetation communities. This is fairly common in all areas of the river basin and occurs sporadically in extremely drained silt clay soils. However the community in this category is exclusive of riparian woody plant species. The area was dominated by *Acacia nigriscence, Albizia glaberina, Acacia mellifera, Acacia tortilis, Acacia siberiana, Terminalia spinosa, Terminalia sambesiaca, Terminalia brevipes, Dalbegia melanoxylon, Afzelia guanzensis, Terminalia brownie,* and *Spirostachys africana.*

Invasive Species

A number of invasive plant species were recorded in many parts of the riparian zones (Table 23).

Table 23: Invasive species in various areas along the channel.

Names	Kongwa (EFA 1)	Kilosa (EFA 2)	Matibwa (EFA 3)	Mandera (EFA 4)	Matipwili (EFA 5)
*Argemone mexicanum**	✓		✓		✓
*Lantana camara**					✓
*Typha capensis***		✓	✓		✓
*Senna siamea**		✓			✓
*Grevillea robusta**		✓			
*Xanthium strumarium**	✓				
*Mimosa pygra***		✓	✓	✓	✓
*Pistia stratiotes***		✓	✓	✓	✓
*Azolla filiculoides***		✓		✓	
*Azolla nilotica***					✓
*Setaria verticilata**		✓	✓	✓	✓

(* invade disturbed flood plains; ** are invasive in aquatic habitats (slow flow streams and stagnant water)

In the dry season data collection, a large population of *Typha capensis* was identified at Kilosa sites, but in the wet season sampling no individuals of this species were in the river banks, only in the flood plain where water is stagnant. In the dry season data collection, water bodies in Matipwili were covered by *Azolla nilotica* and *Pistia stratiotes* but in the wet season sampling none of these were recorded in the same site. This implies that high flow is advantageous for cleaning invasive plant species that have been established during low flow seasons. However, high flows can also be assisting in dispersion of invasive species from the flood plain in the channel, where they can establish themselves during low flow seasons. *Xanthium strumarium* is a very well-known dangerous weed to the environment and found colonizing in the banks of the disturbed parts at Kinyasungwe and Mkondoa. This species is a threat to native riparian plant species as its colonizing power is high and its dispersal distance assisted by animals, channel flow, and humans. Its population needs to be monitored. Managing these invasive plants can be an expensive proposition if they are widespread and abundant. The costs of mechanical and chemical control can be prohibitive, especially in developing countries.

Conservation Species

Several species of special conservation significance were found in the river banks, scrub land and floodplains, categorised in terms of endangered, threatened and endemic species (Table 24):

i. *Diospyros fischeri,* an endemic species, was identified at Kinyasungwe banks;
ii. A number of endemic and rare species found in downstream reaches making the basin important from a plant conservation perspective, many of these plant species were located in the floodplains and the scrub forests in Matipwili floodplains.
iii. Among these species some have been threatened from over utilization due to their high quality products (e.g. *Pterocarpus angolensis* and *Afzelia quanzensis*).

Table 24: Endangered, threatened and endemic species around EFA sites.

Vegetation		Kongwa (EFA 1)	Kilosa (EFA 2)	Matibwa (EFA 3)	Mandera (EFA 4)	Matipwili (EFA 5)
Vulnerability	**Species**					
Endangered	*Asteranthe asteriaris*					✓
	Foetidia africana					✓
Threatened	*Afzelia quancensis*			✓		✓
	Pterocarpus angolensis			✓	✓	✓
	Dalbergia melanoxylon				✓	✓
Threatened and endemic	*Sanseveria bagamoyoensis*					✓
	Manilkara sulcata					✓
Endemic	*Diospyros fischeri*	✓				
	Encephalotus hildebrandtii					✓

Keystone and Indicator Species

The keystone species identified as forming the central supporting hub between the terrestrial and the aquatic system are set out Table 25. These can act as indicators of surface and underground flows in the channels and the floodplain. There were high differences among study sites in terms of the composition of the keystone species related to the persistent flow and level of disturbance. The loss of keystone plant species threatens the aquatic system, affects riparian functions and species interactions.

Table 25: Keystone plant species around EFA sites in the Wami River Basin.

Species	Kongwa (EFA 1)	Kilosa (EFA 2)	Matibwa (EFA 3)	Mandera (EFA 4)	Matipwili (EFA 5)
Ficus sur	✓		✓	✓	✓
Acacia polyacantha		✓			
Diospyros fischeri					
Ficus cycomorus		✓			
Phragmites mauritianus		✓		✓	✓
Syzygium guinense			✓		
Garcinia livingstonia			✓		
Combretum apiculata				✓	
Pennisutum purpureum					✓

Indicator vegetation species have a narrow set of ecological requirements and act as targets for monitoring of the health of riparian habitats. Vegetation species linked to flows have an acute sensitivity to changes in river flows and thus should be monitored in an effort to capture riparian habitat degradation and other links to proximate the impacts of anthropogenic disturbance activities. The distribution of five (5) suitable indicator vegetation species located in the study sites are listed in Table 26.

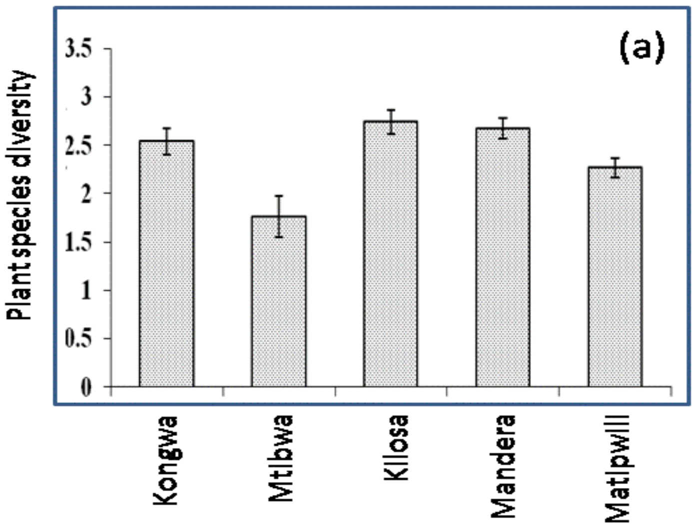
Table 26: Indicator vegetation species around EFA sites in the Wami River Basin.

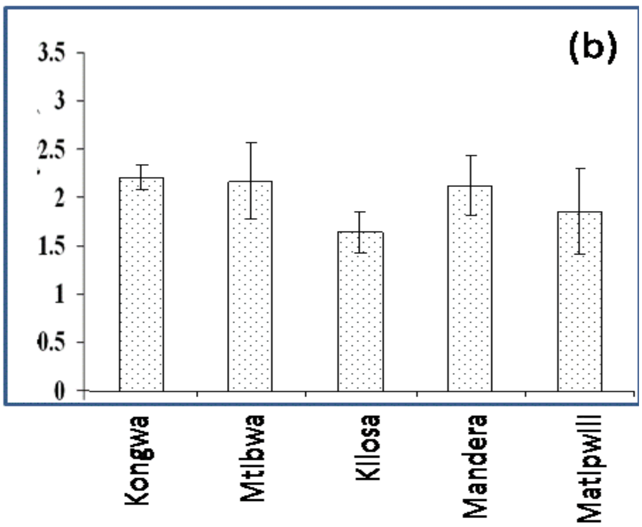
Species	Kongwa (EFA 1)	Kilosa (EFA 2)	Matibwa (EFA 3)	Mandera (EFA 4)	Matipwili (EFA 5)
Cyperus denudatus		✓			
Syzygium guineense			✓		
Combretun apiculata			✓		
Cyperus exaltatus		✓			
Phragmites mauritianus		✓			✓
Equisetum ramosissimum		✓			
Pennisutum purpureum				✓	✓
Tectaria gummifera		✓			

Diversity and Human Influence

Overall, the pattern of plant species diversity was somewhat different between dry and wet seasons with higher species diversity in the wet season than in the dry season (Figure 11 – (a) wet season and (b) dry season). During the wet season, plant species diversity at the Kilosa site was highest (2.74 ± 0.104), followed by Wami-Mandera (2.67 ± 0.124) and Mtibwa sites recorded the lowest (1.762. ± 0.09). Although Kilosa recorded the lowest during the 2007 dry season data collection (1.61 ± 0.21), it recorded the highest among study sites in the wet season. This might be contributed by selective removal of the dominant species in the areas and allowing under-represented plant species to colonize the site. However, low diversity at Matipwili and Mtibwa sites has been contributed by the level of disturbance in the areas where the riparian vegetation was highly affected by cultivation and construction activities.

Figure 11: Plant species diversity during (a) wet and (b) dry season.





The population structures in terms of DBH size class distribution were abnormal in almost all the sampling sites (Figure 12):

i. The most serious problem in terms of human influence was at Kilosa, where most of the woody trees in riparian areas have been completely exploited for firewood and other uses. Most of the remaining individuals of woody plants are with DBH below 10 cm and are being suppressed by cultivation as well. However, the remaining woody species population structure was dominated by *Tectona grandis* and *Pithecelobium busei* that are all exotic species. The previously identified *Acacia polyacantha* species have been exploited, as have *Tectona grandis* and *Ficus cycomorus* with stumps remaining behind. Also the reeds (*Phragmites mauritianus*) have been exploited for various purposes.
ii. Plant populations in Kinyasungwe are affected by grazing pressure and exploitation of trees with small sizes (poles) for construction, although these populations still have representatives at large size classes with poor recruitment.
iii. At Matipwili, most large trees are exploited with only small size classes remaining, probably due to having little use value.
iv. Regardless of prevailing disturbances, the Mandera and Mtibwa sites still have stable population structure with representation in both small and large size classes, and with a significantly higher biomass than the rest of the sites ($P<0.05$) (Figure 13). This means that there are still young trees to replace the aged and dying trees and that the channel geomorphology is not likely to change regardless of change in flow regime. These two (Mtibwa and Mandera) sites can be considered for monitoring in terms of tree population structural changes in the future.

Figure 12: Population structure and DBH size class distribution among the EFA sites.

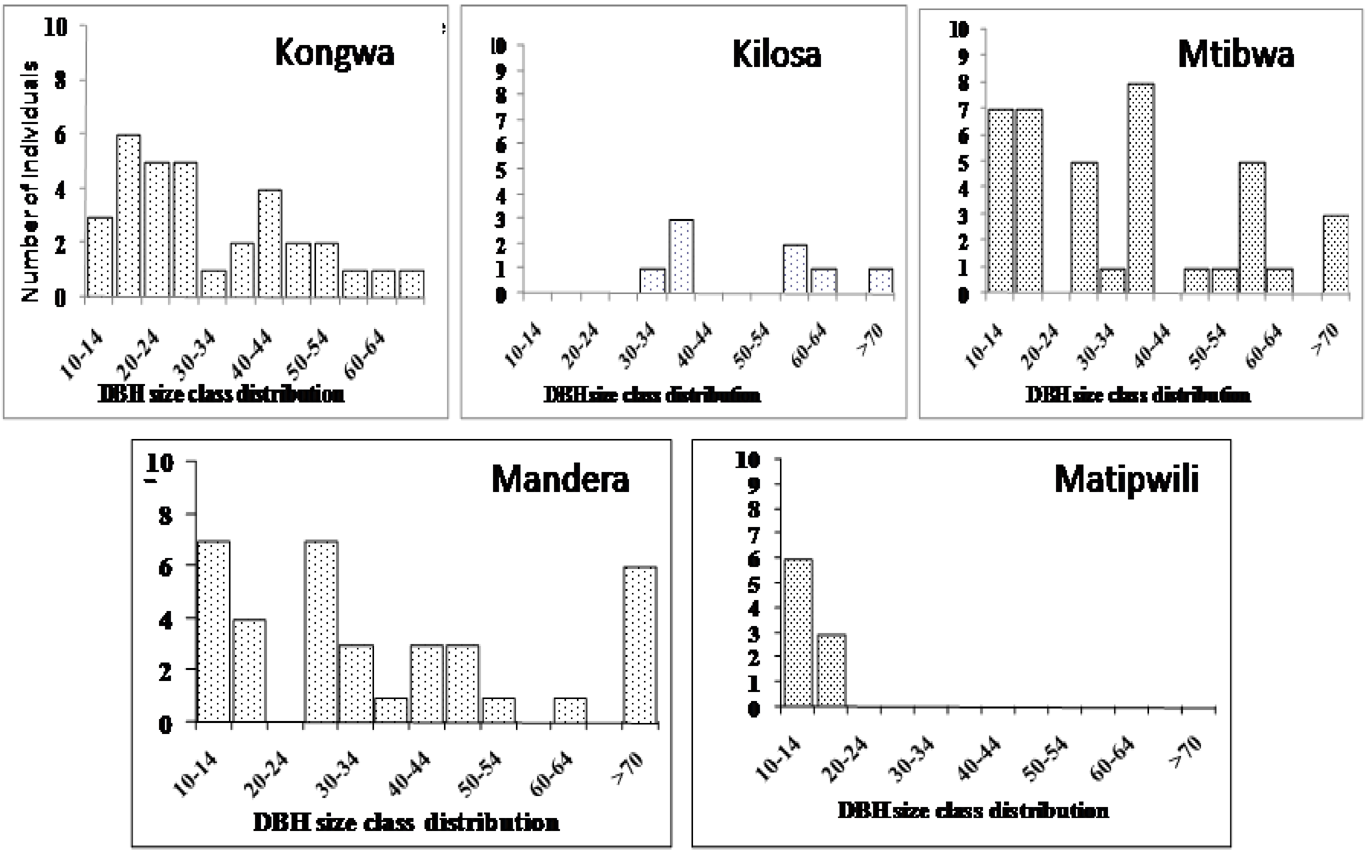
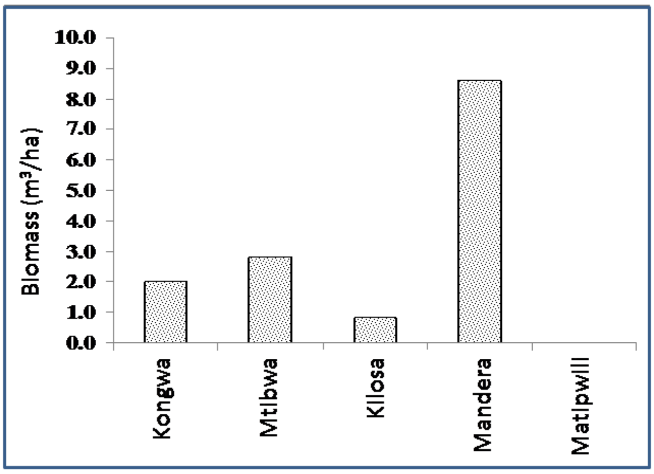


Figure 13: Biomass distribution among EFA sites.



Plant's Flow Dependence

Perennial wet conditions are required for riparian communities with composition as follows:

- *Equisetum ramossismum, Ipomoaea aqautica, Oryza longistaminata, Cyperus denudatus, Cyperus exaltatus Ceratophyllum demersum (*feeding and nursery habitat for young fish*),*
- *Cyperus mundtii, Scoenoplectus nodiflorum, Lersia hexandra, Ficus sur, Acacia polyacantha, Mimosa pigra, Pistia stratoites, Typha capensis, Pennisetum purpureum, phragmites mauritiana, Cyperus exaltatus, Ceratophyllum demersum, Azolla nilotica and Azolla filiculoides (*aquatic ferns*),*
- *Ficus exasperata, Polygonum senegalense* and *Syzygium guineense.*

The perennial flow-dependent plant species are the in-stream macrophytes (aquatic vegetation)—infringing, floating and submerged aquatic plants. They provide shelter and food for many freshwater vertebrates and invertebrates in the aquatic habitats. Some parts of the Wami River are covered with partially submerged reeds as the main source of organic detritus and shelter. They may thus be critical to the recruitment and success of some fish species resident to the river. *Ceratophyllum demersum* forms most important feeding habitat for young fish, small aquatic animals and insects. The plant species prefers constantly flowing streams and typically is attached onto the mobile sediments and debris, therefore acting as potential indicator of permanent flow. *Azolla nilotica and Azolla fluculoides* (the aquatic ferns) are likewise dependent on permanent flow. However, they are regarded as invasive species that prefer colonizing in stream flows with lowest velocity. *Azolla spp*. are also useful in the freshwater ecosystem because they fix nitrogen since they have a symbiotic relationship with cyanobacteria and therefore accumulate high protein content, which is then available for insects and fish.

Image 6: The Diwale River (left) is a tributary of the Wami River whose headwaters drain the Nguru mountains(right)

Socio-Economic Conditions

As reported in the Initial EFA (Hyera *et al.,* 2008) in Table 25, the following water uses are noted in the Wami River Basin (Table 27).

Table 27: River resource use in the Wami River Basin (Initial EFA 2008).

River Resources	Resource use
Fresh water	• Domestic use • Irrigation • Livestock/Wildlife use • Recreation (swimming) • Industrial use • Cultural/religious practices
Fish	• Food
Vegetation	• Timber/poles for building • Habitat for wildlife • Climate regulation • Charcoal/firewood for fuel • Vegetables /fruits for food • Medicine • Wood for furniture/boat making • Raw material for mats, baskets • Cultural practices (e.g. worshipping)
Soil and stones	• Building material • Road construction • Bridge construction • Dam construction
Wildlife	• Food • Tourist attractions (e.g. animals) • Hides
River ecosystem	• Cultural practices • Flood plain for agriculture

Domestic Use

In order to estimate the current level of water use in the villages for domestic uses consisting of i) consumption (drinking and cooking), ii) hygiene (bathing, washing, cleaning), and iii) amenities (watering, non-essential tasks), it was necessary to understand the relative populations and household sizes.

The average household number is around 3 – 5 people, followed by the 6-10 inhabitant size (Table 28). Most households are living as extended families that include the father, mother, children and other relatives. This has been the common type of family in Tanzania due to high dependency rate caused by poverty and death.

Table 28: Dominant household family sizes around EFA sites.

Size (inhabitants)	Kongwa	Kilosa	Mtibwa	Mandera	Matipwili
< 3	7 (14%)	4 (10%)	3 (10%)	5 (12.5%)	3 (7.5%)
3 – 5	27 (54%)	19 (47.5%)	12 (40%)	20 (50%)	22 (55%)
6 – 10	11 (22%)	12 (30%)	11 (37%)	12 (30%)	9 (22.5%)
> 10	5 (10%)	5 (12.5%)	4 (13%)	3 (7.5%)	6 (15%)
Total	**50 (100)**	**40 (100)**	**30 (100)**	**40 (100)**	**40 (100)**

Productive Subsistence Uses

Numerous livelihood activities are carried out in the study villages around EFA sites (Table 29). The main livelihood activity is small-scale agriculture (both rain fed and irrigated) followed by livestock keeping, while only a few engage in fishing and small trade. However, most people engage in a combination of these livelihood activities by doing either agriculture or fishing, small business or agriculture and livestock keeping. There are also few who are employed in different sectors.

Table 29: Dominant livelihood activities around EFA sites.

Livelihood activity	Kongwa	Kilosa	Mtibwa	Mandera	Matipwili
Rainfed agriculture	✓	✓	✓	✓	✓
Irrigation agriculture (vegetables)		✓	✓		✓
Livestock keeping	✓	✓	✓		✓
Fishing			✓	✓	✓
Small trade (e.g. local brewing, shops, mama lishes (little food stalls), etc)		✓	✓		✓

Farm size varies around 1 - 3 acres, while tillage is mainly by crude faming tools like the hand hoe. Modern farm implements like tractors as well as fertilizers are used by a few who can afford them. Small-scale irrigation is also practiced in the Wami River Basin but mainly by traditional furrow while the use of small water pumps in irrigation is currently gaining priority. The types of crops grown in different study villages around EFA sites vary depending on soil and rainfall conditions as well as proximity to river resources for irrigation water availability. Major crops grown include rice, maize, beans, bananas and vegetables. Livestock in the Wami River Basin includes cattle, goats, pigs, donkey, chicken, guinea fowl, sheep and duck.

Riparian and Instream Resources

The study revealed that the Wami River Basin has an abundance of riparian and instream resources (Table 30) that are important to the surrounding community. Most of these resources have been reported to decrease in number due to various reasons, including climate and environmental factors. The resources include fish, wild animals, birds, clay soils, wood plants and grasses/palms/reeds. Most of these resources are described in expert reports related to fish/macroinvertebrates and riparian vegetation.

Table 30: Instream and riparian resources around EFA sites.

Resource	Kongwa	Kilosa	Mtibwa	Mandera	Matipwili
Fish	✓	✓	✓	✓	✓
Wild animals			✓	✓	✓
Birds	✓	✓	✓	✓	✓
Clay soil	✓	✓	✓		
Wood plants	✓	✓	✓	✓	✓
Grasses, palms, reeds, etc	✓	✓	✓	✓	✓

Seasonality of instream and riparian resources is equally related to river flows. High flows are associated with the wet/rainy season while low flows are associated with dry season. Discussions with communities revealed that some river resources are only abundant during the wet season while others are rarely available during dry seasons. Some resources are, however, available throughout the year. This is exemplified by availability of mushrooms at Mandera during the wet season. Similarly, small fish catches correspond to wet season compared to dry seasons. At Ng'ambi village, most fishing activities are carried out during the wet season due to seasonal nature of the Kinyasungwe River.

Generally, there has been a decline in almost all riparian resources in recent years as reported by elders in all villages. The major reason as mentioned by villagers was climatic change such as unpredictable rains. Human activities such as tree cutting for timber and charcoal making, land clearing for agriculture, illegal fishing, bush fire, illegal mining, and unsustainable use of water irrigation activities were reported causes of declining river resources. Moreover, seasonality of streamflow is related to seasonal abstraction of water from riverine systems of the Wami River Basin. However, despite dry bed surface of Kinyasungwe, the river still supplies water from hand dug holes at the riverbed during the dry season.

Some of these livelihood activities and water supply are dependent on functioning of the riverine system. These include water supplies to villages, fishing, irrigation agriculture and livestock keeping (Table 31). The river system is mostly the source for water supply in areas around all study sites. Terrain (soils, landscape) and water conditions are favourable for irrigation agriculture at Mtibwa. Despite reliable water resources of the Mkondoa River, fishing is not a preferred activity at Kilosa. Livestock keeping, on the other hand, is practiced in drier areas of Kongwa as well as areas of Kilosa and Matipwili.

Table 31: Flow dependence of social services and livelihood activities around EFA sites.

Livelihood activity	Kongwa	Kilosa	Mtibwa	Mandera	Matipwili
Water supply	✓	✓	✓	✓	✓
Irrigation agriculture (vegetables)			✓		
Livestock keeping	✓	✓			✓
Fishing	✓		✓	✓	✓

Environmental Flow Considerations

The results from the wet (high flow) season fieldwork and analysis are useful to enable considerations for revision to the initially recommended environmental flows from the first round of EFA studies in 2007 (Hyera, 2007). This section details:

i. Ecological considerations estimated from wet season ecological observations in terms of streamflow discharges;
ii. Site – by – site analysis of ecological, geomorphological and socio-economic considerations and modifications to initial ecological requirements provided following the 2007 dry season fieldwork
iii. Description of additional river discharge records that became available since the 2007 EFA recommendation workshop in terms of their added value to overall environmental flow recommendation process (Hyera, 2007);
iv. Flow availability for each site to facilitate establishment of modified EF recommendations.

Ecological Considerations

Geomorphology

Discharge requirements to sustain geomorphological functions of rivers in the Wami River Basin reflect the seasonal variability of requirements at the five EFA sites in different years.

Water Quality and Aquatic Species

The physical, chemical and biological aspects of water quality are inter-related and must be considered together. The physiology or life history of certain aquatic species makes them very good biological indicators of physical (e.g. flow) and chemical water quality. Essentially, some species are more sensitive to chemical or physical water quality impairment, and if these species are reduced in numbers or not present in a portion of their range, this often indicates a problem with water quality.

For the wet season data collection, *Chiloglanis* and *Amphilius* represented the most sensitive fish species guild, and Perlidae, Teloganodidae, Calopterygidae and Psephenidae as the most sensitive families of macroinvertebrate species. If poor water quality conditions eliminate the more sensitive species from an ecosystem, then one would expect the species richness and diversity to decline.

Based on this concept, aquatic scientists have developed guidelines for some water quality characteristics that will provide a good level of protection for aquatic organisms including most sensitive fish species identified in the Wami River Basin. Some of the guidelines for common water quality constituents for tropical fish species are summarized in Table 32. The values for most of these parameters measured in the Wami River Basin (See Water Quality section under "Field Methodologies") fall within acceptable range for protecting fish species resident to the river. That may also help to explain why several sampling sites in the Wami River still record high fish and macroinvertebrate species richness and diversity scores.

Table 32: Guidelines of key water quality parameters for protection of aquatic organisms including most sensitive fish species in tropical rivers.

Water quality parameter	Ecological or Health Effect	Standard
Dissolved Oxygen	High levels of dissolved oxygen are necessary for fish respiration	Average: 5.0 mg/l Minimum: 4.0 mg/l
pH	pH affects the solubility of other water quality contaminants	6.0 - 9.5
Temperature	Fish suffer metabolic stress at high temperatures.	< 30°C
TSS	Reduced development and survival of fish eggs and larvae within gravel beds by blocking the pores and preventing the sufficient exchange of DO and carbon dioxide between the respiring eggs/larvae and the flowing water. Clogging and damage delicate gill structures through abrasion.	< 100 mg/l
NH_3 (unionized ammonia)	Un-ionized ammonia affects the respiratory systems of many animals, either by inhibiting cellular metabolism or by decreasing oxygen permeability of cell membranes. The toxicity of ammonia to fish increases as dissolved oxygen decreases. Ammonia is quickly oxidized to harmless nitrate in well oxygenated waters.	< 0.05 mg/l
Metals Arsenic Cadmium Chromium Copper Lead Mercury Silver	Heavy metals cause a variety of problems including interfering with vitamin uptake, neurological disorders, and disruption of renal function. These problems result from chronic and cumulative exposure.	 < 0.05 mg/l ≤ 0.01 mg/l ≤ 0.05 mg/l ≤ 1.0 mg/l ≤ 0.05 mg/l ≤ 0.002 mg/l ≤ 0.05 mg/l

Macroinvertebrates and Fish Fauna

Various types of macroinvertebrates and fish fauna were caught during the fieldwork at the five EFA sites. They reveal their existence in different flow ranges, characterized by different flow velocities. Consequently, the maximum flow velocities for the different macroinvertebrates and fish species to exist on particular water flow conditions encountered at the sites vary between sites and seasons. The velocities are high at high flowing waters of the Wami River (Mtibwa, Mandera, Matipwili), moderate for medium water depths of the Mkondoa River at Kilosa, and low for low water of the Kinyasungwe River at Kongwa. For high flow seasons in normal and wet years, the requirements were directly estimated as discharges. The flow velocity requirements for macroinvertebrates and fish species were converted into river discharges using developed hydraulic models at EFA sites. The resulting discharges reflect the variability of requirements at the five EFA sites in different seasons and years.

Riparian Vegetation

Various types of riparian vegetation were identified on transect walks during fieldwork at the five study sites. As with the macroinvertebrates and fish species, they reveal their existence in different flow ranges characterized by different flow depths. Consequently, the minimum flow depth for the different riparian vegetation species to exist on particular water flow conditions encountered at the sites varies between sites and seasons. The depths are high at high flowing waters of the lower Wami River (Mandera, Matipwili), moderate for the Kinyasungwe River at Kongwa and low for low water depths of the Mkondoa River at Kilosa. The flow depth requirements for riparian vegetation species were converted into river discharges using developed hydraulic models at EFA sites.

Socio-economics

Apart from shallow wells, water supply sources to study villages are mainly river water. Consequently, rivers should at a minimum be left flowing to provide this much needed water for domestic uses. The determination of the amount to be left is usually based on current level of water use in the villages for i) consumption (drinking and cooking), ii) hygiene (bathing, washing, cleaning), iii) amenities (watering, non-essential tasks) and iv) productive subsistence use (livestock watering, kitchen garden, local brewing, etc).

A study of Thompson *et al.* (2001) indicated per capita total daily water consumption of 21.5-55.4 liters from consumption use (3.9-4.4 literliters for unpiped and piped systems), hygiene (washing: 6.4-15.2 liters; bathing: 9.6-24.2 liters), amenities (0.1-9.6 liters) and productive use (1.5-2.0 liters). The lower figure is for unpiped systems as in rural areas around the study sites in the Wami River Basin, while highest uses are for piped systems. Gleick (1996) gave estimates of per capita total daily water use of 10-20 liters (humid climate), 20-30 liters (average climate) and 30-40 liters (dry climate) from a stand pipe water supply in rural areas of developing countries. He further recommended a daily minimum requirement of 50 liters per capita from thorough analysis.

Therefore, a minimum of 25 liters was then adopted for study villages and recommendations of Gleick (1996) of 40 (for dry Kongwa) and 30 liters (other study sites) were adopted for average requirements (Table 33). The estimation of total daily use considers population size and minimum and recommended per capita total daily water use. This indicates very low equivalent discharges related to daily village water uses.

Table 33: Estimation of village water consumptions at EFA sites.

			Per capita daily water consumption (*l*)		Village daily water requirement (m^3)		Equivalent discharge (m^3/s)	
EFA Site	**Villages**	**Population**	**min**	**Average**	**min**	**average**	**Min**	**average**
Kongwa	Ng'amba	8,377	25	40	209.43	335.08	0.00242	0.00388
Kilosa	Kibaoni	2,100	25	30	52.50	63.00	0.00061	0.00073
Mtibwa	Lukenge	1,960	25	30	49.00	58.80	0.00057	0.00068
Mandera	Mandera	2,878	25	30	71.95	86.34	0.00083	0.00100
Matipwili	matipwili	1,995	25	30	49.88	59.85	0.00058	0.00069

Site-by-Site Analysis

Kinyasungwe River at Kongwa (EFA Site 1)

The ecological and geomorphological water considerations suggested following the wet season data collection at this site of the River Kinyasungwe at Kongwa were higher in some cases than those established during the 2007 dry season. The highest considerations for high flow season during dry and wet years were higher than previously estimated. The reason for recommending bigger flows during high flows in a wet year is that spawning success of two of the species recorded at Kinyasungwe (*Tilapia zillii* and *Clarias gariepinus*) is related with floods. Also extensive inundation of the floodplain in a wet year helps to replenish nutrient and increase primary productivity in the river. **Consequently, these new higher flow considerations for ecological and geomorphological maintenance were considered for further water availability analyses to facilitate in the modification of environmental flow recommendations.**

Mkondoa River at Kilosa (EFA Site 2)

The ecological and geomorphological water considerations suggested based on wet season data at this site of River Mkondoa at Kilosa were lower than those established during the 2007 round of EFA studies. The highest considerations for low and high flow season during dry, normal and wet years were predominantly lower than previously estimated. Consequently, the 2007 flow considerations for ecological and geomorphological maintenance were maintained and therefore **no revisions to the 2007 considerations are recommended.**

Wami River at Mtibwa (EFA Site 3)

The ecological and geomorphological water considerations suggested following wet season data collection at this site of the Wami River at Mtibwa were lower than those established during the 2007 dry season. It should be noted that the original site has been significantly modified since the dry season sampling by a bridge construction downstream (< 100 m) and the channel has been dredged to distribute the river flow from the main channel to side culverts. **This dredging and river training make this section no longer suitable as a study or reference site and the most preferable new site chosen was located downstream.**

The highest considerations for low and high flow season during dry, normal and wet years were equal or slightly lower than previously estimated. Consequently, the 2007 flow considerations for ecological and geomorphological maintenance were maintained and therefore **no revisions to the 2007 considerations are suggested.**

Wami River at Mandera (EFA Site 4)

The ecological and geomorphological water considerations suggested following wet season data collection at this site of the Wami River at Mandera were lower than those established during the 2007 dry season. The highest considerations for low and high flow season during dry, normal and wet years were equal or slightly lower than previously estimated. Consequently, the 2007 flow **considerations for ecological and geomorphological maintenance were maintained and therefore no revisions to the 2007 considerations are suggested; however, there is a need to update the ratings curves due to the unusual results shown.**

Wami River at Matipwili (EFA Site 5)

The ecological and geomorphological water considerations suggested following wet season data collection at this site of the Wami River at Matipwili were predominantly lower than those established during the 2007 dry season.

The highest considerations for low and high flow season during dry, normal and wet years were equal or slightly lower than previously. Consequently, the 2007 flow considerations for ecological and geomorphological maintenance were maintained and therefore **no modifications to the 2007 considerations are suggested.**

Additional Hydrological Records

Additional hydrological information has become available for hydrological analysis since the (Hyera, 2007) EFA study. This information is categorized as:

i) New discharge data sets
ii) Modification of flow routing to include additional information

This additional hydrological information is up until 2011.

New Discharge Data Sets

New discharge data have become available for hydrological analysis since the 2007 study (Basin Annual Hydrology Reports since 2007). These discharge data sets include:

i) New discharge data of the Mkindu River at Mkindu (1GB2), the Chazi River at Chazi (1GB3) and the Mto wa Mawe River at Hembete (1GB4), which were not used in the (Hyera, 2007) EFA analyses (Table 39)
ii) Discharge updates at gauging stations of the Kinyasungwe River at Kongwa (1GD16), the Mkondoa River at Kilosa (1GD2), the Wami River at Dakawa (1G1), the Lukigura River at Kwamvemo (1GA1), thr Lukigura River at Miono-Mziha road (1GA1A), the Mziha River at Maziha (1GA2) and the Wami River at Mandera (1G2) (Table 38)

The monthly and seasonal discharges were recalculated using entire periods of available data (Table 34).

Image 7: The Wami estuary has both socioeconomic and ecological importance.

Table 34: Additional discharge information in the Wami River Basin.

SN	Station			Available data	
	No.	Name	River/location	2007	2011
1	14	1G2	Wami at Mandera	9 Jun 1954-30 Nov 2002	9 Jun 1954-30 Sep 2010
2	52	1GA1	Lukigura at Kwamvemo	22 Jul 1961-30 Apr 1970	22 Jul 1961-31 May 1981
3	76	1GA1A	Lukigura at Miono-Mziha road, Kimamba	15 Oct 1964-30 Sep 1981	15 Oct 1964-25 Feb 1988; 1 Nov 2009-30 Sep 2010
4	77	1GA2	Mziha at Mziha	16 Oct 1964-28 Apr 1987	16 Oct 1964-28 Apr 1987; 10 Jan 2007-30 Sep 2010
5	53	1GB1A	Diwale at Ngomeni	1 Nov 1964-31 Dec 2000	1 Nov 1964-31 Dec 2000; 26 Jan 2007-30 Sep 2010
6	78	1GB2	Mkindu at Mkindu	-	14 Nov 1953-31 Jul 1970
7		1GB3	Chazi at Chazi	-	9 Aug 1954-31 Oct 1960
8		1GB4	Mto wa Mawe at Hembete	-	26 Jan 1959; 8 Mar 1959
9	16	1G1	Wami at Dakawa	14 Nov 1953-30 Sep 1988	14 Nov 1953-30 Sep 1988; 27 Sep 2006-30 Sep 2010
10	61	1GD2	Mkondoa at Kilosa	1 Apr 1952-29 Mar 1981	1 Apr 1952-30 Apr 1997; 1 Nov 2009-28 Feb 2010
11	71	1GD16	Kinyasungwe at Dodoma-Kongwa road bridge	7 Mar 1958-20 May 1987	7 Mar 1958-28 Feb 2010

This inventory indicates more availability of data in the middle the Wami River that improves estimation of flows within the catchment of the Diwale/Mkindu River (1GB) and updated information in the Basin to at least September 2008. The new discharge series and updates were assessed in terms of added value of information that will facilitate modification of flow recommendations whenever new information provides useful statistics. The analysis involved comparison of minimum, average and maximum discharges that would affect estimated environmental flows at EFA study sites. For minimum discharges, the added value is when the new information provides discharges below what was extracted in the previous records. For maximum discharges, the added value is when new maxima exceed the previous maxima.

Modification of Routing Model

Substantial improvement of the flow routing model has been carried and documented in a separate Water Allocation Tool Development Report (See McClain *et al.*, 2012). The modifications include

i) Adding the contributions of flows of the Mkindo and Lukigura Rivers
ii) Revisions of characteristic equations at key gauging sites (1G1, 1G2 and 1GB1A)
iii) Improvement of flow routing mathematics

A comparison indicates new minimum and average discharges within the extreme values extracted from records used in 2007. **The analysis indicates slightly higher maximum discharges at 1GA1 and 1GD16, stations, which had available information in 2007. This would affect discharge quantiles estimated previously and therefore would require re-analysis of flow-frequency relationship.**

Flow Availability

Modifications to the 2007 flow requirements for ecological and geomorphological maintenance of rivers at the five (5) EFA sites in the Wami River Basin were only proposed for the Kinyasungwe River at Kongwa (EFA Site 1). Therefore, only flow availability at this site was analyzed (see Table 35).

Table 35: Assessment of flow availability at 1GD16 from revised flow requirements at EFA Site 1.

Year	Dry years				Normal years				Wet years			
Season	Zero flow season		High flow season		Zero flow season		High flow season		Zero flow season		High flow season	
Dates	7th Jun - 2nd Dec		3rd Dec - 6th Jun		7th Jun - 2nd Dec		3rd Dec - 6th Jun		7th Jun - 2nd Dec		3rd Dec - 6th Jun	
	REQ	**AV**	**REQ**	**AV**	**REQ**	**AV**	**REQ**	**AV***	**REQ**	**AV**	**REQ**	**AV**
Geomorph	0	WS	1	**NA**	1	**NA**	6	4th Dec – 22nd Apr	28	**NA**	44	18th Dec – 17th Feb
Riparian	0.3	**NA**	3.5	**NA**	1.5	**NA**	5	4th Dec – 22nd Apr	3.5	**NA**	7	3rd Dec – 24th Apr
Fish	1	**NA**	11	**NA**	3	**NA**	7	5th Dec – 22nd Apr	4	**NA**	90	**NA**
Macro-Invert.	1	**NA**	7	**NA**	1.1	**NA**	4	28 Nov – 22 Apr	3	**NA**	25	16th Dec – 7th Apr
Socio-econ	0.004	**NA**	0.004	WS	0.004	**NA**	0.004	WS	0.004	**NA**	0.004	WS

(occur as pulse flows for a few days (normally 1-4 days for high discharges) within the season*
REQ – flow requirement; AV – flow availability period; WS – available in the whole season;
NA – Not available in the whole season)

The non-zero modified flow requirements for ecology are available for a limited period during the December-January period. High flow requirements for geomorphological maintenance of the channel are usually available as isolated high flow events between late-December and mid-January. The seasonal nature of the river could not supply any flows during the zero flow season (7th June-2nd December) when the river is dry.

For the normal (maintenance) and wet years, pulse (flood) discharges are taken as the highest flow requirements. These are 7 m^3/s in normal years and 90 m^3/s in wet years, which have risen from the initial values of 6 m^3/s and 44 m^3/s respectively derived from the 2007 dry season assessment.

Initial flow requirements established during the low flows of November 2007 and extrapolated for high flow season were higher than or comparable to those estimated following the 2011 wet season fieldwork. Therefore, revision to initial EF recommendations was carried out for Kinyasungwe at Kongwa site while the 2007 recommendations for average flows and flow pulses are retained at the 4 other sites. However, additional annual flood flows ($Q_{T=1}$) are proposed at each site for geomorphological channel maintenance. The revision considers the following:

i) Average discharge that could be reserved in the river for ecological maintenance
ii) The pulse annual flood for geomorphological channel cleaning
iii) The pulse floods for channel maintenance

For practical management applications, it is usually advisable to effect monitoring and management at the monthly timescale rather than the daily timescale due to involved activities. Average discharges referred here are therefore average monthly discharges derived from comparison of:

i) The highest flow requirement at the site
ii) The lowest available discharge
iii) Seasonal average discharge

The pulse discharges are high flows required to facilitate particular geomorphological function of either maintaining or cleaning river channels. They are related to discharges of different recurrence interval (return period) usually ranging from annual channel maintenance floods ($Q_{T=1}$) in normal (maintenance) years to centennial ($Q_{T=100}$) and millennial ($Q_{T=1000}$) channel cleaning floods usually occurring during the wettest years. They are derived from Flood Frequency Analysis (FFA) of observational annual maximum discharges fitted by the Method of Maximum Likelihood (MML) to 60 distributions and provided for from comparison with the historical highest recorded discharges. For the EFA study sites, FFA indicated that several probability distributions best describe recurrence of annual maximum discharges at the sites. They were therefore used to derive Q_T for different return periods at the 5 EFA study sites (Table 36).

Table 36: Estimated flood discharges at EFA study sites.

Return period (T) (years)	Discharge Quantile (Q_T) (m^3/s)			
	Kongwa	Kilosa	Mtibwa	Mandera/ Matipwili
Used Prob. Distr.	Weibull	Lognormal	GEV	GEV
1	5.86	35.55	73.95	93.3
2	12.41	62.8	185.9	329.8
5	28.81	110.2	276.7	493.0
10	41.22	147.9	338.9	611.3
20	53.63	188.5	400.1	732.9
25	57.63	202.4	419.9	773.2
50	70.04	247.8	481.8	903.1
100	82.45	297.3	544.8	1041
200	94.86	351.2	609.2	1188
500	111.30	429.9	696.7	1397
1000	123.7	495.3	764.7	1567
Recorded highest	**78.6**	**172.0**	**-**	**1612.5**

Environmental Flow Recommendations

Environmental flow recommendations are summarized for low flow and high flow seasons in the five sites in the Wami River Basin based on the fieldwork observations and analysis of dry (2007) and wet (2011) data. The recommendations are similar for all months within the low flow or high flow season. For other intermediate (medium) flow seasons between the two (low and high) flow seasons, interpolation of flow requirement is carried out to provide monthly environmental flows. These considerations of flow needs are based on the professional judgment and scientific knowledge of the experts that collected and analyzed these data.

Kinyasungwe River at Kongwa (EFA Site 1)

Daily discharge hydrographs indicate that in the driest years the river is usually dry, observing no river flows in the river. Therefore this river flows only when there is rainfall. Zero flows have therefore been recorded in the low, medium and high flow during the driest years. Species at this site have adapted to this historical condition. **Therefore, the recommended flows for ecological maintenance are zero (0 m^3/s) (Table 37).**

Table 37: Recommended Environmental Flow (m^3/s) at EFA site 1 (the Kinyasungwe River at Kongwa).

Month	Driest year			Maintenance year			Wettest year		
	RAD	AAD	RIP	RAD	AAD	RIP	RAD	AAD	RIP
Oct	0.0	0.0		0.0	0.0		0.0	0.1	
Nov	0.0	0.0		0.0	0.1		0.0	0.7	
Dec	0.0	0.0		1.1	2.3	7 (T= 1.5 yr)	8.0	16.0	50 (T= 17 yrs)
Jan	0.0	0.0		1.1	3.8	7 (T= 1.5 yr)	8.0	33.6	50 (T= 17 yrs)
Feb	0.0	0.0		1.1	2.6		8.0	16.4	
Mar	0.0	0.0		1.1	1.5		8.0	11.8	
Apr	0.0	0.0		1.1	1.8		8.0	13.8	
May	0.0	0.0		0.4	0.4		1.9	1.9	
Jun	0.0	0.0		0.0	0.0		0.0	0.0	
Jul	0.0	0.0		0.0	0.0		0.0	0.0	
Aug	0.0	0.0		0.0	0.0		0.0	0.0	
Sep	0.0	0.0		0.0	0.0		0.0	0.0	

(RAD = recommended average discharge; AAD = available average discharge;
RIP = recommended instantaneous peak (pulse) discharge)

Seasonal monthly average discharges are between 0 and 3.8 m^3/s in normal years, whilst the seasonal average discharge is 1.1 m^3/s. It is therefore recommended that an average discharge of 1.1 m^3/s is left in the channel while a higher pulse discharge of 6 m^3/s is recommended for geomorphological functioning. This 1.1 m^3/s discharge is much smaller than the suggested discharge of 7.0 m^3/s for ecological maintenance, but the April 2011 wet season sampling discharge at this site was only 0.4 m^3/s, and fish species were still caught. This suggests that the current fish species can tolerate such low discharges at this site. The consideration of a flow of 40 m^3/s during the wet season for fish could not be met as such a high flow has not been recorded at the site. Historically, the highest recorded discharge at this site is 78.6 m^3/s, recorded only once. The 20-years recurrent discharge ($Q_{T=50}$) of 53.63 m^3/s historically has only been exceeded twice. Therefore, 53.63 m^3/s is adopted for pulse channel cleaning discharge at this site. Discharges of such magnitude have been recorded in January-March period and therefore recommended in these months.

Mkondoa River at Kilosa (EFA Site 2)

The ecological and geomorphological flow considerations in the driest years at this site exceed seasonal averages and it is therefore **recommended that the current flow levels remain (Table 38**).

Table 38: Recommended Environmental Flow (m^3/s) at EFA site 2 (the Mkondoa River at Kilosa).

Month	Driest year			Maintenance year			Wettest year		
	RAD	AAD	RIP	RAD	AAD	RIP	RAD	AAD	RIP
Oct	0.0	0.0		4.2	4.2		10.0	15.2	
Nov	0.1	0.1		4.3	6.7		10.0	40.0	
Dec	0.1	0.1		6.7	10.5		27.9	55.7	
Jan	0.1	0.1		9.2	14.5		47.2	94.4	
Feb	0.3	0.3		11.6	12.6		29.0	57.9	
Mar	0.4	0.4		14.0	13.9		80.7	87.2	
Apr	1.0	1.0	3.6 (T < 1 yr)	14.0	21.3	31 (T = 1.15)	80.7	91.9	166 (T = 14 yrs)
May	1.3	1.3		14.0	14.4		45.1	60.2	
Jun	0.2	0.2		5.7	7.5		21.2	28.2	
Jul	0.2	0.2		4.3	5.8		12.6	16.8	
Aug	0.1	0.1		4.3	5.2		12.2	16.3	
Sep	0.1	0.1		4.3	4.6		10.0	14.5	

(RAD = recommended average discharge; AAD = available average discharge;
RIP = recommended instantaneous peak (pulse) discharge)

Historically, the highest instantaneous discharge in the driest years has been 3.6 m^3/s. It is recommended this be left to cross this section for channel maintenance purposes. In normal years, the flow of 31 m^3/s has infrequently been recorded in April and therefore is recommended as a pulse discharge. The highest flow of 166 m^3/s (corresponding to bank full discharge every 14-years) assists with maintenance of floodplain vegetation and channel cleaning. This has only been exceeded once to 172 m^3/s in January 1962. However, the 10-year discharge ($Q_{T=100}$) of 147.9 m^3/s has been exceeded a few times and acts as an overbank discharge at some cross-sections which can support floodplain vegetation. Therefore, 166 m^3/s is recommended to be left as the pulse discharge to satisfy these functions and not be prevented by damming.

Wami River at Mtibwa (EFA Site 3)

As already noted, the original site has been significantly modified since the dry season sampling by a bridge construction downstream and **dredging which make the original section no longer suitable as a study or reference site and the most preferable new site chosen was located downstream.** The ecological and geomorphological flow considerations in the driest years at this site exceed seasonal averages and therefore it is **recommended that the current flow levels should remain (Table 39**).

Historically, the highest instantaneous discharge in the driest years is 18 m^3/s, usually recorded in April. This also is recommended to be left to cross the section for channel maintenance purposes. In normal years, the highest flow consideration of 67 m^3/s (equivalent to annual flood ($Q_{T=1}$) has been recorded each April and November-July of wet years and is therefore recommended as a pulse discharge.

Table 39: Recommended Environmental Flow (m^3/s) at EFA site 3 (the Wami River at Mtibwa).

Month	Driest year			Maintenance year			Wettest year		
	RAD	AAD	RIP	RAD	AAD	RIP	RAD	AAD	RIP
Oct	2.0	2.1		10.0	15.0		41.3	41.3	
Nov	2.0	2.1		10.0	19.7		46.0	71.7	75 (T = 1.05 yr)
Dec	2.8	2.0		24.2	48.3		51.3	247.9	
Jan	3.5	3.5		31.4	62.8		56.5	250.2	
Feb	3.2	3.2		24.6	49.2		61.8	287.9	
Mar	3.0	3.0		27.5	54.9		67.0	283.7	
Apr	5.0	27.6	18 (T <1 yr)	67.0	120.7	67 (T < 1 yr)	67.0	524.4	75 (T = 1.05 yr)
May	5.0	26.3		67.0	108.2		67.0	298.4	
Jun	5.0	16.6		26.3	52.5		56.5	229.9	
Jul	4.1	10.2		13.2	26.3		51.3	71.1	
Aug	3.1	6.1		10.0	23.0		46.0	64.5	
Sep	2.0	4.7		10.0	18.8		46.0	52.4	

(RAD = recommended average discharge; AAD = available average discharge;
RIP = recommended instantaneous peak (pulse) discharge)

For the wettest year, the average discharge of 67 m^3/s is recommended at this site for geomorphological channel maintenance, although ecological considerations are much smaller, to below 20 m^3/s. This discharge exceeds available flows during the low flow period and consequently seasonal averages are used as environmental flows whenever they are below 67 m^3/s The highest flow of 75 m^3/s (corresponding to bank full discharge) considered for maintenance of riparian vegetation is provided for a limited period of time. This discharge has historically recorded for the whole high flow season during the wettest years. It is therefore recommended to be left as the pulse discharge to satisfy the functions and not be prevented by damming.

Wami River at Mandera (EFA Site 4)

The ecological and geomorphological flow considerations in the driest years at this site are below monthly averages and therefore they were **recommended as environmental flows for driest years (Table 40).**

The highest flow consideration of 48 m^3/s in the driest years is usually recorded in April. This is recommended to be left to cross the section for channel maintenance purposes. In normal years, the highest flow consideration of 53 m^3/s for geomorphological functions is less than annual flood ($Q_{T=1}$), recorded first in December through April and May. It is recommended as a pulse discharge in December of normal years.

For the wettest year, the highest consideration of 170 m^3/s for high flow season does not exceed available average monthly discharges during the high flow season, while the highest low flow consideration of 23 m^3/s for ecological maintenance is below the available average monthly discharge. Consequently, with interpolations for medium flow seasons, these ecological flow considerations are used as environmental flows. The highest flow consideration of 104 m^3/s for geomorphological functions is contained within the recommended reserve flow of 170 m^3/s during the high flow season. Therefore, 170 m^3/s is recommended as the pulse discharge to satisfy these functions and not be prevented by damming. **It should be noted that there is a need to update the ratings curves due to the unusual data collected.**

Table 40: Recommended Environmental Flow (m^3/s) at EFA site 4 (the Wami River at Mandera).

Month	Driest year			Maintenance year			Wettest year		
	RAD	AAD	RIP	RAD	AAD	RIP	RAD	AAD	RIP
Oct	3.0	4.3		13.3	13.3		23.0	65.0	
Nov	3.0	5.9		14.0	26.0		23.0	265.9	
Dec	7.7	15.9		27.3	54.6		59.8	503.9	
Jan	7.7	10.1		32.8	65.7		96.5	412.9	
Feb	7.7	12.3		24.6	49.2		133.3	325.1	
Mar	5.6	5.6		52.4	69.9		170.0	466.6	
Apr	21.7	102.1	48 (T <1 yr)	65.0	192.9	53 (T <1 yr)	170.0	1240.5	170 (T = 1.1 yr)
May	21.7	261.7		65.0	145.4		170.0	465.9	
Jun	15.5	42.6		37.5	49.9		91.4	182.8	
Jul	9.2	27.9		20.8	27.7		30.1	60.3	
Aug	3.0	15.4		14.0	21.1		23.0	51.3	
Sep	3.0	10.4		14.0	15.5		23.0	61.5	

(RAD = recommended average discharge; AAD = available average discharge;
RIP = recommended instantaneous peak (pulse) discharge)

Wami River at Matipwili (EFA Site 5)

The ecological and geomorphological flow considerations at this site are below monthly averages and therefore they were **recommended as environmental flows for driest, normal and wettest years (Table 41**).

Table 41: Recommended Environmental Flow (m^3/s) at EFA site 5 (the Wami River at Matipwili).

Month	Driest year			Maintenance year			Wettest year		
	RAD	AAD	RIP	RAD	AAD	RIP	RAD	AAD	RIP
Oct	4.6	4.6		6.6	13.9		37.0	68.3	
Nov	5.5	6.2		6.6	27.3		37.0	279.1	
Dec	8.3	16.7		14.7	57.3		86.5	529.1	
Jan	5.3	10.6		22.8	69.0		136.0	433.5	
Feb	6.4	12.9		30.9	51.6		185.5	341.4	
Mar	5.9	5.9		39.0	73.4		235.0	490.0	
Apr	21.2	107.2	37 (T = < 1 yr)	39.0	202.5	39 (T = < 1 yr)	235.0	1302.5	235 (T = 1.33 yrs)
May	21.2	274.8		39.0	152.7		235.0	489.2	
Jun	16.0	44.7		28.2	52.4		169.0	192.0	
Jul	10.7	29.3		17.4	29.1		103.0	63.3	
Aug	5.5	16.2		6.6	22.2		37.0	53.9	
Sep	5.5	11.0		6.6	16.3		37.0	64.6	

(RAD = recommended average discharge; AAD = available average discharge;
RIP = recommended instantaneous peak (pulse) discharge)

Historically, the highest flow consideration of 37 m^3/s in driest years is usually recorded in April-June period, 39 m^3/s in normal years in medium and high flow seasons and 220 m^3/s has normally been observed between November and June of wettest years. The 39 m^3/s discharge is recommended for a normal year. The highest flow recommendation of 235 m^3/s for ecology slightly exceeds 220 m^3/s for geomorphological functions. This 1.33-year discharge corresponds to bank full discharge and is recommended as pulse flow for maintaining river and floodplain ecology and geomorphology.

All sites: water quality considerations

Water within the Wami River Basin rivers are still of good quality, as indicated by water quality parameters having values within allowable limits under Tanzanian or international standards. However, planned developments and population increase within this basin are likely to bring about intensified socio-economic activities which are likely to result in increased water pollution. As a result, it is important that the amount of pollutant loading into surface water resources is restricted in this basin. **The maximum recommended water quality values for the conservation of aquatic ecology, based on the water quality Guidelines and Standards set out in Table 32, are set out in Table 42**.

Table 42: Recommended maximum water quality levels at all 5 EFA sites.

Water quality parameter	Recommended value
Dissolved Oxygen	Average: 5.0 mg/l Minimum: 4.0 mg/l
pH	6.0 - 9.5
Water temperature	< 30ºC
TSS	< 100 mg/l
NH_3 (unionized ammonia)	< 0.05 mg/l
Metals	
Arsenic	< 0.05 mg/l
Cadmium	≤ 0.01 mg/l
Chromium	≤ 0.05 mg/l
Copper	≤ 1.0 mg/l
Lead	≤ 0.05 mg/l
Mercury	≤ 0.002 mg/l
Silver	≤ 0.05 mg/l

Conclusion

This report forms part of a series of Environmental Flow Assessment (EFA) studies available for the Wami River Basin in Tanzania. As with the initial EFA carried out in Phase I in 2007, the goal of this report was to provide more scientific information for sound decision making on water resource allocation in the Wami River Basin, and to assist with the implementation of Tanzania's water legislation that establishes ecosystems as second order of priority in this decision making. This report fills an important gap in scientific understanding of the Wami River Basin by providing a set of data and analysis from wet-season sampling from 5 EFA sites selected as part of the initial EFA, and then using that data to reconsider earlier recommendations for environmental flows in that same initial EFA (Hyera *et al.*, 2008).

The timing of wet season fieldwork was adequately arranged so that it coincided with flood flow conditions at most study sites following good rains in the Basin. This enabled field sampling of fish, macroinvertebrates, riparian vegetation, geomorphology and water quality, and hydrometric measurements whilst socio-economic data in the nearest villages were also collected. However, high flow conditions with high flow velocities prevented direct discharge measurements at three study sites along the main Wami River (Mtibwa, Mandera, Matipwili) due to safety reasons. The fieldwork indicated existence of some fish and macroinvertebrate species that were not collected in the 2007 fieldwork, and absence of some vegetation species that were observed during the 2007 fieldwork. Water quality (WQ) information at the 5 study sites was only collected during the wet season fieldwork and indicated that most WQ parameters are still below permissible values. Additional information supplementing that used in hydrological analysis in 2007, which includes new discharge data and discharge updates at gauging stations used in the (Hyera, 2007) EFA analyses, has also been included. This information facilitated significant improvement of the flow routing developed for the lower Wami that is used in flow estimation at ungauged sites between Wami-Dakawa/Turiani and the Indian Ocean coastline. The improvements include revised relationships between river discharge and flow velocity, area, top width at gauging sites and ungauged EFA sites, as well as new conditionality in the routing algorithm.

The key recommendations to supplement those set out in the initial EFA Synthesis Report (Hyera *et al.*, 2008) as summarized in this report are:

i. The wet season data and analysis confirmed there was no need to revise the environmental flow recommendations given in Phase I initial EFA for EFA Sites 2 - 5.

ii. The wet season data and analysis did suggest, however, revisions are needed for the environmental flow recommendations to support wet season ecological and geomorphological flow the Kinyasungwe River at Kongwa (EFA Site 1).

iii. Although water quality measurements indicate good quality of water within the Wami River Basin, minimum water quality standards have been recommended for the Wami River Basin to support the continued conservation of aquatic ecosystems and the quality and availability of ecosystem services.

iv. More fieldwork and research is needed to continue increasing the scientific understanding of the Wami River and its tributaries, and particularly the flow dependence of ecosystems and ecosystem services. Additional research would increase the reliability of river hydraulics information at study sites and provide more information on the Wami River Basin aquatic ecology, geomorphology, water quality and socio-economics. Additionally, more research will help broaden the Environmental Flow information available for water resources management in the Wami River Basin and it is recommended that this includes:

a) More in-depth study of ecologically important areas of the basin, such as the shoals at Wami-Mandera and the estuary of the Wami at Saadani National Park.

b) More study and inventory of aquatic and riparian biodiversity is needed to complete species lists for the basin; these studies should be accompanied by social research into human uses of aquatic and riparian resources.

v. Robust hydrological models that will provide longitudinal linkages between the sites within the basin's hydrographic network for practical applications in basin water allocation should be developed to assist in the implementation of recommended environmental flows.

vi. Finally, given that EFA should be viewed as a process, the WRBWO and the scientific experts' team should periodically revisit the recommended environmental flows for the five sites as more scientific information on the Wami River Basin becomes available.

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