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# Environmental Flow Assessment

## The Great Ruaha River and Ihefu Wetlands, Tanzania, and options for the restoration of dry season flows

**July 2010**

## Acknowledgements

The project team would like to thank the following organisations for their involvement, support and input during the course of this project:

WWF-TPO

WWF-UK

RBWO

SCANAGRI

Pegasys International

UNESCO-IHE

The authors gratefully acknowledge the support provided by the WWF-Tanzania Project Office and WWF-UK for project and logistics management, and for providing key guidance and support on stakeholder engagement and participation. The authors also recognise the key support received from the Rufiji Basin Water Office, in particular the Water Officer (Mr Willie Mwaruvanda) and the Basin Hydrologist (Ms Grace Chitanda).

In addition, the authors acknowledge the significant contribution made to the report and the process by various reviewers, notably Ms Sue Stohlberger, Mr Rafik Haiji, Mr Geoff King and Prof Jay O'Keeffe. The authors also gratefully acknowledge the assistance of Dr Bruce Lankford, School of Development Studies, University of East Anglia in providing feedback on drafts of sections of this report. Some of the science that feeds into this report was derived from two projects SMUWC and RIPARWIN where he was irrigation specialist and team leader respectively.

The authors wish to note the significant contribution the late Dr Kossa Rajabu made to this report and to the wider Ruaha Programme – his knowledge, understanding, commitment and passion will be sorely missed.

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For bibliographic purposes, this document should be cited as:

WWF Tanzania Country Office (WWF-TCO). Assessing Environmental Flows for the Great Ruaha River, and Usangu Wetland, Tanzania.

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# About this document

**Purpose**

This report describes the process and product of a river and wetland Environmental Flow Assessment (EFA) and options analysis undertaken between 2008-2010 on the Great Ruaha River, (GRR) a major tributary of the Rufiji Basin, in Tanzania, and the associated /Usangu Wetland, respectively. The objectives of the study were to

i) recommend flow rates, for different seasonal scenarios, required to restore dry season flows to the middle section of the GRR and Usangu wetland in the Ruaha National Park (RNP); and

ii) identify a range of options to support implementation of environmental flows, providing a short-list of preferred options, identified against agreed criteria, in consultation with a wide range of stakeholders at local and national levels in Tanzania.

**Structure**

Section 1 of this document comprises the executive summary

Section 2 introduces the study and gives background to the area of interest, and to the situation that prompted the EFA study, i.e. the loss of low flows in the GRR during the dry season.

Section 3 provides a brief overview of the Building Block Methodology (BBM) which was used to determine the EFAs

Section 4 outlines the steps taken to determine the present state of representative sections of the GRR, and the results of the work undertaken by each specialist: (Hydrologist, hydraulician, geomorphologist, riparian vegetation specialist, fish and aquatic invertebrate specialist). It goes on to describe the desired state of the river, and the flows required to achieve this.

Section 5 comprises a review and analysis of proposed options for restoring dry season flows to the middle section of the GRR, with reference to the Eastern Wetlands of the Usangu Plain.

Section 6 describes the process and outcomes of EFA undertaken for the Eastern Wetlands of the Usangu Plain, on the GRR upstream of Ng'iriama.

**Supporting documents**

The following documents complement this report and are available from WWF-TCO and RBWO.

All river EFA starter reports and their appendices

All wetland EFA starter reports and their appendices

Outcomes of all workshops

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## List of abbreviations and acronyms

| | |
|---|---|
| ADF | Average Daily Flow |
| ANOVA | Analysis Of Variance |
| ASL | Above Sea Level |
| ASPT | Average Score Per Taxon |
| ASTER | Global Advanced Spaceborne Thermal Emission and Reflection Radiometer DEM, |
| BBM | Building Block Methodology |
| DCA | Detrended Correspondence Analysis |
| DEM | Digital Elevation Model |
| DO | Dissolved oxygen |
| DOC | Dissolved Organic Carbon |
| EFA | Ecological Flow Assessment |
| EIS | Ecological Importance and Sensitivity |
| EMC | Ecological Management Class |
| GCP | Ground Control Point |
| GGP | Gross Geographic Product |
| GPS | Global Positioning System |
| GRR | Great Ruaha River |
| HEC-GEORAS | An Arc View Environment based software/Extension/Subroutine |
| HEC-RAS | Hydrologic Engineering Center-River Analysis System: A hydraulic model |
| ITCZ | Inter-Tropical Convergence Zone |
| IWMI | International Water Management Institute |
| IWRM | Integrated Water Resources Management |
| JTU | Jackson Turbidity Units |

| | |
|---|---|
| MAR | Mean annual runoff |
| MoWI | Ministry of Water and Irrigation |
| MCM | Million Cubic Metres |
| MGRR | Middle Great Ruaha River |
| NEMC | National Environment Management Council |
| PES | Present Ecological State |
| PET | Potential Evapotranspiration |
| RBWO | Rufiji Basin Water Office |
| RIPARWIN | Raising Irrigation Productivity and Releasing Water for Intersectoral Needs |
| RNP | Ruaha National Park |
| RQOs | Resource Quality Objectives |
| RUBDA | Rufiji Basin Decision Aid |
| SASS | South African Scoring System, |
| SCANAGRI | Scandinavian Agricultural Institute |
| SRTM | Shuttle Radar Topography Mission |
| SMUWC | Sustainable Management of the Usangu Wetlands and Catchment |
| TANAPA | Tanzania National Parks |
| TIN | Triangular Irregular Network |
| USD | United States Dollars |
| WRED | Water Resources Engineering Department (of the University of Dar es Salaam) |
| WRMA | Water Resources Management Act (Act no.11 of 2009) |
| WRM | Water Resources Management |
| WWF | World Wildlife Fund |
| WWF-TCO | World Wildlife Fund Tanzania Country Office |
| WWF UK | World Wildlife Fund United Kingdom |

# 1. Executive summary

## 1.1. Background

WWF is implementing a project "Integrated Water Resource Management in the Great Ruaha River Catchment, Tanzania" (Section 2.3 provides a full description of the study area). One of the main outputs of this project is a river and wetland Environmental Flow Assessment (EFA) and options analysis to determine the flows needed, and options for implementing them, to maintain the ecological and hydrological services provided by freshwater ecosystems. The work took place between 2008-2010, culminating in this report. The project was funded by the European Union.

The major issue to be dealt with was the need to reinstate the dry season flows in the reaches of the river through the Ruaha National Park (RNP).

Dry season flows into the RNP began to cease in 1993. These flows are important for the people living in the catchment who are dependent on the river for domestic use and for irrigation of cash and subsistence crops. They're also important for maintaining the biodiversity of the riverine ecosystem, and the long term sustainability of the entire RNP, which is likely to be dependent on the reinstatement of perennial flows in this, the only naturally occurring year round river in the national park. These and other issues regarding flows within the GRR led to the pronouncement in 2002 by the then Prime Minister that the GRR must have "year-round flows by 2010".

## 1.2. Objectives

The objectives of the study were to:

1. recommend flow rates, for different seasonal scenarios, required to restore dry season flows to the middle section of the GRR and Usangu wetland in the Ruaha National Park (RNP); and
2. identify a range of options to support implementation of environmental flows, providing a short-list of preferred options, identified against agreed criteria, in consultation with a wide range of stakeholders at local and national levels in Tanzania, and
3. determine the required inflows into the eastern Usangu wetland, in order to meet the recommended flow rates, downstream, in the RNP; as well as to determine the response of the wetland to changing flow regimes, not only those caused by upstream abstraction, but also with respect to proposed engineering modifications, i.e. the construction of the Lugoda Dam, and the Ndembera transfer option.

During the course of this assessment another team, coordinated and supported by the Scandinavian Agriculture Institute (SCANAGRI), conducted various complementary social and economic studies in the upper catchment and wetland areas of the GRR.

## *1.3. Methodology*

### 1.3.1. Environmental flows

EFAs are becoming the global standard for determining the amount of water required to sustain aquatic ecosystems and socio-economic development. Environmental flows are defined here as:

"The quantity, timing, and quality of water flows required to sustain freshwater and estuarine ecosystems and the human livelihoods and well-being that depend on these ecosystems"

Recognising their importance to river health and function, Tanzania has adopted the principle of environmental flows in their National Water Policy (2002), promulgating them more recently in the concept of the "environmental reserve" in the Water Resources Management Act (WRMA) No. 11 of 2009, where the term *environmental reserve* is defined (in Part I, Section 3), as:

*"The quantity and quality of water required for –*

*(a) satisfying basic human needs by securing a basic water supply for people who are now or who shall in the reasonably near future, be-*

*(i) relying upon*

*(ii) taking water from; or*

*(iii) being supplied -from the relevant water resources; and*

*(b) protecting to protect aquatic ecosystem in order to secure ecologically sustainable development and use of relevant water resources"*

An Environmental Flow analysis (EFA) helps to inform water allocation decisions by water managers. Part II, Section 6 - (2) of the WRMA No. 11 of 2009 stipulates that:

*"… the preference for water allocations shall be for –*

*(a) domestic purposes;*

*(b) environmental reserve; and*

*(c) socio-economic activities depending on the availability of water resources."*

### 1.3.2. The Building Block Methodology

Section 3 provides further information on the Building Block Methodology. The BBM was selected as the methodology for the EFA of the GRR. It is among the most widely applied holistic method that addresses both the structure and function of all components of the river ecosystem (King *et al.* 2000).

### 1.3.3. Process

In 2007 WWF, using a grant from the EU, began to work with stakeholders in Tanzania to decide on the objectives and methodology for conducting an EFA in the GRR. A team of International and Tanzanian specialists were commissioned for this work, including a geomorphologist, hydrologist, hydraulic engineer, fish and macroinvertebrate biologist, and vegetation ecologist.

A combination of desk and field studies was carried out (the reports of which are available through WWF-TCO and RBWO), as well as a series of consultative workshops involving stakeholders from the Rufiji Basin, which formed an integral part of each component of the study (the outcomes of these workshops are also available from WWF-TCO and RBWO).

### 1.3.4. GRR EFA

Section 4 of this report describes the methodology of the GRR EFA in detail. Two representative sites – BBM1 at Msembe and BBM2 at Muhuwa – were selected in the RNP, upstream and downstream of Msembe. The specialist team conducted a river field study at these two sites in July 2008, to:

- determine the present state of the GRR,
- compare it with natural conditions, and to
- infer from this the objectives for the physical characteristics of the river and the indicator species that would demonstrate that a sustainable flow had been achieved in the river.

The present state of the GRR was described in terms of:

- Present Ecological State (PES), which recognises the natural, or reference, conditions at each site and includes a judgment of how far each site has changed from those conditions, with sites ranked from A (natural) to F (critical/extremely modified).
- Trajectory of Change, which indicates whether each component was getting better or worse under conditions.
- Ecological Importance and Sensitivity (EIS), indicating the importance of the site for maintenance of ecological diversity and system functioning on local and wider scales, their ability to resist disturbance and their capability to recover from disturbance, and

- Ecological Management Category (EMC), summarising the overall objective or desired state for each site, ranked from A (natural) to D (largely modified).

The EFA then determined the volume, duration and timing of flows required to meet these objectives.

### 1.3.5. Options study

The study of options to restore flows to the GRR within the RNP was undertaken in parallel with a study assessing the environmental flow requirements of the GRR in the RNP.

During the options study, the findings of significant previous studies on the Usangu Catchment were collated and summarised, identifying water use for irrigated agriculture in the Usangu (and particularly rice production in the Usangu Plains) as the predominant reason for reduced dry season flows into the Ihefu and cessation of dry season flows in the GRR downstream of Ihefu (Ng'iriama). Table 1 summarises the options to restore flows to the GRR, which were subjected to rigorous analysis and a stakeholder consultation process including a workshop in November 2008. Section 5 of this report describes the options study in detail.

**Table 1: Options to restore flows to the GRR**

| Option type | Options considered |
|---|---|
| Technical (engineering) options | Engineering based options that require construction of infrastructure<br>• Storage options<br>• Transfer options<br>• Groundwater options |
| Institutional options | Management of the resource through development of particular institutional arrangements and use of WRM instruments<br>• Allocation planning and scheduling of abstraction (planning)<br>• Reducing illegal abstraction (authorisation)<br>• Increased compliance with existing regulations, licence conditions and agreements (compliance)<br>• Pricing and economic instruments (pricing to drive efficiency and water trading to enable purchase of water use rights) |
| Environmental options | Management of land/land-use to retain environment services and functions<br>• Management of the highlands - reduce soil losses, land degradation and stream-flow reduction activities |
| Agricultural options | Management of agricultural activity and adaptation of agricultural practices<br>• Increased efficiency of irrigation practises<br>• Alternative crop use<br>• Cessation of dry-season irrigation |
| Economic options | Economic development alternatives to current economic practices |

The options were screened to see if they met the criteria of sustainably achieving the objective, and were then subjected to a viability screening to determine whether they were both feasible and implementable.

### 1.3.6. Wetland EFA

Field sampling and assessment took place in March 2010 at three sites; Nyaluhanga, Ruaha Ponds, and Ng'iriama. As in the river study, the PES, trajectory of change, EIS and EMC were determined by each specialist at each site, the specialist objectives were defined and motivated, and the EFA undertaken to determine the required flows to achieve the recommended flows downstream at BBM1 and BBM2. The wetland EFA also assessed the extent to which the proposed flow restoration options might have an impact on the GRR. Section 6 provides details of the wetland EFA.

## *1.4. Findings*

### 1.4.1. GRR EFA results

Full results of the GRR EFA are provided in Section 4.4. Table 2 shows the present state and trajectory of change (comparison with the natural state) of the river at Msembe (BBM1) and Muhuwa (BBM2).

**Table 2: Present state and trajectory of change at BBM sites on MGGR**

| Discipline | Present Ecological State | Trajectory of change | Ecological Importance and Sensitivity | Ecological Management Class |
|---|---|---|---|---|
| **BBM1 Msembe** | | | | |
| Geomorphology | C | Negative | High | C |
| Riparian vegetation | D | Negative | High | C |
| Fish and invertebrates | B | Negative | Very high | A/B |
| **BBM 2 Muhuwa** | | | | |
| Geomorphology | D | Negative | High | C |
| Riparian vegetation | C | Negative | High | C |
| Fish and invertebrates | B | Slightly Negative | High | A/B |

Table 3 shows the summary of recommended flows in terms of natural and present Mean Annual Runoff, (MAR), in Million Cubic Metres (MCM).

**Table 3: Summary of recommended flows at BBM1 and BBM2**

| | |
|---|---|
| **BBM1** | |
| Natural MAR | 3154 MCM |
| Present MAR | 2193 MCM |
| Long term average annual requirement for environmental flows MCM | 303.2 MCM |
| Environmental flow requirement as a percentage of natural MAR | 9.6 % |
| Environmental flow requirement as a percentage of present MAR | 13.8% |
| **BBM2** | |
| Natural MAR | 3154 MCM |
| Present MAR | 2193 MCM |
| Long term average annual requirement for environmental flows | 324 MCM |

| | |
|---|---|
| Environmental flow requirement as a percentage of natural MAR | 10.3% |
| Environmental flow requirement as a percentage of present MAR | 15.0% |

The level of confidence expressed by the specialists in the results of the GRR EFA varied from 3 (Moderate confidence) to 5 (Very high confidence).

### 1.4.2. Options study results

Three preferred options for the restoration of flows in the GRR emerged from the evaluation and consultation process. Section 5.2 provides full details of this process.

1. Institutional strengthening and support to ensure improved water resources management, including improved management of irrigation water;
2. Construction of an impoundment on the Ndembera River (Lugoda Dam); and
3. Transfer from the Ndembera River.

All three options must be implemented concurrently in order to fully restore flows to the GRR. However, options 1 and 2 are only likely to achieve this objective within the medium- to long-term, whilst an urgent intervention is required in the short term to prevent further degradation of the GRR and loss of natural (and financial) capital within the RNP.

Accordingly, the third option – transfer from the Ndembera River – was highlighted as the most likely to restore flows in the short-term.

### 1.4.3. Eastern wetland EFA results

Section 6.5 describes the results of the wetland survey in detail.

***Recommended wetland inflows and-outflows***

A total inflow into Eastern wetland of 5.52-6.81 $m^3/s$ is required in order to sustain an outflow of 1-2 $m^3/s$ past Ng'iriama and hence meet the "minimum" recommended flow rates further downstream at BBM1 and BBM2 during drought low flow conditions, the rationale being that a satisfactory flow during drought low flow conditions will guarantee sufficient flows during low flow periods in normal and wet years.

***The construction of the Lugoda Dam***

The option of supplying the wetland with flows from the proposed Lugoda reservoir (to be located on the Ndembera River) was explored. At the presumed existing flow regime of the GRR at Nyaluhanga, the 6.81 $m^3/s$ total Eastern wetland inflow required to supply the outflow of 1-2 $m^3/s$ past Ng'iriama should all be supplied from the reservoir to the wetlands during zero inflows of the GRR at Nyaluhanga, in order to sustain the EF requirement at RNP.

***The Ndembera transfer option***

The water transfer can be considered to take place either in-channel through the Eastern wetland or off-channel (or canal transfer) using the shortest aerial distance before the wetlands.

Given the existing situation of zero GRR inflows into Ihefu, the entire 6.81 $m^3/s$ would need to come from the Ndembera River, which could not be assured without the reservoir.

The first option of on-channel transfer of water would require a minimum of 0.93 $m^3/s$ and a maximum of 6.81 $m^3/s$ from the Lugoda reservoir, under the situation of 5.81 and 0.0 $m^3/s$ inflows of Great Ruaha at Nyaluhanga respectively, to ensure a minimum discharge of 1.0 $m^3/s$ across BBM sites.

Any required high flow (> 1 $m^3/s$) across the BBM sites would require a much higher discharge (> 0.93 – 6.81 $m^3/s$) from the Ndembera River.

The second option for a canal transfer of water before the wetlands would require that 0.93 – 6.81 $m^3/s$ be left into the river to flow into the wetlands to cater for instream flow requirements resulting in a discharge of 1 $m^3/s$ flowing through the BBM sites downstream of the Eastern wetland. For the canal to fully supply this 1 $m^3/s$, the required inflow into the Eastern wetlands from the Ndembera River would vary between 0.93 and 4.65 $m^3/s$ depending on the amount of inflows of the GRR.

## *1.5. Recommendations for further work*

### 1.5.1. GRR EFA

Section 4.6 provides detailed recommendations for further work with regard to the GRR EFA. The specialists indicated that two more study sites would be required, and that further studies at different flow conditions, (including where possible extreme high and low flow conditions) would increase the degree of confidence in the findings of the GRR EFA.

As the sampling was conducted during medium flows, another sampling programme in low flow seasons is recommended. During the latter season it is expected to adequately capture the micro-topography of the hydraulic controls and critical low flow conditions for the aquatic life.

Further, the need for a socio-economic survey was emphasised, as well as an up-to-date study to disaggregate anthropogenic impact from climate change impact.

### 1.5.2. Wetland EFA

Section 6.7 details the areas where further work was indicated as necessary by the specialists undertaking the wetland study. There is a need to increase the number of rating measurements at gauging stations, spot measurements taken at catchment outlets, and the number of observation stations (discharge, rainfall, climate, groundwater) around the Eastern wetland and to carry out further field measurement studies to accurately estimate groundwater flows and evapotranspiration from the wetlands. Harmonisation of data sets, and further bathymetric surveys were also indicated as important. Further sampling of fish and invertebrates at a range of flows was recommended, together with monitoring of riparian vegetation. The need for more recent water quality data was also highlighted.

## 1.6. Implementation and monitoring

The operating rules of the Lugoda Dam will need to be carefully developed to achieve the recommended environmental flows whilst avoiding the risk of focussing on implementing “minimum flows”, and also meeting the wider multi-use objectives of ensuring adequate flows for hydropower production, flows to meet irrigation demand, and emulating, as far as possible, the natural characteristics of the Ndembera River hydrograph.

It is crucial to emphasise the importance of improved WRM for the long-term sustainability of any approach to restore flows within the GRR in the short- to medium-term. Without appropriate institutional arrangements and improved management of the water resources of the GRR, any gains achieved in the short-term in terms of flow within the GRR will likely be negated through increased abstraction, and unsustainable agricultural and land-use development of the Usangu catchment (highlands and plains).

Careful monitoring of the results of implementing environmental flows in the GRR will be important, to determine whether the flows are achieving the desired state of the river. Accordingly, some flexibility may be required in water resource management policies and decision making in the catchment. This will also allow for successive modifications in the light of increased knowledge, changing priorities, and changes in infrastructure (e.g. removal of dams) over time.

# 2. Introduction

## *2.1. Environmental Flows – the master variable for maintaining biodiversity and ecosystem functions/services*

EFAs are becoming the global standard for determining the amount of water required to sustain aquatic ecosystems and sustain socio-economic development. EFAs comprise structured, science-based approaches to determining how much water must be left in the river to protect the aquatic ecosystems and achieve the desired ecological state.

Environmental flows are those flow regimes needed to maintain important aquatic ecosystem services. Whilst there are a number of definitions of environmental flows, they are defined here as:

"The quantity, timing, and quality of water flows required to sustain freshwater and estuarine ecosystems and the human livelihoods and well-being that depend on these ecosystems"

Recognising their importance to river health and function, Tanzania has adopted the principle of environmental flows in their National Water Policy (2002), promulgating them more recently in the concept of the "environmental reserve" in the Water Resources Management Act (WRMA) of 2009, where the term *environmental reserve* is defined (in Part 1, Section 3), as:

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An Environmental Flow analysis (EFA) helps to inform water allocation decisions by water managers. Section 6 (2) of the WRMA stipulates that:

*"… the preference for water allocations shall be for –*

*(a) domestic purposes;*

*(b) environmental reserve; and*

*(c) socio-economic activities depending on the availability of water resources."*

Many different methodologies exist worldwide; however, the Building Block Methodology (BBM), refined in field studies in South Africa during the 1990's, is among the most widely applied holistic methods that address both the structure and function of all components of the river ecosystem (King *et al*. 2000). The BBM was selected as the methodology for the EFA of the GRR, because it is a flexible robust method which is suitable for use in regions where there is limited data available, and where the specialist team is relatively inexperienced.

## *2.2. Background to the Great Ruaha Environmental Flow Assessment*

The GRR EFA was launched during an initial planning workshop convened on 28-30 January 2008 at Rufiji Basin Water Office in Iringa to provide technical guidance on the methodology to a team of scientists recruited to carry out the analytical components of the assessment. Specialists included a geomorphologist, hydrologist, hydraulic engineer, fish and macroinvertebrate biologist, vegetation ecologist, water quality specialist, and socioeconomist.

The major issue to be dealt with in this EFA was the requirement to reinstate the dry season flows in the reaches of the river through the RNP. Dry season flows into the RNP have ceased every year since 1993, with significant environmental and economic consequences for the Park. These and other issues regarding flows within the GRR led to the pronouncement in 2002 by the then Prime Minister that the GRR must have "year-round flows by 2010".

These flows are not only important to maintain the biodiversity of the riverine ecosystem, but the long term fate of the entire RNP is very likely to be dependent on the reinstatement of perennial flows in this, the only naturally occurring year round river in the national park.

For fish and macroinvertebrate components of the EFA, several key indicators were identified for use in future monitoring of the river to determine if instream flows are sufficient to maintain desired ecological processes. These indicators include: presence of sensitive species that reflect suitable water quality and flow levels, rare or threatened fish species that depend on appropriate timing of variable flows for feeding and reproduction, and sensitive macroinvertebrate species that indicate subtle fluctuations in water quality and pollution levels.

## *2.3. The study area*

### 2.3.1. Catchment context

Whilst focussing on the GRR within the RNP, it is necessary to understand the the origin of the flow cessation in the RNP originate in the Usangu Catchment, upstream of the RNP.

## General description

The Usangu catchment has an area of approximately 20 800 $km^2$ of which about 28 % constitutes the Usangu plain, the remaining 72% being highlands.

The catchment is in the form of a bowl, tilted towards the north-west. The rim of the catchment is formed by the highlands of the Poroto, Kipengere and Chunya Mountains, with elevations up to 3000m above sea level (ASL). The Usangu Plains form the centre of the catchment, at about 1000m asl (Figure 1).

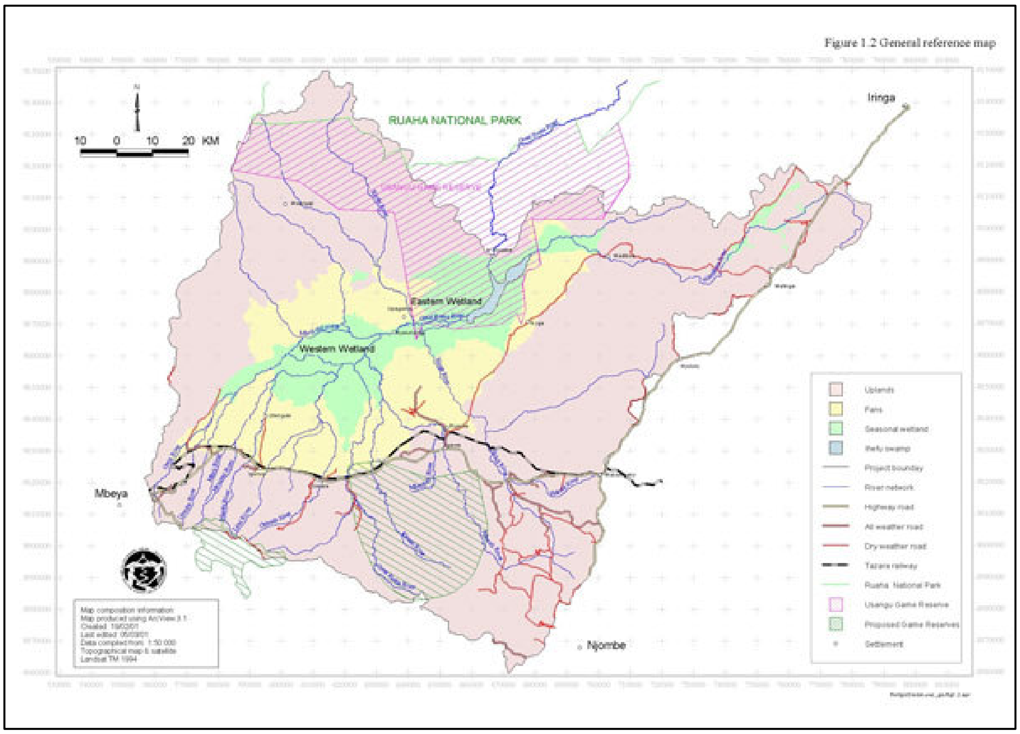


**Figure 1: Usangu Catchment, showing highlands, plains, wetlands and rivers (Source: SMUWC 2001)**

The climate of the catchment is controlled by the Inter-Tropical Convergence Zone (ITCZ), and rainfall is highly seasonal, with a single rainy season from November to April, and characterised by high intensity rainfall events (thunderstorms). This rainfall pattern is reflected in the hydrology, with rivers showing extremely peaked flow patterns and a clearly distinguishable wet and dry season. The GRR downstream of Usangu Wetland receives most of its annual runoff over about four months of the year.

The highlands make up about 15 000$km^2$ of the Usangu catchment. Rainfall is strongly correlated with altitude, with the higher areas receiving up to about 1, 600 mm of rain, annually, but also with a large inter-annual variability as the minimum and maximum over 45 years values are estimated at 1.3 and 1.6 m $y^{-1}$.

As a result, the highlands are extensively dissected by rivers that have cut into the steep erosional surfaces. Much of the highlands retain their natural vegetation, with mountain forest and afro-alpine vegetation occurring on the highest regions, and miombo woodland below 2000m ASL. Areas of gentler slope have been cleared of natural vegetation to allow cultivation.

The Usangu Plain has an area of about 5 800 $km^2$ and lies significantly below the surrounding mountains. In geological history, the plain was an inland lake (Lake Buhoro) that has been filled by erosional sediments transported from the highlands. Thus, the Usangu Plain consists of a series of alluvial fans enclosing a floodplain wetland (area approximately 2 000 $km^2$) which, in turn, contains a small perennial swamp locally called *ihefu* (area approximately 80 $km^2$). There are five large ponds in the ihefu, namely; Nyankokolo, Ruaha, Lyang'ulage, Nyamwono, and Marihemu.

The perennial swamp and surrounding wetland act as a regulator on flows downstream from Usangu. The perennial and seasonal flooding of the wetland is also important for biodiversity; in particular, the wetland supports an exceptional bird population, with species diversity within Usangu of more than twice that of the whole of Europe. The permanent swamp also supports a small, but locally very important, fishery.

A granite bar on the north-eastern extent of the ihefu serves as to impound water within the Usangu Plains, giving rise to the perennial swamp. Outflow over the outcrop occurs in a series of cascades at Ng'iriama.

The floodplain wetland shows a distinct 'figure-of-eight' form, with western and eastern wetlands joined by a narrow corridor at Nyaluhanga. Rainfall on the plain is low, averaging between 500 and 700 mm per annum. Mean rainfall is about 0.72 m $y^{-1}$ and mean potential evaporation of about 1.7 m $y^{-1}$. This rainfall has considerable inter-annual variability as the minimum and maximum values over 45 years were 0.60 and 0.83 m $y^{-1}$.

This is far below the potential evapotranspiration, such that little if any rainfall runs off to feed the ihefu and the GRR downstream. Accordingly, the Usangu Plains are almost entirely dependent on runoff from the surrounding highlands.

The alluvial fans, especially in the south of the plain, are intensively cultivated and much of the native Acacia woodland has been removed. Degradation and soil erosion is evident, particularly on the fans at the junction of the highlands and the plain. However, severe degradation appears to be localised to the southern plains. The grassland mbuga are largely used for livestock production and is considered relatively resilient as long as it is allowed to flood annual. Unfortunately many parts of the western wetland no longer flood, and here the grasslands are experiencing marked changes in land cover.

## Land and water use

The Usangu catchment offers a range of economic and livelihood opportunities centred on water and land, which has resulted in significant immigration into the catchment in recent times. A population estimate in 2000 suggested a total catchment population of 750 000 people, made up of 500 000 people in the highlands and a further 250 000 people in the Usangu Plains, primarily the southern fans. Agriculture is the dominant economic activity in the Usangu catchment - cropping and livestock husbandry together account for more than 80% of employment within the catchment.

Settlement in the highlands is long established. Agriculture makes up about 25% of land-cover (approximately 375 000 ha), with 70% of that (approximately 260 000 ha) under low intensity cultivation. Agricultural activities are primarily dry-land maize, with some livestock and limited irrigation (vegetables). Elsewhere in the highlands the woodlands have been exploited for timber and fuel, but large areas remain wooded, although with varying degrees of degradation (Table 4).

**Table 4: Land-use and land cover of the Usangu Catchment (modified from SMUWC 2001)**

| LAND USE / COVER | AREA (Ha) | % OF TOTAL CATCHMENT |
|---|---|---|
| Total cultivation | 504 895 | 24.29% |
| *Rainfed: Intensive cultivation* | *114 058* | *5.49%* |
| *Rainfed: moderate cultivation* | *316 525* | *15.23%* |
| *Irrigation (wet season)* | *71 812* | *3.46%* |
| *Irrigation (dry season)* | *2 500* | *0.12%* |
| Forest and woodland | 1 084 770 | 52.19% |
| Bushland | 206 425 | 9.93% |
| Grassland | 274 039 | 13.19% |
| Perennial swamp | 8 263 | 0.40% |
| **TOTAL** | **2 078 392** | **100%** |

In the plain, the alluvial fans have been substantially converted to cultivation, with rainfed maize on the higher, sandier soils, and irrigated rice on the lower, heavier soils. Livestock are the primary economic activity on the seasonal wetland, mixed with varying degrees of cultivation. About 300 000 cattle are run on the plains.

Access to markets through good road and rail connections has resulted in the proliferation of agricultural activity in the southern fan of the Usangu Plains. Paddy rice is the predominant irrigated crop: a core area of 15 000 to 20 000 ha can be irrigated every year, which can expand to a maximum area of about 40 000 to 45 000 ha depending on water availability (Figure 2).

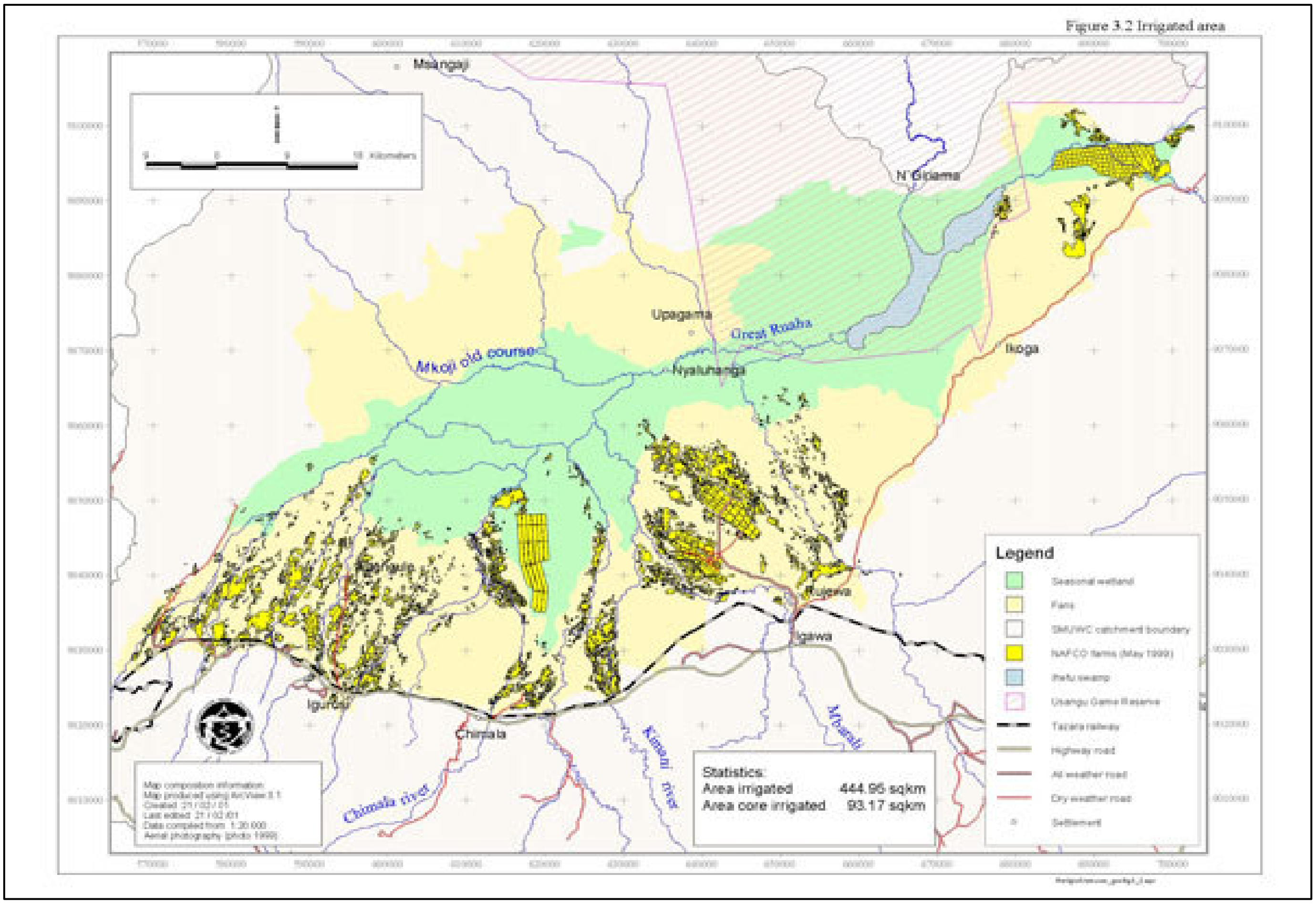


**Figure 2: Irrigated area on the Usangu Plains (source: SMUWC 2001)**

A number of large paddy enterprises, up to several thousand ha, have been established on the southern fans, and make up the majority (about 60%) of the core area under irrigation. These farms were developed under government ownership, but have subsequently been sold to private sector interests. Small-scale enterprises make up the remainder of rice paddy production on the fans and much of it is opportunistic, depending on the availability of water. Ownership of these small-scale enterprises is diverse, varying from city businessman to local farm-worker on the large commercial schemes. The diversity in ownership and opportunistic nature of small-scale production poses significant challenges to assessment and management of this water use.

Historically, irrigation of paddies was confined to the rainy season (approximately 5 months). However, for a number of reasons linked to the market, technology and employment / labour issues, the cultivation season has extended into both the early- and the late dry season and now extends over 11 months of the year. In addition, expansion of paddy production into marginal areas has been driven by opportunistic small-scale farmers that are responding to low opportunity and input costs of rice production.

Water use follows the patterns of land-use and economic activity within the catchment (Table 5).

**Table 5: Water use in the Usangu Catchment and productivity of water use sectors (modified from RIPARWIN 2005 and SMUWC 2001)**

| **Water use** | **Wet season[1]** | **Dry season[2]** | **Productivity** |
|---|---|---|---|
| | **Millions $m^3$** | | **USD (1000)** |
| Irrigation | 775.6 | 64.8 | 22 000 |
| Livestock | 3.5 | 3.0 | 6 000 |
| Industrial and manufacture | - | 0.2 | 200 |
| Domestic | 2.6 | 3.5 | 6 000 |
| **TOTAL** | **781.7** | **71.5** | **34 200** |

Six main water resource users from upstream to downstream can be differentiated:

1) Rainfed farmers and domestic water users in the highlands;

2) Irrigators in the plains;

3) Domestic users and rain-fed maize cultivators in the plains;

4) Pastoralists and fisherpeople in the central wetland;

5) Wildlife and tourists to the RNP; and

6) The Mtera / Kidatu hydropower schemes of the Tanzania Electricity Supply Corporation.

Total annual water use in the Usangu Catchment is approximately 850 $Mm^3$, or 35% of mean annual run-off (2 442 $Mm^3$ at Msembe). It is clear that water availability is not a constraining factor of production in the Usangu Catchment, when viewed over an annual cycle. However, dry season water use is approximately 70$Mm^3$, or about 80% of mean dry season inflow to the wetland. As this is for an average year, the figures are markedly different for a dry year, with 55% abstraction in the wet season and over 90% abstraction in the dry season. In fact, some reports state that, in recent years, 100% of flow entering ihefu from the western wetland has been abstracted for dry season irrigation, and that the only flow entering the permanent swamp during these months is a limited input from the Ndembera River.

Water use for livestock watering and domestic consumption is insignificant compared to the volumes abstracted for irrigation – both respectively account for less than 0.5% of mean annual runoff and about 3% of mean dry season inflow to the wetland.

Hydropower requirements at Mtera and Kidatu are about 4 100 $Mm^3$ per annum, or approximately 170% of the GRR MAR. The hydropower demand is met through significant input from other systems downstream of the RNP (Little Ruaha River, Kisigo River and Lukosi Rivers) and through storage in the Mtera Reservoir.

Gross geographic product (GGP) for the Usangu Catchment is estimated as United States Dollarss (USD) 100 million, although the sum is difficult to determine accurately as the majority of crops in the catchment (maize) is traded informally or grown for subsistence consumption. Irrigated agriculture in the Usangu Plains accounts for about USD 25 million and livestock for about USD 6 million per annum.

Water productivity is highest for livestock, manufacturing (brick making) and domestic uses, averaging at around USD 1 per $m^3$ of water consumed. Productivity of water in irrigated agriculture, and in particular irrigated paddy, is relatively low (USD 0.02 per $m^3$ of water abstracted). However, irrigated agriculture in general and paddy rice production in particular plays a very important role in the livelihoods of local people and the national economy, and reflects Tanzanian national economic and political objectives (development and poverty reduction strategy and policy).

Irrigated paddy in the Usangu Plains supports about 30 000 agrarian families and rice production is one of the key determinants of wealth in the Usangu Catchment. Hydropower production at Mtera-Kidatu generated the greatest annual net benefits, at about USD 230 Million.

Accordingly, a number of drivers for land and water use in the Usangu Catchment are apparent. Agriculture, be it subsistence or commercial, irrigated or dry-land, is a major employer and primary source of household income in much of the catchment. Tanzania remains largely an agrarian economy and government policy on economic growth and the country poverty reduction strategy highlight agriculture, and irrigated agriculture in particular, as a focus area for development.

Tanzania aims to significantly expand irrigated agriculture, doubling the area under irrigation, with the Ruaha-Rufiji and Pangani Basins in particular earmarked for this expansion. This drive, coupled with global food shortages and escalating food prices (particularly rice), clearly shows that population pressures on the scarce land and water resources of the Usangu catchment are going to increase. Whilst Tanzania has some progressive natural resource management and conservation policy and legislation, it is evident that solutions to the low flows problems in the RNP cannot come at the expense of agricultural productivity or livelihood activities in the Usangu catchment, as this would be inconsistent with the key development drivers in Tanzania (and the Usangu) today.

### 2.3.2. Hydrology

Most rainfall in the Usangu Catchment occurs in the highlands and flows via a number of rivers into the Usangu Plains and the wetlands. Run-off reflects the markedly seasonal nature of rainfall and most of the flow in the GRR occurs over 5 months from December to May (Figure 3).

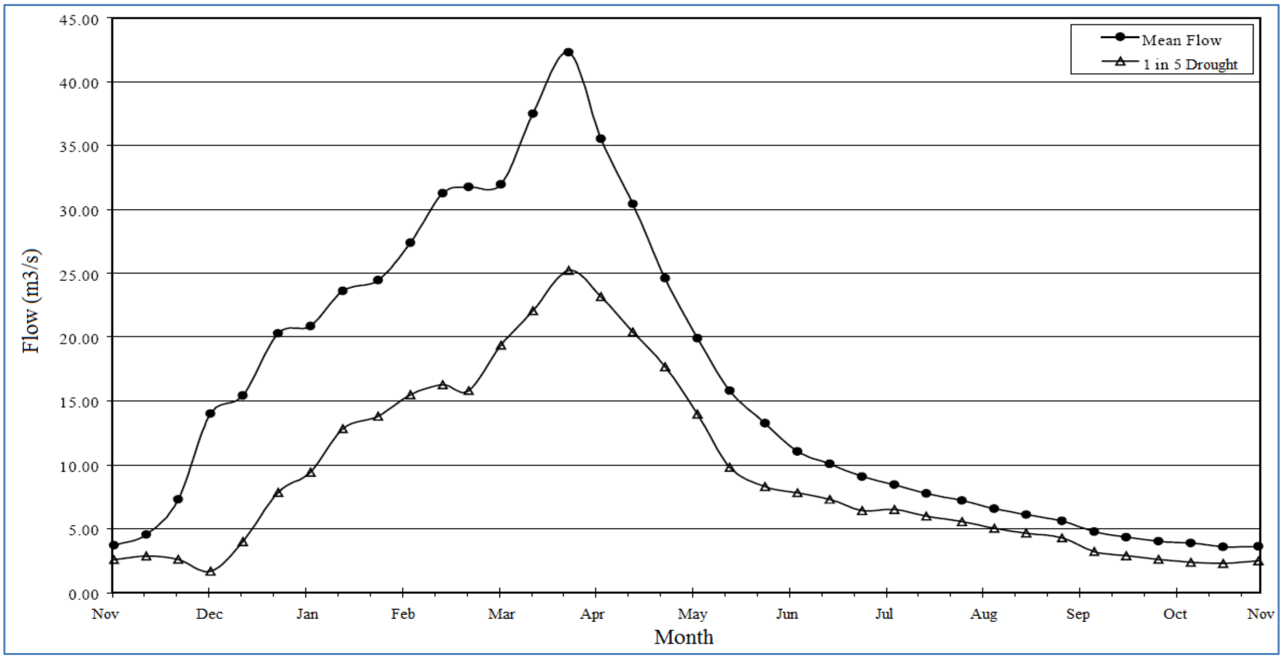


**Figure 3: GRR hydrograph of average year and 1 in 5 drought year at Msembe (modified from SMUWC 2001)**

Dry season flows are small and add little to MAR (Figure 4; Figure 5).

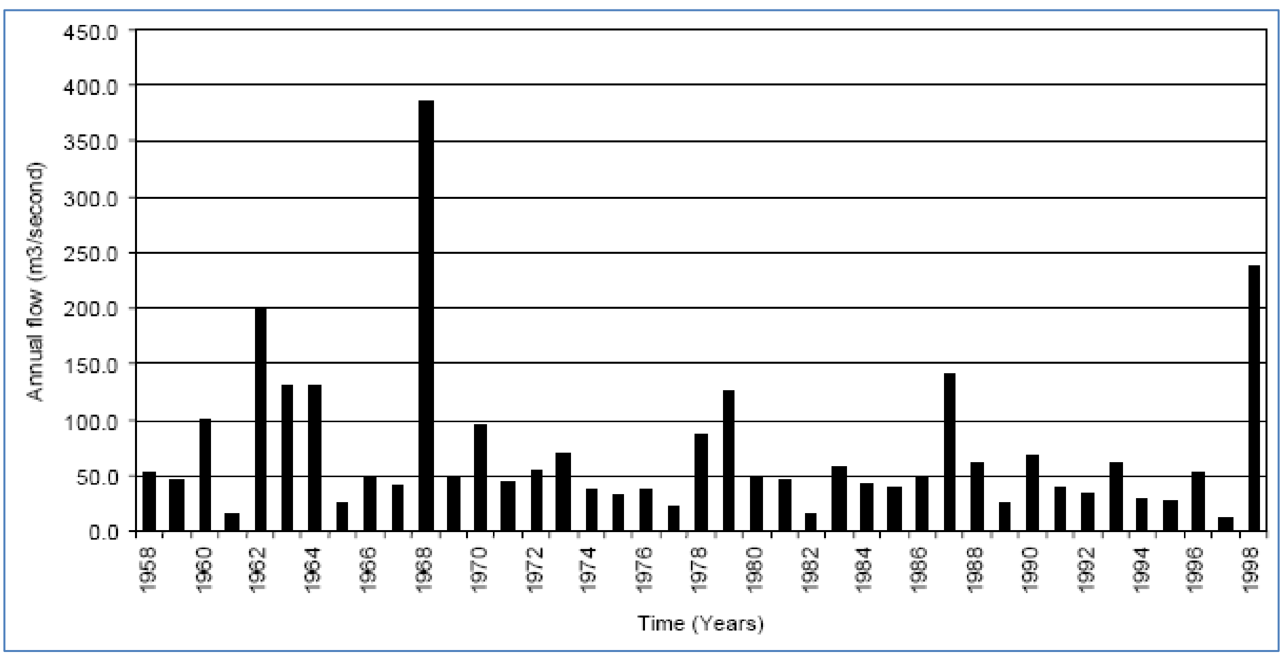


**Figure 4: Average annual flow in the GRR at Msembe (Source SMUWC 2001)**

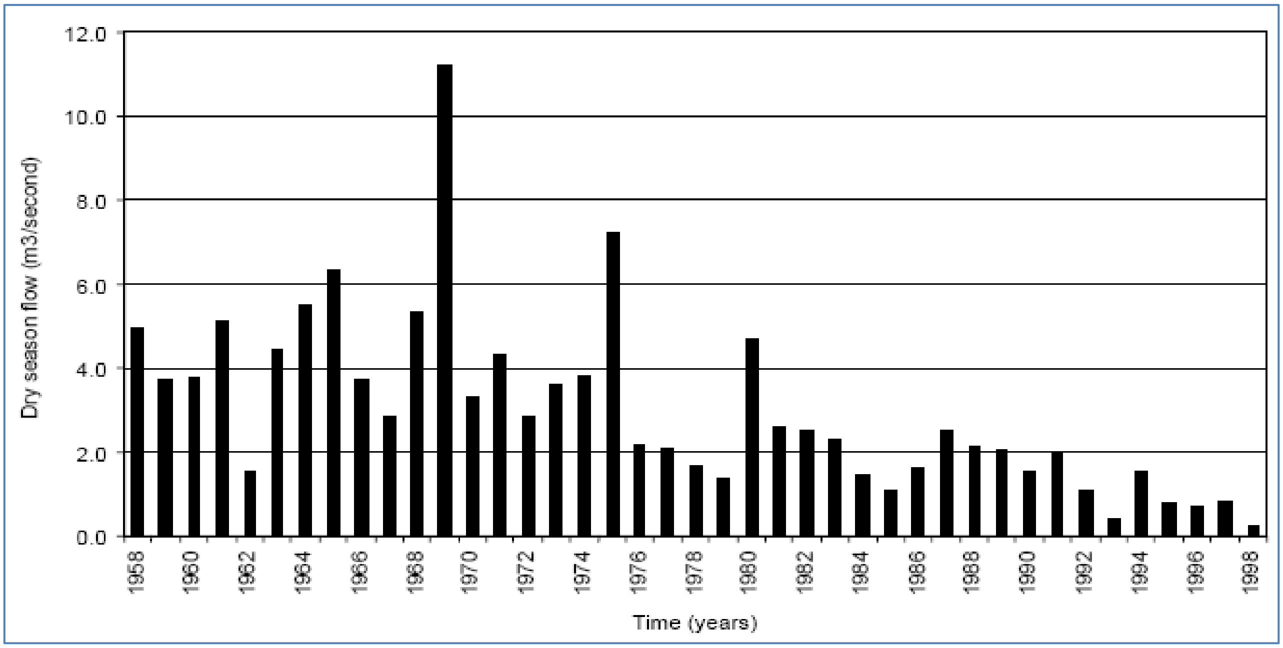


**Figure 5: Average dry season flow (1 July – 30 November) in the GRR at Msembe (Source SMUWC 2001)**

Given the distribution of rainfall within the Usangu catchment, flow within the GRR is substantially dependent on water transfers within the system, i.e. transfer from the highlands to the lowlands; within the lowlands from the western to the eastern wetlands; and from the eastern wetland across the sill at Ng'iriama into the GRR. As a result, three main hydrological components to the system can be described, i.e. the highlands; the fans and western wetland within the lowlands; and the eastern wetland within the lowlands.

All significant rivers rise in the highlands and flow into the Usangu plain. Only five large rivers are recorded as being perennial: Tthe Chimala, the GRR, the Kimani, the Mbarali, and the Ndembera Rivers. The first four account for 70% of measured average annual flow, while the Ndembera River accounts for an additional 15%. Several other smaller rivers, especially in the south-west, are known to be perennial at least to the main Iringa-Mbeya road.

Almost all inflow to the central plain is into the western plain and western wetland. The main inflow to the eastern wetland is from the western wetland through the constriction at Nyaluhanga. The only other significant river flowing directly into the eastern wetland is the Ndembera River.

The seasonal wetlands play a critical role in moderating downstream flow, reducing spate flows and prolonging flow past the end of the rainy season. The western wetland receives the majority of run-off from the highlands. Flow from the western wetland to the eastern wetland is via the channel at Nyaluhanga. Flow from the highlands rapidly fills the channel in the western wetland and spills over to inundate the seasonal floodplain. Much of this water on the western wetland floodplain is lost to evapotranspiration, and is therefore not transported to the eastern wetland. Within the eastern wetland the water again spreads out over the plain, involving further evaporative losses, before flowing into the permanent swamp. During the dry season, Ihefu has been described as consisting of a series of pools connected through discrete flow paths within the dense swamp vegetation. Formerly, the permanent swamp behaved like a single, large water body, but changes in swamp hydrology and morphology have resulted in ponding of water within a series of smaller reservoirs.

As inflows increase in the wet season, so the swamp fills and spills over the eastern wetland and over the rock bar at Ng'iriama, thus providing the GRR downstream. As inflows decline in the dry season, the combination of flows over the bar at Ng'iriama and evapotranspiration from the swamp surface empty the swamp to a water level where overflow over the rock bar ceases, and the GRR downstream dries up. Further losses from evapotranspiration result in further declines in the swamp water level. Flow downstream will not start again until the swamp refills to above the level of the rock bar.

Groundwater is largely an unknown component of the Usangu Catchment hydrological system, although a groundwater study was commissioned as part of the SMUWC project. Broadly, the highlands are extensive recharge zones into shallow, perches aquifers in the sandy soils and into fissures and fractures within the granitic base-rock. Dry season flow in the highland rivers is entirely maintained by groundwater discharge from these aquifers. The alluvial fans are a further important zone for groundwater recharge, and extensive aquifers are anticipated within the alluvial soils of the plains. While the movement and role of groundwater within the central plain is unknown, there is no evidence of extensive groundwater discharge out of the Usangu catchment, although some groundwater transport across the catchment boundaries in fractures and fissures within the crystalline basement rock is possible. Therefore, it is reasonable to assume that most groundwater must flow into the central plain and be contained there, where it may be lost to evapotranspiration (deep rooting trees) or contribute to base-flow in the water balance of the seasonal wetland and perennial swamp.

### Changes in low flow

The Usangu Catchment has seen many changes over the past half-century. These changes are almost exclusively related to population increase associated with exploitation of natural resources and major land use changes.

The changes in human population and land-use have had a marked effect on the environment. Most of the southern alluvial fans have been cleared of the original vegetation, and are now occupied by cultivation or by secondary-growth bushland. Cultivation is also pushing onto the wetland and the floodplain is now largely occupied by cattle, with much of the wildlife lost. The plains show signs of progressive degradation, with the encroachment of woody species and changes to grass communities noted. Degradation is particularly severe on the southern alluvial fans. The expansion of cultivation has taken traditional grazing areas, forcing livestock onto marginal lands and resulting in conflict between pastoralists and farmers.

In the highlands, changes have been less dramatic. Work undertaken in 2000 suggested that the highlands are largely in good state. However, significant changes in land-use over the past decade appear to be having marked impacts on the highlands, with anecdotal evidence suggesting that degradation of the highlands is progressing rapidly. Ever-increasing areas have been (and are being) converted to cultivation and settlement, erosion on steep slopes is advanced in places, and the woodland is been exploited for the important timber species. Degradation of the highlands poses a significant threat to the highlands themselves and the livelihoods that depend on the highland resource, and to the Plains as runoff changes (reduced dry season runoff) and sedimentation progresses.

This complex set of impacts and changes underpins arguably the most significant change within the Usangu Catchment, namely the cessation of dry-season flow into the RNP. While late dry season flow at Ng'iriama has stopped every year since 1993 (Table 6), the phenomenon of declining dry-season flows within the Usangu Catchment started around the mid-1970s.

**Table 6: Periods of zero flow in the GRR from 1994 to 2004 (source: Sue Stohlberger, modified from RIPARWIN 2005)**

| **Year** | **Period of no flow** | | **Number of no-flow days** |
|---|---|---|---|
| | **start** | **end** | |
| 1994 | 17-Nov | 15-Dec | 28 |
| 1995 | 19-Oct | 23-Dec | 65 |
| 1996 | 17-Oct | 16-Dec | 60 |
| 1997 | 20-Sep | 22-Nov | 63 |
| 1998 | 18-Nov | 09-Mar | 111 |
| 1999 | 21-Sep | 20-Dec | 90 |
| 2000 | 17-Sep | 22-Nov | 66 |
| 2001 | 12-Nov | 23-Dec | 41 |
| 2002 | 02-Nov | 24-Dec | 52 |
| 2003 | 21-Sep | 16-Jan | 117 |
| 2004 | 03-Nov | 04-Dec | 31 |

Whilst this change is insignificant from a MAR perspective, it has had some very important consequences for the RNP, impacting the natural habitat and the economics of the park.

A further layer of complexity is introduced by potential climate change impacts on the hydrology of the Usangu system. While it is currently unclear what the impacts of a future climate are going to be, we know from studies in other parts of Southern Africa that such impacts can have significant consequences on the nature and volume of run-off.

There appears to be emerging consensus that climate change over the coming 20 to 50 years will result in increased mean annual temperature. Early climate modelling suggests that this will result in reduced rainfall in central and coastal Tanzania, with a greater number of high-intensity rainfall events. The result of such a scenario would be reduced mean annual run-off, with increased stormflow suggesting that dry spells will be prolonged during the rainy season.

Increased temperature would also result in increased crop water demand, owing to increased evapotranspiration. The implication of this scenario for low flows in the GRR is dire – increased irrigation demand in both the dry and wet season coupled with reduced run-off will result in severe stress being placed on the water resources of the Usangu catchment. While these conclusions are very preliminary and should be interpreted with caution, the significance lies in the potential impact that a changing climate will have on future flows and the need for planning that takes into account the “worst case” climate scenarios.

Finally, there are some important institutional changes within the catchment that have direct relevance to the hydrology of the GRR. Reforms in local government have placed more responsibility on local people for water management, although the resources and capacity to assume these responsibilities is often lacking. Water user associations have been established and play an important role in regulating water use in the irrigation area, through management of diversions (programme requiring mandatory reduction / cessation of irrigation off-takes was initiated in 2001 – closure typically takes place on 1st August).

Improved water resources management is envisaged under the revised water policy, which introduces various institutional mechanisms for water resources management, such as water pricing, licencing and self-regulation. With respect to the wetland, the gazettment of the Usangu Game Reserve has excluded livestock and fishermen from the Usangu wetland.

## Causes of dry-season flow cessation

In detailed studies of the causes of dry-season flow cessation in the GRR, the SMUWC (2001) report, RIPARWIN (2005) report and IWMI research report (2005) highlight a few significant findings related to the hydrology of the highlands, the Usangu Plains and the Usangu Wetland:

- No evidence of declining rainfall or shifting rainfall patterns in the highlands was found in the rainfall data, contrary to anecdotal evidence;

- No evidence of declining river flows entering the plains was found in the historic run-off data – this finding is supported by land-use and land cover in the highlands that has not changed significantly over the past decades;
- No long-term decline in average annual or wet season flows in the GRR in the RNP is noted;
- A delay in the start and a flattening of the peak of flood flows in the RHP is evident;
- Flooding on the western wetland is very limited and infrequent – hydrological changes on the western wetland are so dramatic that the area is no longer considered wetland (vegetation is not reflective of wetland / floodplain);
- There is clear evidence that water entering the Usangu Plains is being diverted in large amounts into irrigation schemes;
- Dry season inflows to the eastern wetland are markedly reduced;
- Rainfall over the Usangu Plains shows a decreasing trend in recent times;
- The area of the ihefu swamp has decreased, resulting in decreasing storage in the swamp and reduced dry-season outflow; and
- Channel changes are evident within the eastern wetland, with channels previously clear now blocked, which may be hindering water passage through the swamp, resulting in ponding.

Given the significance of the reduced flows in the GRR, various causes of the flow cessation have been put forward over time. Many studies have been undertaken on the catchment to test these theories. Emerging consensus suggests that while the Usangu Catchment is a complex system and a number of changes are collectively resulting in the observed dry season flow cessation, the most dominant cause appears to be water abstraction and use for irrigated agriculture in the fans. An important secondary cause may be the clogging of channels in the ihefu swamp, resulting in ponding and increased loss of water through evapotranspiration.

These impacts are most significant during the dry season, when flow from the highlands reduces and the impact of irrigation abstraction is much more significant. While about 35% of wet season flow is abstracted for irrigation, up to 100% of inflows at Nyaluhanga are being diverted to irrigation during the dry season (Figure 6).

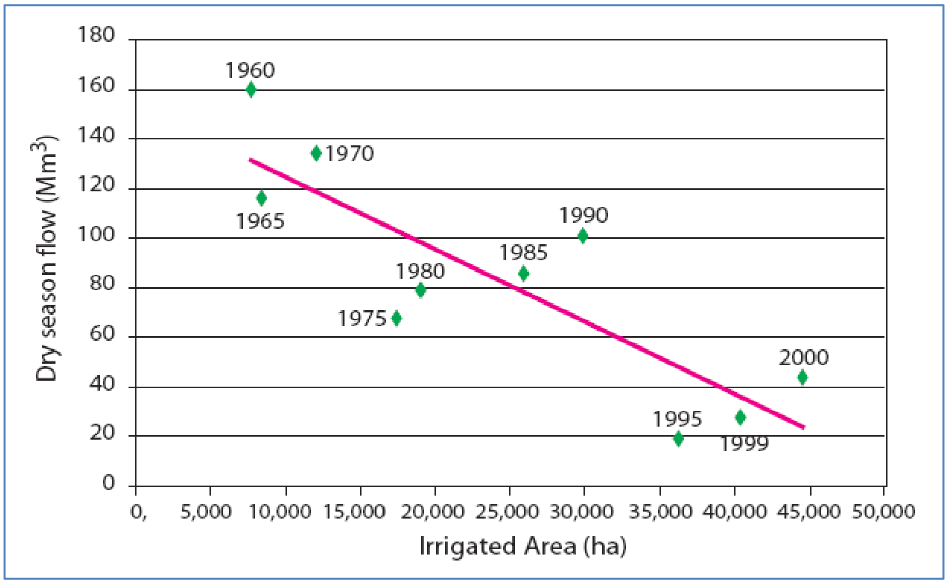


**Figure 6: Correlation between dry season flow at Msembe and irrigated area, showing linkage between reduction in low flows and irrigation abstraction (Source: IWMI Reseach Report)**

The most significant dry season abstractions are for rice irrigation. Although there is no dry season rice production, the 'wet season' rice production has extended greatly, starting earlier in the season and extending to later in the season. This expansion of the rice season has been facilitated by irrigation improvements and infrastructure. While estimated water use efficiency in the wet season is high (SMUWC calculated 75% efficiency, although other reports frequently cite 15%), efficiencies during the dry season are very low indeed (SMUWC calculated 20% efficiency).

A further area of dry season water loss from the system is through wastage. Much water is wasted in the irrigation systems. Even where there is no dry season irrigation, water continues to be abstracted throughout the dry season and dispersed onto field, and lost through evapotranspiration, seepage and conveyance losses. SMUWC estimated that 50% of water abstracted for rice irrigation during the dry season could be left in the river without negatively affecting production (Table 7, Table 8).

**Table 7: Dry season excess abstraction on various irrigation systems in the Usangu Plains (Source: SMUWC 2001)**

| **Irrigation system** | **Estimated gross demand** | **Current abstraction** | **Excess use over requirements** |
|---|---|---|---|
| | **cumec ($m^3$/ sec)** | | |
| Mbarali (farm offtake) | 0.350 | 2.000 — 4.000 | 1.650 — 3.650 |
| Kimani river (various offtakes) | 0.040 — 0.050 | 0.200 — 0.500 | 0.150 — 0.350 |
| Hassan Mulla (Mbarali river) | 0.110 | 0.150 — 0.200 | 0.040 — 0.090 |
| Kapunga (Ruaha river) | 0.200 – 0.300 | 0.600 — 1.200 | 0.300 — 0.900 |
| **Total excess use** | | | **2.140 — 5.000** |

**Table 8: Estimated average discharges to Ihefu due to savings from canal closures (Source: RIPARWIN, 2005)**

| | **Average discharges to Ihefu ($m^3$ / sec)** | | | | | |
|---|---|---|---|---|---|---|
| | **June** | **July** | **Aug** | **Sep** | **Oct** | **Nov** |
| Kimani | 1.700 | 1.100 | 0.710 | 0.600 | 0.500 | 0.100 |
| Mbarali | 4.300 | 4.100 | 3.500 | 2.000 | 1.000 | 0.700 |
| Ndembera | 1.500 | 1.000 | 0.700 | 0.500 | 0.400 | 0.300 |
| GRR | 1.500 | 1.500 | 0.150 | 0.100 | 0.100 | 0.100 |
| **Total** | **7.650** | **6.350** | **5.060** | **3.200** | **2.000** | **1.200** |

# 3. The Building Block Methodology

The BBM is ideally suited for assessing flows for rivers in which there is no single species (such as salmon or trout) of overriding importance – in other words systems in which the aim is to ensure a healthy, functioning ecosystem. The methodology is designed to identify a series of important flows (the building blocks) which will together provide the essential aspects of the natural hydrological regime that ensure the persistence of as much of the biodiversity as possible. A variety of different flows provides the mosaic of habitats in time and space that allow all of the species native to the system to persist. This is quite different from the concept of a “minimum flow” which many people still associate with environmental flows.

The building blocks identified in the BBM will normally be:

- Low flows for the dry season
- Low flows for the wet season
- Elevated flows and floods for the dry season
- Elevated flows and/or floods for the dry season
- The above flows are further differentiated for drought years and for maintenance years. Maintenance years are those years when average to high rainfall would provide flow conditions under which all ecological processes and functions would be operating.

For specific rivers, other building blocks could be identified, e.g. monsoonal areas that have long and short rains, and therefore two wet seasons per year.

The process for the BBM assessment of environmental flows is a series of steps. These are described in detail in the BBM manual (see references) and are summarised in Figure 7.

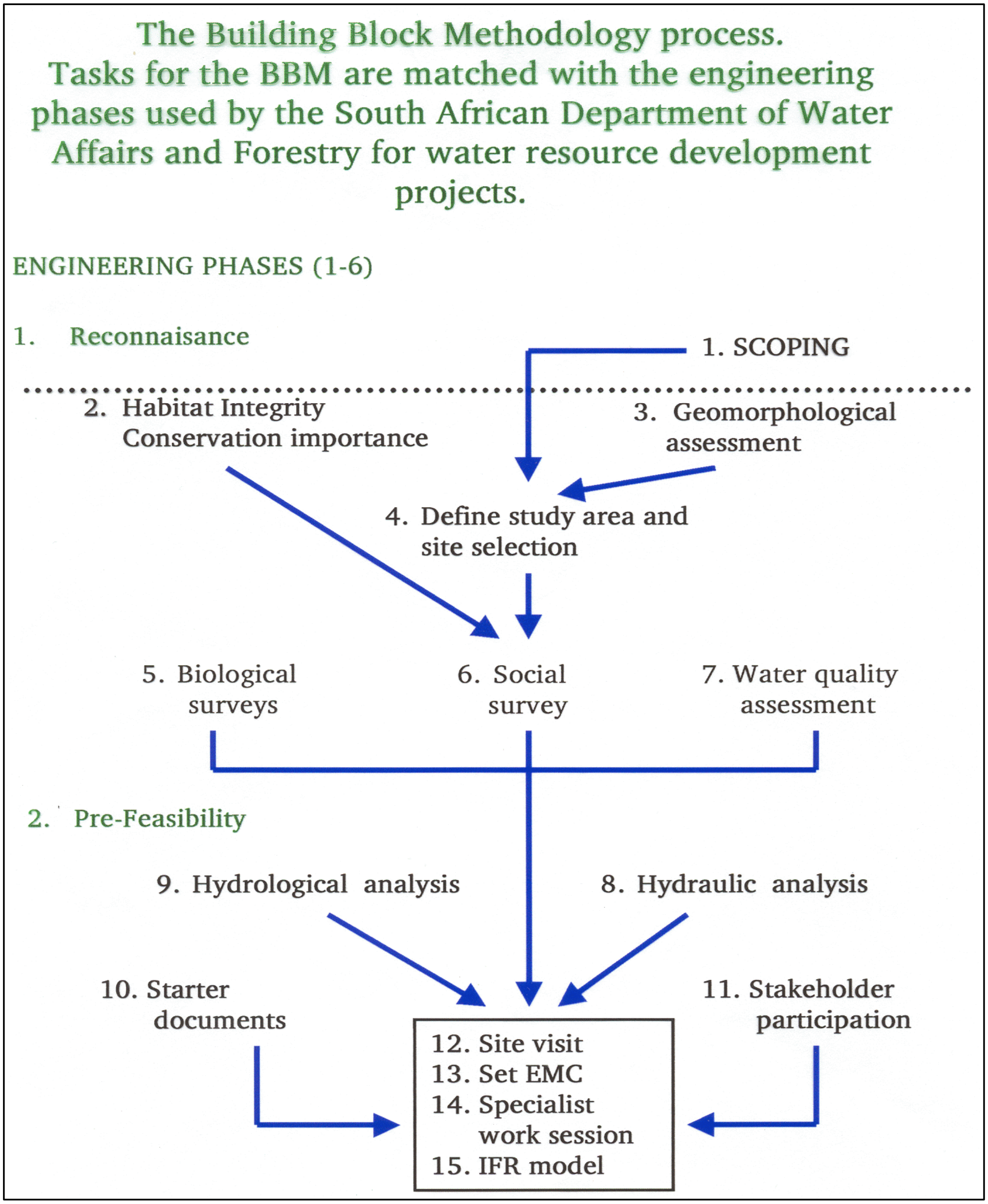


**Figure 7: Initial steps in the BBM process**

N.B. Figure 7 only illustrates the process up to and including the initial assessment of flows necessary to maintain or achieve a predetermined environmental state. The process for examining the availability of flows, and the sources for implementation follows on from Step 14, the specialist work-session.

# 4. Environmental Flow Analysis of the Great Ruaha River

## *4.1. The study area*

The GRR arises in the highlands of the Usangu catchment, located in the rift valley in south-west Tanzania. Water drains off the highlands into the Usangu Plains and is collected within a wetland system, the Usangu Wetland. This wetland empties at the north-eastern extreme of the catchment into the GRR, which flows through the RNP to the Mtera reservoir and power plants at Mtera and Kidatu, before joining the Rufiji River and emptying into the Indian Ocean. Figure 1 shows the wider catchment area whilst Figure 8 specifically shows the location of the GRR and the BBM stations.

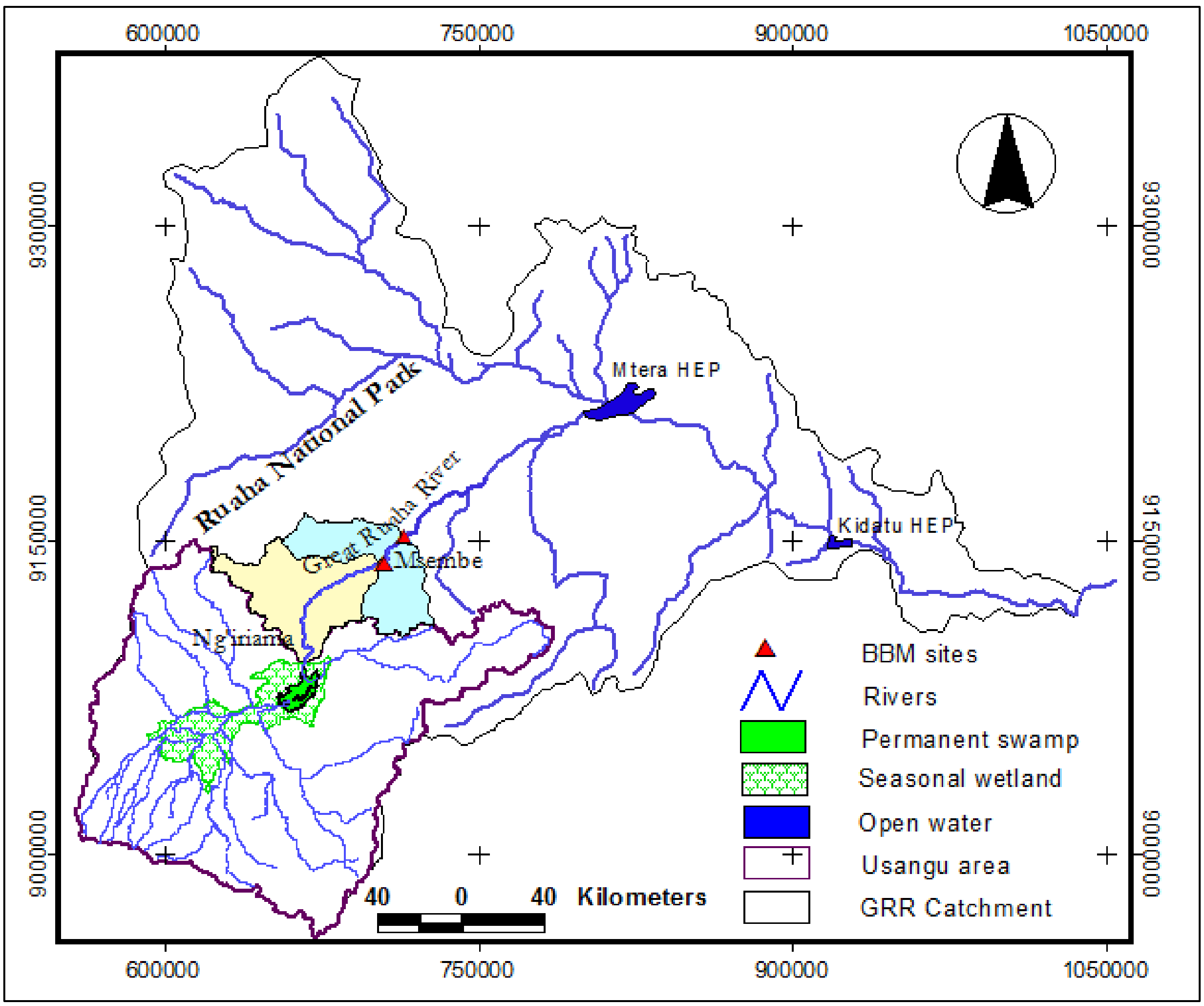


**Figure 8: The GRR Catchment and the location of BBM stations**

The focus area for this EFA study is the stretch of river which flows between Ng'iriama and the Mtera Dam.

The GRR is of significant national interest and bears a high national profile, principally owing to concerns about water availability. Water shortages at Mtera have led to national power shortages, prompting high-level policy decisions on the management of Usangu Catchment. Dry season flows into the RNP have ceased every year since 1993, with significant environmental and economic consequences for the Park. These and other issues regarding flows within the GRR led to the pronouncement in 2002 by the then Prime Minister that the GRR must have “year-round flows by 2010”.

The status of the river underpins the functioning of the entire ecosystem of the RNP, especially during the dry season, in order to avoid congregations of animals, and subsequent stress on animal populations and their habitat, with consequent loss of riparian vegetation and channel structure.

## *4.2. Objectives*

### 4.2.1. Catchment context

The focus of the river component of the EFA study was the section of the GRR between the wetland outlet at Ng’iriama and the inlet to Mtera Dam, 211 km downstream. This section of river is referred to throughout this document as the middle GRR (MGRR). The reason for focussing the study on the MGRR was that this is the section of the river in which the low season flows have ceased since 1993, because of abstractions and catchment modifications upstream.

Although this part of the study is restricted to the MGRR, the results must be seen within the framework of the catchment as a whole, and particularly the catchment upstream of the wetlands. Other parts of this study comprised an EFA of the Eastern wetlands, and an intensive review and analysis of the different options for restoring flows into the MGRR, and the consequences for the wetlands and upstream water use.

This initial EFA therefore aims to predict the flows necessary to maintain or restore riverine conditions in the MGRR in the RNP, so that the water resource management of the upper catchment can take these requirements into account. In any integrated water resource management (IWRM) plan, the first step is to define the management objectives, and the water required to achieve them. The following section defines the overall objective (vision) for the MGRR, and is followed by specific objectives and indicators for a variety of components of the ecosystem: fish, invertebrates, riparian vegetation, and geomorphology.

### 4.2.2. Overall objectives

This section of the GRR flows through a national park, with a high diversity of large mammals, and a thriving and potentially growing tourist industry, which earns much-needed foreign currency for Tanzania. The GRR is the only water source in the park which, in natural conditions, flows constantly. Flows in the river are therefore the major driver of conditions in the park, for the following reasons:

- The riparian and floodplain vegetation, which depends on the flows and water levels in the river, are the critical habitat for the large mammal populations during the dry season. A range of low-flows and floods is necessary to maintain root moisture, growth, seed dispersion/germination, and seedling establishment.
- The riparian vegetation plays a critical role in stabilising the river banks, particularly during floods. If the riparian vegetation disappears, bank and riverbed erosion will result in the destruction of characteristic channel forms and habitats, typically with excessive sedimentation of the channel – a condition which cannot be rehabilitated in less than decades or centuries.
- The loss of low flows during the dry season results in a series of disconnected, isolated pools (at approx. one per kilometre, but concentrated in the upper middle section of the river). Hippos, crocodiles and fish are crowded into these refuge areas, resulting in anoxic polluted conditions, and aggressive interactions. Terrestrial mammals are also concentrated around the remaining water, resulting in local overgrazing, especially of riparian vegetation. This exacerbates the effects of vegetation loss and erosion described above.
- The concentration of game – both terrestrial and aquatic, increases aggression and the incidence of parasites and disease (e.g. anthrax outbreak in 2003).

The above sequence shows the interrelated consequences of extended periods of low-flows in the MGRR. At present it appears that the riverine ecosystem is still in the early stages of this sequence, with the possibility of halting or even reversing the progression of degradation if flows can be restored. In the short-term, even a restoration of a minimum continuous flow during the dry season will go a long way to halting the cycle of degradation.

If the present flow situation persists, particularly the increasing periods of no-flow during the dry season, then the major changes in the riparian and channel zones, and the lack of open water areas, will result in the loss of much of the riverine biodiversity, the breakdown of the channel morphology, the loss of dry season refuge feeding areas for terrestrial animals, and increased social disruption and disease. Ultimately, unless the functions of the MGRR are conserved, the entire RNP will lose the biodiversity for which it was founded. The national and international heritage value of the area will disappear, with the concurrent loss of tourist revenues.

The overall objective (vision) of the MGRR EFA is therefore:

Acknowledging the flow changes which have and are occurring in the middle Ruaha: “To recommend a modified flow regime which will maintain the biodiversity, processes and functions of the RNP, and will reverse the trajectory of degradation which the present flow regime is responsible for”.

### 4.2.3. Specialist objectives at BBM1

Each specialist makes a determination of the current state of the river at the study site, expressed in terms of its present ecological state (PES), ecological importance and sensitivity (EIS), and ecological management class (EMC). This provides a snapshot of the condition of the river, and provides a starting point for the EFA whereby each specialist will describe what objectives (within the ambit of their expertise) need to be achieved at that site, that would indicate that year-round flows adequate for the mainainance of the health of the river have been achieved.

Whilst, in general, the specialist objectives were equally applicable to both BMM sites, the following specific objectives were determined.

#### Geomorphology

The present ecological state (PES) is classified as C: Moderately modified.

The trajectory of change is negative.

The ecological importance and sensitivity (EIS) is high.

The ecological management class (EMC) is C: Moderately modified.

***Objectives and motivations***

The general flow objectives are to maintain continuous low and high flows in Ihefu-Mtera segment of the GRR. Table 9 provides specific geomorphological objectives and motivations derived at BBM1.

**Table 9: Geomorphological objectives and motivations derived at BBM1**

| Objectives | Reasons/motivation |
|---|---|
| To maintain low flows for channel maintenance | To provide continuous flows in the pools to prevent them being obliterated by sandy deposition |
| Maintain wet season high flows. | To allow entrainment of gravels and movement of point bars thus reducing lateral erosion of the left bank and allowing channel to re-adjust to the previous condition |

***Target indicators***

Low flow quantitative level indicators: Water at the maximum depth of 0.5 m moves into thalweg in the left bank, flows are capable of remobilising the sand materials in pools.

High flow quantitative level indicators: Water at a depth of 3 m flows overbank, and is capable of inundating and remobilising sand bars.

## Riparian vegetation

The PES is classified as D: Greatly modified

The trajectory of change is negative

The EIS is high

The EMC is C

***Objectives and motivations***

The riparian vegetation community at BBM1 contains the lowest proportion of flow-sensitive plant species. There was a high diversity of plant species in the BBM1, but the diversity of flow-dependent species was poorer than the common terrestrial species, due to their being denied the required flows.

The general flow objectives are to maintain low flows in both the dry and wet season. Table 10 provides specific objectives and motivations for riparian vegetation derived at BBM1.

**Table 10: Specific objectives and motivations for riparian vegetation derived at BBM1**

| **Objectives** | **Reasons/ motivation** |
|---|---|
| To maintain low flows during the dry and wet seasons | Most of the flow-dependent riparian plant species can survive and perform with low flows. The sedges and hydrophilic grasses perform better in the channel low flows than in high flows. Low flows above $0.85m^3/s$ are sufficient for the performance of flow-dependent riparian plant species and the survival of trees and shrubs in the banks. |
| Maintain the duration of low flows | There is a direct link between the duration of flows and reproductive cycle of the plant species; flows must provide sufficient inundation for the performance of flow-dependent riparian vegetation. |
| Maintain low flows in the driest years | Low flows are required in the driest years to allow the permanent flow-dependent riparian plant species to survive and support aquatic life. The roots of plant species at the banks can still access water. |
| Maintain high flows in the wet season | High flows allow propagules (seeds) to germinate for community regeneration, and supply nutrients to the woody species at the bank and the fans. These flows also flush debris from the bank into the channel, to act as a food source for fish and invertebrates. |

***Target indicators***

The plant species for follow up purposes include those in specified in Table 11.

**Table 11: Target indicators for riparian vegetation at BBM1**

| Plant species | Conditions |
|---|---|
| *Leersia hexandra* | Both fast and slow |
| *Pennisetum purpreum* | Slow high low flows |
| *A.albida, T. indica, C.apiculata* and *Diospyros fischeri* | Slow high flow and flooding once a year |

## Fish and invertebrates

The PES is classified as: B: slightly modified.

The trajectory of change is negative.

The EIS is very high.

The EMC is A/B.

***Objectives and motivations for fish***

Fish communities should include a large proportion of flow-sensitive taxa including *Chiloglanis deckenii* and *Amphilius uranoscorpus*. Fish species diversity should = H' < 2 i.e. even distribution of individuals among species. Table 12 provides details of specific objectives and motivations for fish, derived at BBM1.

**Table 12: Specific objectives and motivations derived at BBM1for fish**

| Objective | Motivation |
|---|---|
| Maintain the low flow requirements during the driest month of a drought year. | • inundate an appreciable area of the critical habitats (e.g. riffles) to sustain flow-sensitive species of fish such as *Chiloglanis deckenii* |
| Maintain the low flow requirements during the wettest month of a drought year. | • inundate more riffle sections to increase habitat diversity<br>• inundate a greater area of the channel to permit fish passage over obstacles. |
| Maintain the low flow requirements during the driest month of a maintenance year. | • inundate more habitats to provide natural variability to maintain diverse fish species assemblage<br>• maintain active channel flows to inundate benches and sustain emergent vegetation<br>• permit more fish passage over obstacles<br>• Inundate pools to improve water quality (DO, temperature, etc). |
| Maintain the low flow requirements during the wettest month of a maintenance year. | • provide cue for migration in spawning migrant fishes such as *Labeo*.<br>• inundate macrophytes and emergent vegetation along banks to provide more habitats (shelter, feeding) for fishes especially juvenile stages |
| Maintain small pulses of higher flow that occur in the drier months. | • prevent sediment build-up on river bed, thus increasing habitat variability for fish and invertebrates<br>• flush out organic matter, thus improving water quality for |

| | |
|---|---|
| | fish<br>• facilitate nutrient transfer between floodplains and the river. This will increase primary productivity and food for fishes. |
| Maintain major peaks in the river's flow level that occur at a given recurrence interval. | • maintain macro channel features and provide diversity of physical habitats for fish<br>• scour and flush bed of sediment deposits to expose riffles which were clogged with sediments<br>• Cue for spawning migrant fishes such as *Labeo* to start upstream spawning migration.<br>• inundate and recharge larger higher banks, allowing for nutrient transfer into the main river channel (increase primary productivity).<br>• inundate higher bank vegetation to provide more habitat (shelter, feeding, breeding) for fishes. |

***Target indicators for fish***

The following will be used as indicators, with the objective of maintaining abundances comparable to reference conditions:

Target species: *Chiloglanis deckenii* and *Amphilius uranoscorpus* (riffles guild)

*Brycinus, Synodontis, Barbus* (pool guild)

*Labeo, Citharinus, Alestes, Hydrocynus* (Lotic guild)

***Objectives and motivations for invertebrates***

A SASS4 score = >100 and Average score per taxon (ASPT) score >6 should be maintained.

The invertebrate community should include a large proportion of sensitive taxa such as *Perlidae*, *Oligoneuridae, Leprophlebiidae, Baetidae, Caenidae, and Elmidae,* with lower relative abundances of *Chironimidae* and *Oligochaeta*. Community diversity should = H' >2 i.e. an even distribution of individuals amongst species, reflected by a low gradient rank-abundance curve. Table 13 provides details of specific objectives and motivations for invertebrates derived at BBM1.

**Table 13: Specific objectives and motivations for invertebrates derived at BBM1**

| Objective | Motivation |
|---|---|
| Maintain the low flow requirements during the driest month of a drought year | • to inundate appreciable area of the critical habitats (e.g. riffles) to sustain flow-sensitive species of macroinvertebrates such as stoneflies (*Perlidae*) and mayflies (*Oligoneuridae* and *Leprophlebiidae*) which were collected from BBM 1 |
| Maintain a major flood at the beginning of the wet season i.e. March/April, and several more | • The first major flood resets the river to the wet season conditions, flushing away fine sediments and pollution tolerant species such as *oligochaetes* and *Chironomidae*. Subsequent |

| | |
|---|---|
| during the wet season | floods sort and rework sediments maintaining physical heterogeneity of the channel |
| Maintain small pulses/freshes of higher flow that occur in the drier months | • Enhance downstream drift of animals and flush out areas of poor quality water accumulated during dry season lowflow |
| Mimic natural pattern of average monthly flows | • Different species are adapted to react to different flow cues for life history stages. |

***Target indicators for invertebrates***

The following target taxa will be used as indicators with the objective of maintaining abundances comparable to reference conditions: *Perlidae, Oligoneuridae,* and *Leprophlebiidae*: (riffles)

### 4.2.4. Specialist objectives at BBM2

### Geomorphology

The PES is D: largely modified.

The trajectory of change is negative (deteriorating).

The EIS is high.

The EMC is C (Moderately modified).

***Objectives and motivations***

The general objective is to maintain continuous low and high flows in Ihefu-Mtera Segment of the GRR. Table 14 provides details of the specific geomorphological objectives and motivations derived at BBM2.

**Table 14: Specific geomorphological objectives and motivations derived at BBM2**

| Objectives | Reasons |
|---|---|
| To maintain maintenance low flows | To maintain the braided channel characteristics.<br>Continuous flows will prevent sand filling micro channels, therefore maintaining the surface flow. |
| Maintain maintenance high flows | Remobilisation and translocation of sand bars therefore preventing continuous gradation of channel.<br>Channel incision will prevent excessive bank erosion.<br>Supply of suspended sediments and deposition in flood plains thus replenishing overbank deposition.<br>Entrainment of gravels that are the source of accumulation of sand bars that clog and aggrade the channel. |

Channel adjustment depends on the sediments supplied, where a change of cobble to gravel transforms the channel from straight to a braiding and anostomising channel, increasing aggradations of the channel.

Continuous aggradations reduce the channel depth, but increase the channel with due to lateral erosion and slumping.

***Target indicators***

Low flow quantitative level indicators: Water at the maximum depth of 0.5 m moves into braided channels and remobilises the sand materials in the channel.

High flow quantitative level indicators: Water in the channel at the a average depth of depth of 3 m and average velocity of 2 m will move sand bars in the channel with about half depth of flows.

## Riparian vegetation

The PES is classified as C: Moderately modified.

The trajectory of change is negative (deteriorating).

The EIS is high

The EMC is C

***Objectives and motivations***

The general flow objectives are to maintain continuous low flows in both dry and the wet season. The specific objectives and motivations for riparian vegetation derived at BBM2 are detailed inTable 15.

**Table 15: Specific objectives and motivations for riparian vegetation derived at BBM2**

| **Objectives** | **Reasons/ motivation** |
|---|---|
| Maintenance of low flows during the dry and wet seasons in a maintenance year | Most of the riparian plant species are adapted to low flows rather than high flows. The sedges and hydrophilic grasses perform better in the channel in low flows than in high flows. At these flows, the woody species and shrubs are likely to get water for survival since the roots of the bank species are likely to be inundated in water. |
| Maintain duration of low flows | There is a direct link between the duration of flows and the reproductive lifecycles of most of the flow dependent riparian plant species, which have been modified to be completed within a certain period. |
| Maintain high flows of about 757$m^3$/s in the wet season | High flows allow propagules to regenerate, and supply nutrients to the woody species at the bank |

| | |
|---|---|
| | High flows of 757m$^3$/s are needed to inundate the bank surface and fans, allowing the expansion of riparian habitats beyond to the bank and the recently created fans. The riparian vegetation in the banks and the fans will be provided with nutrients to perform and expand their communities beyond the banks. This will be achieved through regeneration of woody species from propagules (seeds) in the banks and the fans where they can get sufficient moisture and nutrients to germinate and grow sufficiently. The floods need to occur once every five years and will provide sufficient favourable conditions for the performance of woody species in the river. |
| Maintain low flows in the driest year | This flow should allow the flow sensitive riparian plant species, includin *Leersia hexandra, Schoenoplectus corymbosus, Phragmites mauritianum, A.albida, T. indica,* and *C.apiculata*, to survive and support the aquatic life |

The riparian vegetation community in BBM 2 contains a large proportion of plant species sensitive to flows. The diversity of the flow dependent species was higher than that of the common terrestrial species.

***Target indicators***

The plant species detailed in Table 16 will be used as indicators for the purpose of maintaining abundance compared to the current conditions, particularly the changes in flow regime when minimum flows are available in both the driest years and the wettest years.

**Table 16: Riparian vegetation target indicator species**

| **Plant species** | **Conditions** |
|---|---|
| *Leersia hexandra* | Both fast and slow |
| *Schoenoplectus corymbosus* | Slow flows |
| *Phragmites mauritianum* | Slow flows |
| *A.albida, T. indica, C.apiculata, Diospyros fischeri* | Slow high flow and flooding once a year |

## Fish and invertebrates

The PES is classified as A/B: Pristine to slightly modified, evidenced by the following:

- A good number of the fish species reported to be resident in GRR were caught at this site (18 out of 57).
- Two (*Oreochromis urolepis* and *Hydrocynus tanzaniae*) of the five endemic species of GRR were caught at this site.

The trajectory of change is slightly negative, evidenced by:

- A good number of the fish species reported to be resident in GRR are still present (18 out of 57).
- Baseline information (estimates of fish abundance, biomass or catch per unit effort) for the component is lacking and therefore difficult to indicate, with certainty, the direction of change under the present river management regime. A negative value is given to indicate that the component is possibly slightly changed from natural conditions.

The EIS is very high, due to the following factors:

- *Oreochromis urolepis*, Hydrocynus tanzaniae*, Labeo ulangensis, Alestes stuhlmanni, Distichodus rufijiensis,* and *Citharinus congicus* are endemic to the GRR basin, hence there is a strong motivation for maintaining or improving the present river management regime.
- *Oreochromis urolepis* has a peculiar sex determination (monosex) trait.
- The site is within in a conservation area (RNP)

The EMC is set at A/B, Pristine to slightly modified, (the same level as the PES) in order to maintain the present good conditions.

***Objectives and motivations for fish***

Table 17 details the specific objectives and associated motivations for fish species at BBM2

**Table 17: Specific objectives and associated motivations for fish species at BBM2**

| **Objective** | **Motivation** |
|---|---|
| Maintain the low flow requirements during the driest month of a drought year | • to inundate appreciable area of the channel to sustain fairly flow-sensitive species of fish such as *Labeo* |
| Maintain the low flow requirements during the wettest month of a drought year | • to inundate more riffle sections to increase habitat diversity<br>• to inundate more area of the channel to permit fish passage over obstacles. |
| Maintain the low flow requirements during the driest month of a maintenance year | • inundate more habitats to provide natural variability to maintain diverse fish species assemblage<br>• maintain active channel flows to inundate benches and sustain emergent vegetation<br>• permit more fish passage over obstacles<br>• Inundate pools to improve water quality (DO, temperature, etc). |
| Maintain the low flow requirements during the wettest month of a | • provide cue for migration in spawning migrant fishes such as *Labeo*. |

| | |
|---|---|
| maintenance year | • inundate macrophytes and emergent vegetation along banks to provide more habitats (shelter, feeding) for fishes especially juvenile stages |
| Maintain small pulses of higher flow that occur in the drier months | • prevent sediment build-up on river bed, thus increasing habitat variability for fish and invertebrates<br>• flush out organic matter, thus improving water quality for fish<br>• facilitate nutrient transfer between floodplains and the river. This will increase primary productivity and food for fishes. |
| Maintain major peaks in the river's flow level that occur at a given recurrence interval | • maintain macro channel features and provide diversity of physical habitats for fish<br>• scour and flush bed of sediment deposits to expose riffles which were clogged with sediments<br>• Cue for spawning migrant fishes such as *Labeo* to start upstream spawning migration.<br>• inundate and recharge larger higher banks, allowing for nutrient transfer into the main river channel (increase primary productivity).<br>• inundate higher bank vegetation to provide more habitat (shelter, feeding, breeding) for fishes. |

The fish community should include a large proportion of fairly flow sensitive species such as Labeo. Fish species diversity = H' < 2 i.e. even distribution of individuals among species.

***Target indicators for fish***

The following will be used as indicators with the objective of maintaining abundances comparable to reference conditions:

Target species: *Brycinus, Synodontis, Barbus* (pool guild)

*Labeo, Citharinus, Alestes, Hydrocynus* (Lotic guild)

***Objectives and motivations for invertebrates***

Table 18 outlines the specific objectives and associated motivations for invertebrate species derived at BBM2.

**Table 18: Specific objectives and associated motivations for invertebrate species at BBM2**

| **Objective** | **Motivation** |
|---|---|
| Maintain the low flow requirements during the driest month of a drought year | • to inundate appreciable area of the critical habitats (e.g. riffles) to sustain moderately flow-sensitive species of macroinvertebrates caught at this site such as Caenidae, Tricorythidae, Naucoridae and Hydroptilidae. |

| | |
|---|---|
| Maintain a major flood at the beginning of the wet season i.e. March/april and several more during the wet season | • The first major flood resets the river to the wet season conditions, flushing away fine sediments and pollution tolerant species such as oligochaetes and Chironomidae. Subsequent floods sort and rework sediments maintaining physical heterogeneity of the channel |
| Maintain small pulses/freshes of higher flow that occur in the drier months | • Enhance downstream drift of animals and flush out areas of poor quality water accumulated during dry season lowflow |
| Mimic natural pattern of average monthly flows | • Different species are adapted to react to different flow cues for life history stages. |

A SASS4 score = >100 and ASPT score >6 should be maintained.

The invertebrate community should include a large proportion of sensitive taxa such as *Perlidae, Oligoneuridae, Leprophlebiidae, Baetidae, Caenidae,* and *Elmidae* with lower relative abundances of *Chironimidae* and *Oligochaeta*.

Invertebrate community diversity should = H' >2 i.e. displaying an even distribution of individuals amongst species, reflected low gradient rank-abundance curve.

***Target indicators for invertebrates***

The following will be used as indicators with the objective of maintaining abundances comparable to reference conditions:

Target taxa: *Caenidae, Tricorythidae, Naucoridae and Hydroptilidae* (moderately flow-sensitive).

## *4.3. Description of preparatory work*

### 4.3.1. Selection of study sites

During initial field visit to the study area (30th January 2008), the multidisciplinary group of specialists chose two representative sites of the MGRR in the RNP upstream and downstream of Msembe, the headquarters of RNP. The selected sites exhibit fluvial processes characteristic of the macro-reach. Additionally, these sites incorporate smallscale habitat diversity; as such, all sites were placed on 100 meter-long, straight stretches of the river that as much as possible included runs, pools and riffles.

The two sites were established to include Msembe BBM1 (Msembe bridge downstream) and Muhuwa BBM2 (Msembe bridge upstream), taking the following considerations into account:

- Ease of accessibility
- Suitability for measuring a rated hydraulic cross-section
- Proximity to a flow gauging site

- Representation of conditions in the river zone (geomorphology)
- Critical flow site (i.e. where flow will stop first if discharges are reduced). A site with riffles is a good example.
- River reaches that are characterised by the presence of riffles, pools and runs are ideal.
- A site where a series of rated cross-sections within a river reach could be placed
- Suitability for modelling the hydraulics at different water depths

### 4.3.2. Hydrology

#### Data collection

The daily flow data from the Msembe Ferry gauging station within the RNP were used in this work. The Msembe Ferry gauging station operated from 1963 to date but the record was extended back to 1958 during the Sustainable Management of the Usangu Wetlands and Catchment (SMUWC) project using data measured at Haussman’s Bridge, a flow gauging station, located approximately 50km upstream of Msembe Ferry which operated between 1958 and 1988.

#### Historical changes in flow

Considering the historical developments in the GRR Catchment, three phases of development interventions were identified. These include the pre-1974 which is considered to be near natural (pristine) condition with very limited human interventions. The period between 1974 and 1989 was considered to be an intermediate period characterized by rapid increase in both population and irrigated area while the period 1990 to present represented the present day condition characterised by more frequent zero flows for the GRR through the RNP.

The flow data from 1958 to 1973 for the GRR at the Msembe Ferry was considered to be natural flow and this provided the basis for naturalising the modified flow from 1974 to 1989.

Since the BBM stations are located at some distance from the source site (Msembe Ferry), the flow to the two BBM stations was extrapolated. Figure 9 shows the BBM sites and the catchment in more detail.

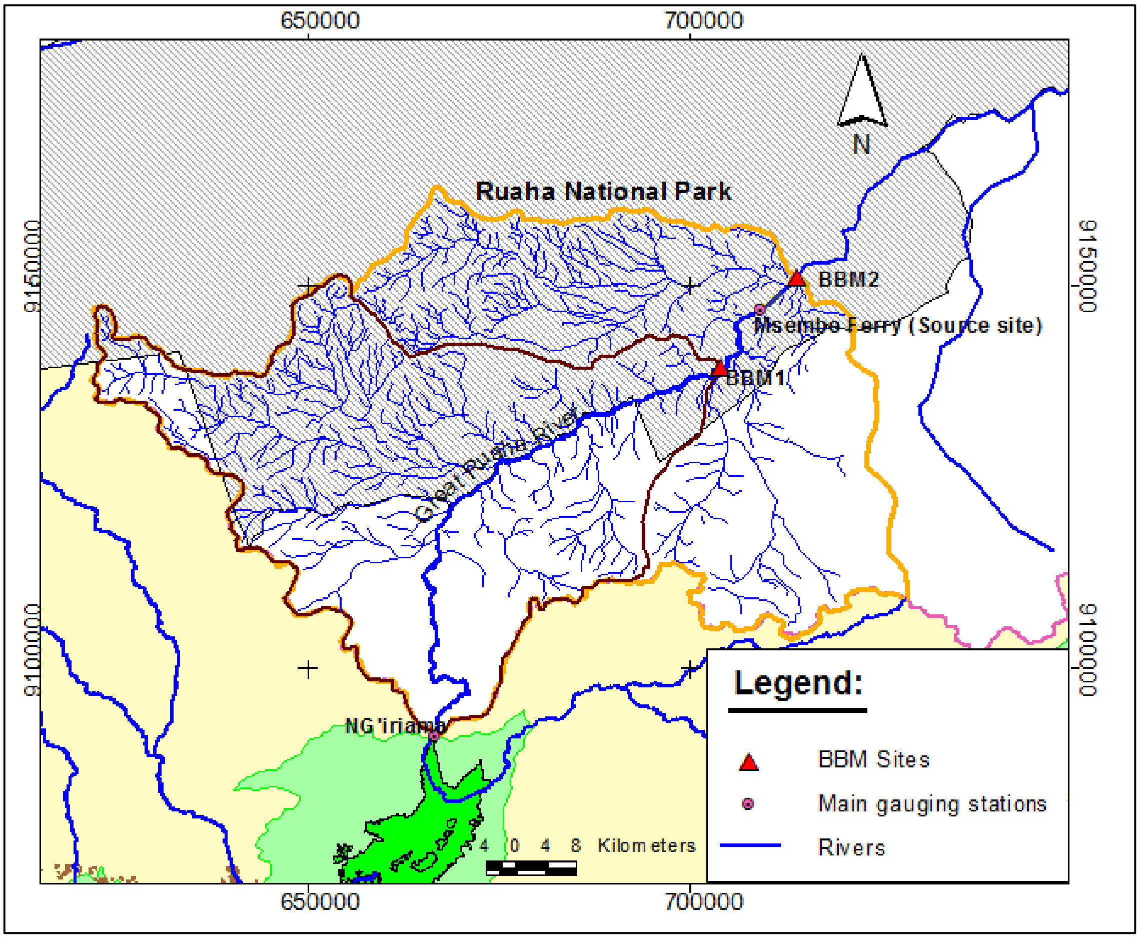


**Figure 9: Detailed map showing location of BBM sites and their contributing catchment after the Ng'iriama exit of the Usangu wetland including the flow source station (Msembe Ferry)**

A report describing the hydrological study undertaken as part of this EFA is available from WWF TCO and RBWO.

### 4.3.3. Hydraulics

#### Background

Understanding how changes to a flow regime (hydrology) affects instream habitats requires an understanding of hydraulics. Hydraulics refers to water depth, velocity, wetted perimeter and width of the surface of the water. These variables govern the substrate types and conditions in which the different aquatic species live. Hydraulics are altered by a change in flow, and in turn the change in hydraulics leads to changes in the availability of instream habitaits.

Hydraulic conditions are determined by the interaction of the velocity, channel cross-section geometry with flow. For a particular cross-section, the hydraulic conditions depend on channel hydraulic roughness, channel morphology comprising slope and channel geometry and boundary conditions.

### Field work

The geometric survey entailed accurate location of riverine mesohabitat (Riffle, pool, run etc.), survey of bed elevation, and establishment of survey control points. A dumpy level, tape measure and engine-powered boat were used. The surveys provided information such as distance between transects, water-surface elevation, bed-elevation profiles, stage of zero flow elevation, water depths, and bench-mark locations and elevations. Flow discharge measurements were carried out in the placed cross sections using a current meter.

### Analysis

In order to interpolate or extrapolate hydraulic parameters other than the measured ones, a hydraulic model was set. The hydraulic model used manning and/or energy equation (s) to simulate river hydraulics. Water surface profiles and velocity data were used to calibrate the model parameters. Water levels during floods validated the model's performance. The modelling exercise was conducted using a series of rated cross-sections (i.e., between three to four cross sections).

A report describing the hydraulics study undertaken as part of this EFA is available from WWF TCO and RBWO.

## 4.3.4. Geomorphology

### Background

Flow exerts significant control of stream channel morphology. Channel morphology is a key determinant of habitat structure and geomorphologic processes such as erosion, deposition and sedimentation. Therefore, geomorphologic processes have implications on the ecology of the river and human uses of the stream and adjacent land.

The health of the river depends on healthy ecosystems and geomorphologic processes that do not undermine the ecological habitat. To maintain ecological and morphological processes for a healthy river is a challenge with increasing demand for water in the GRR Basin. In the basin there are competing uses, such as irrigation and water for electricity generation needed in Mtera, agricultural production and ecological conservation in RNP and Usangu Game reserve, and poor water management such as cultivation of vinyungu practice and destructive fishing practices that involve draining water from the river. Abstraction of water in Usangu plain is increasing while water demands downstream are soaring as a result of increasing agricultural production of sugar, sisal, rice and vegetables, industrial use for sugar refinery, domestic uses of water, cattle keeping, game reserve and future needs for hydro-eclectic power production.

Geomorphology therefore is a vital component in determining environmental flows for the GRR not only because geomorphogical processes directly impact the river health but also have implications for river management and human use.

Furthermore, hydraulic, geomorphologic and ecological responses to river flow changes are interdependent. The major input into an appropriate environmental flow management is the knowledge about the response of the river channel and sediment transport in relation to changing flow regimes.

### Methodology

To understand impacts that result due to changing flows of the GRR, the configuration of the GRR catchment was determined, the river channel geomorphology was assessed and the river channel characteristics were described. Based on Digital Elevation Models (DEM), generated from the Shuttle Radar Topography Mission (SRTM), 90 m resolution satellite, the Ruaha basin was delineated, the long profile of the main rivers calculated and geomorphologic units of the river channel established.

On the two BBM sites geomorphologic characteristics of the river were described, geomorphologic units that regulate flows were identified, and sediments characteristics assessed.

### Present geomorphological state

The geomorphological studies show that the channel bed is stable. No serious degradation was identified on site. However, decreasing flows in the GRR have increased alluvial deposition and infilling of the channel. Little land cover occurs in the Ihefu-Mtera segment of the channel and much sediment is found in the channel resulting from the natural processes of weathering, mass wasting erosion and channel bank slumping. Clayey banks are eroding through slumping because there are limited floods to replenish clays in the flood plains. Consequently, aggradation of the channel, degradation of the banks and increases in channel deposition have resulted, due to decreased flows.

A report describing the geomorphological study undertaken as part of this EFA is included in Appendix A.

## 4.3.5. Riparian vegetation

### Data collection

The riparian vegetation ecological study aimed to provide baseline data that was needed for the assessment of water requirements for riparian habitats as well as the individual functions and processes in the aquatic ecosystem.

As part of the BBM component riparian vegetation was sampled at the two BBM sites using the Quadrat technique (along the pre-determined transect lines at a cross section) which were surveyed for hydraulic analysis.

### Present state

It was found that the riparian vegetation was a heterogeneous mosaic of patches without any defined pattern. The a seasonal flow in the GRR is causing the vegetation to decline from the typical riparian plant species composition. The present vegetation is in a transition state from typical riparian communities to terrestrial communities with an undefined transitional zone.

The communities identified in the GRR basin were characterized by dominant plant species. Woody species such as *Tamarindus indica, Acacia albida* (*Faidherbia albida*), *Combretum paniculata, Diospyros fischeri* and *Cordia sinensis* were common in all the cross sections and dominated the riparian zones and the flood plains. These form thickets and scattered vegetation communities in the river banks and the flood plains.

The *Penisetum-Phragmites* community formed scattered stems along the sand bars and river banks at BBM1 site. The *Tamarindus indica* and *Acacia albida* species trapped large amounts of sediments forming sand islands in the channel where the channel shifted 60m to the far northern side probably during the el Nino year in 1998. It appears that there was high composition of riparian plant species in the GRR when the flow was perennial but has declined due to lack of dry season flows. The sediment islands have been covering the riparian vegetation which remained dry for a long period of time in the dry season and their populations dropped over time.

*Schoenoplectus corymbosus, Leersia hexandra* and *Cyperus rotundus* (a grass community) exclusively dominated all the grass species on alluvial soils in permanently wet areas as well as the seasonally inundated flood plains. These provide forage for fish during flow seasons and at times when there is connectivity between the Matera dam and Usangu wetlands. On the other hand, *Tamarindus indica* and *Acacia albida* community stabilized the river bank and provide debris as the major source of food to aquatic organisms. *Acacia albida* has a very high protein content which is the major source of food to fish and wildlife. The *Leersia-Spirogyra* community provides habitat, refuge and food to small fish.

Terrestrial communities are characterised by heterogeneous vegetation types. The common species were the *Acacia tortilis* and the monodominant woody species (*Combretum paniculata*) in the greater part of the RNP. The vegetation of the seasonally inundated grassland was commonly dominated by *Panicum heterostachys* and *Pennisetum purpreum,* as grass species while the dry areas were dominated by *Hyparrhenia filipendula, Echnocloa pullurans, Eragostis cyclindifolia* and *Brachiaria deflexa.*

The density and diversity of plant species was higher at Muhuwa than at Msembe. Drying of the river bank that started in the last decade resulted in a decrease in populations of flow dependent plant species since they had no chance of surviving in the riparian areas. Similarly the effect of grazing and trampling by wildlife communities modified the natural vegetation where colonizing species were more abundant.

The riparian vegetation has high ecological significance to the GRR ecosystem. It helps to reduce bank erosion during flow seasons as well as in times when the flow regime changes. The riparian woody plant species has characteristic prop and convoluted roots systems that support the mass of the plant itself and the soil structure. The roots systems of both *Tamarindus indica* and *Acacia albida* form a network at a very wide range which holds the soils of stream banks in place. The riparian area in the GRR channel is a critical habitat of flora and fauna of special conservation value regardless of its size being small.

The present study however, found that the riparian habitat in the GRR has diminished in terms of its riparian plant species populations. It is recommended to improve the current ecological status through reinstating the dry season low flows. The flows required for the riparian vegetation at both sites should ideally be a discharge of 5 $m^3$ $s^{-1.}$ However, considering the use of water for irrigation in the upstream and the natural flows, which apparently reduced to 1 $m^3$ $s^{-}$, it would not be reasonable to recommend such high environmental flows.

A report describing the riparian vegetation study undertaken as part of this EFA is available from WWF TCO and RBWO.

### 4.3.6. Fish and invertebrates

### Present state of fish

Critical flow regime characteristics can be ascertained by studying the environmental guilds of fish present in the river, i.e. grouping fish species in the manner that they respond to changing hydrology and geomorphology of the river.

During the sampling expedition 205 fish specimens belonging to 12 genera and representing 17 different species were collected from two sampling sites. Fish samples were collected by gillnets and a seine net.

The project area has large number of fish species, many of which were in the environmental guilds ranging from moderately to highly sensitive to flow timing and/or quantity. Several species including those in genera *Barbus*, *Brycinus* and *Synodontis* were in the pool guild, species which are sensitive to reductions in flow that alter the balance between riffles and pools in the river, or leave the pools anoxic. *Labeo* and to a less extent *Alestes, Hydrocynus* and *Citharinus* are among the fairly sensitive species representing the lotic guild, species which are typically annual breeders whose breeding seasonality and migration patterns are tightly linked to the timing and quantity of peak flow events. Lotic guild members also require fairly high levels of dissolved oxygen, necessitating high flow velocities. On the other hand, *Chiloglanis deckenii* encountered in BBM 1 is in the riffle guild, generally considered to be most sensitive genus in African EFAs due to its high requirement for fast flowing water (0.5 $m^3$ / sec).

### Requirements for fish

On the basis of fish guilds found in the GRR it can be recommended that for BBM 1 dry season base flows must maintain inundation of the riffles. In both sites the wet season base flows must inundate lower banks and benches, allowing the input of nutrients from those systems to the river as well as fish passage over larger obstacles. Wet season high flows must inundate the floodplains to inundate and recharge wetlands as well as provide access to floodplain nursery grounds.

### Present state of invertebrates

Aquatic invertebrates are very sensitive indicators of water quality and flow regime in rivers and overall ecological health of the system. Species used in the present survey included insects, worms, molluscs and crustaceans that occur on the riverbed or along the channel margins.

A total of 1113 macroinvertebrates belonging to 19 taxa, were encountered in the samples collected from two BBM sites in GRR. These numbers are comparable to the other stream macroinvertebrate studies conducted in the tropics.

The sampling sites in the GRR were dominated by *Ephemeroptera* (59.5% of the total macroinvertebrates). Many taxa within this group are considered to be moderately to highly sensitive to water pollution. In particular, BBM 1 had incredibly high diversity of macroinvertebrates, the majority of which were moderately or highly sensitive species. In fact, BBM1 had representatives of each of the three highly sensitive families sampled in this effort: the nymphs of stoneflies *Perlidae* (*Plecoptera*), brush-legged mayflies *Oligoneuridae* (*Ephemeroptera*), and prongill mayflies *Leptophlebiidae* (*Ephemeroptera*).

### Requirements for invertebrates

Due to the positive correlation between river current and density of sensitive macroinvertebrates, flow velocities of 0.4 - 0.6 m/s are recommended. BBM 2 had a fairly high density of macroinvertebrates, although it had lower diversity and evenness scores compared to BBM 1. Additionally, the majority of families found at this site were considered “highly tolerant” to pollution together with the moderately tolerant species. Although this site may not serve as a refuge for rare or sensitive species, it likely plays an important role in harbouring large populations of common groups of macroinvertebrates.

At BBM 1, adequate flow levels are required to maintain populations of the sensitive flow-dependent species. While nymphs of these species are favoured by moderate flow conditions in rapids and riffles adults rely on marginal vegetation and are favoured by periodic inundation of the banks. High flows are also necessary for drift to promote recolonisation of disturbed biotopes in order to increase diversity.

For all sites, normal and more frequent floods are necessary to reset species composition by shifting dominance of some species via drift from upstream. Yearly bigger floods are necessary to flush out accumulated organic matter, promote biomass increase and foster recolonisation of habitats. Small spates during the dry season are needed to rejuvenate organic matter levels and improve stagnant water quality.

A report describing the fish and invertebrate studies undertaken as part of this EFA is available fromWWF TCO and RBWO.

## *4.4. Recommended flows*

The flows required to meet the desired state objectives were assessed for both BBM sites in the GRR. The following flows were considered:

a. Dry season low flows for maintenance years

b. Wet season low flows for maintenance years

c.. Wet season high flows for maintenance years

d. Dry season low flows for drought years

e. Wet season low flows for drought years

f. Wet season high flows for drought years

### 4.4.1. BBM Site 1

**Hydrology**

Figure 10 and Figure 11 illustrate the recommended flows for BBM1.

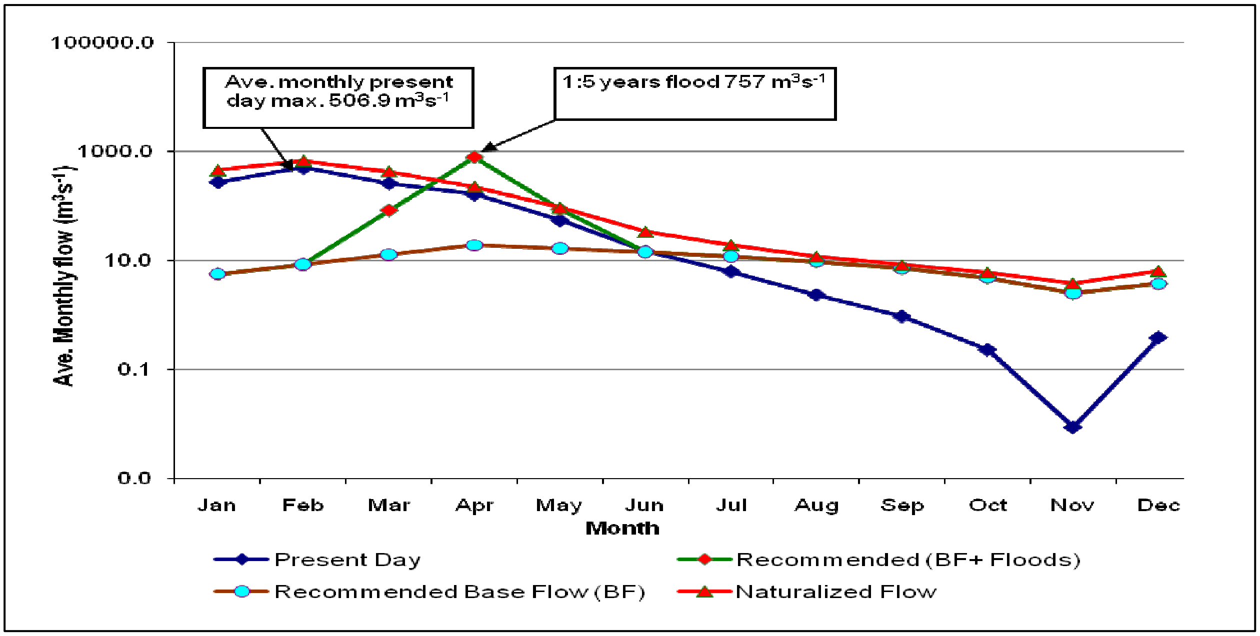


**Figure 10: Recommended maintenance flow against present day and naturalised flow for BBM1**

***NB. Floods DO NOT run continuously from February to June (they are discrete high flow events). A 1 in 5 years flood occurs in April, with small floods of small magnitude occurring in March and April.***

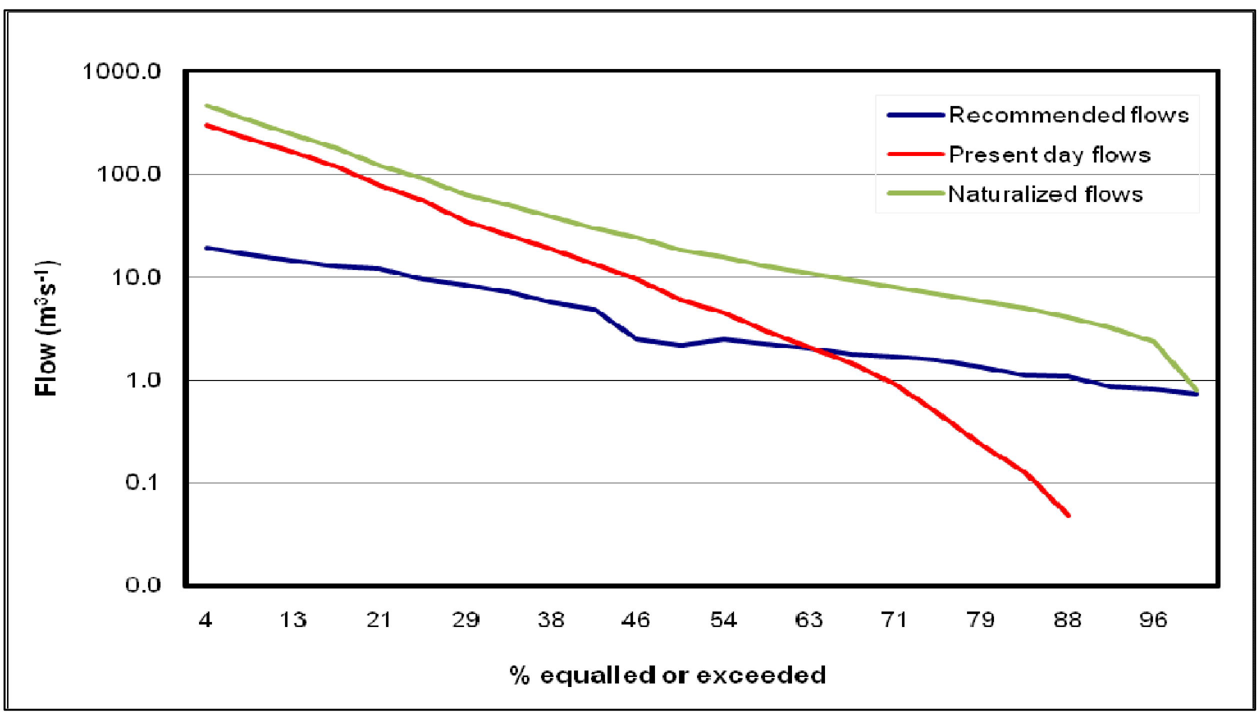


**Figure 11: Flow duration curve for recommended maintenance and drought flow for BBM1**

Table 19 shows the summary of recommended flows for BBM1

**Table 19: Summary of recommended flows for BBM1**

| | |
|---|---|
| Natural MAR | 3154 MCM |
| Present MAR | 2193 MCM |
| Long term average annual requirement for environmental flows MCM | 303.2 MCM |
| Environmental flow requirement as a percentage of natural MAR | 9.6 % |
| Environmental flow requirement as a percentage of present MAR | 13.8% |

## Hydraulics

Figure 12 shows the water surface level for the various required flow volumes specified during the EFA workshop.

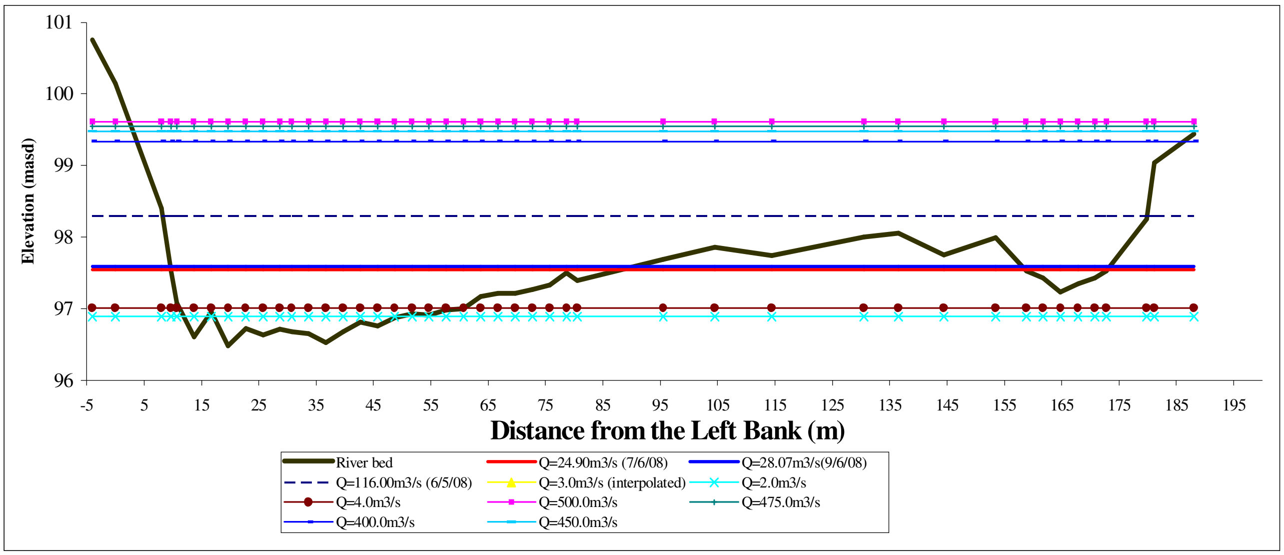


**Figure 12: Water surface levels at BBM1 for various flow volumes**

Figure 13 depicts velocities at BBM1 for various flow volumes

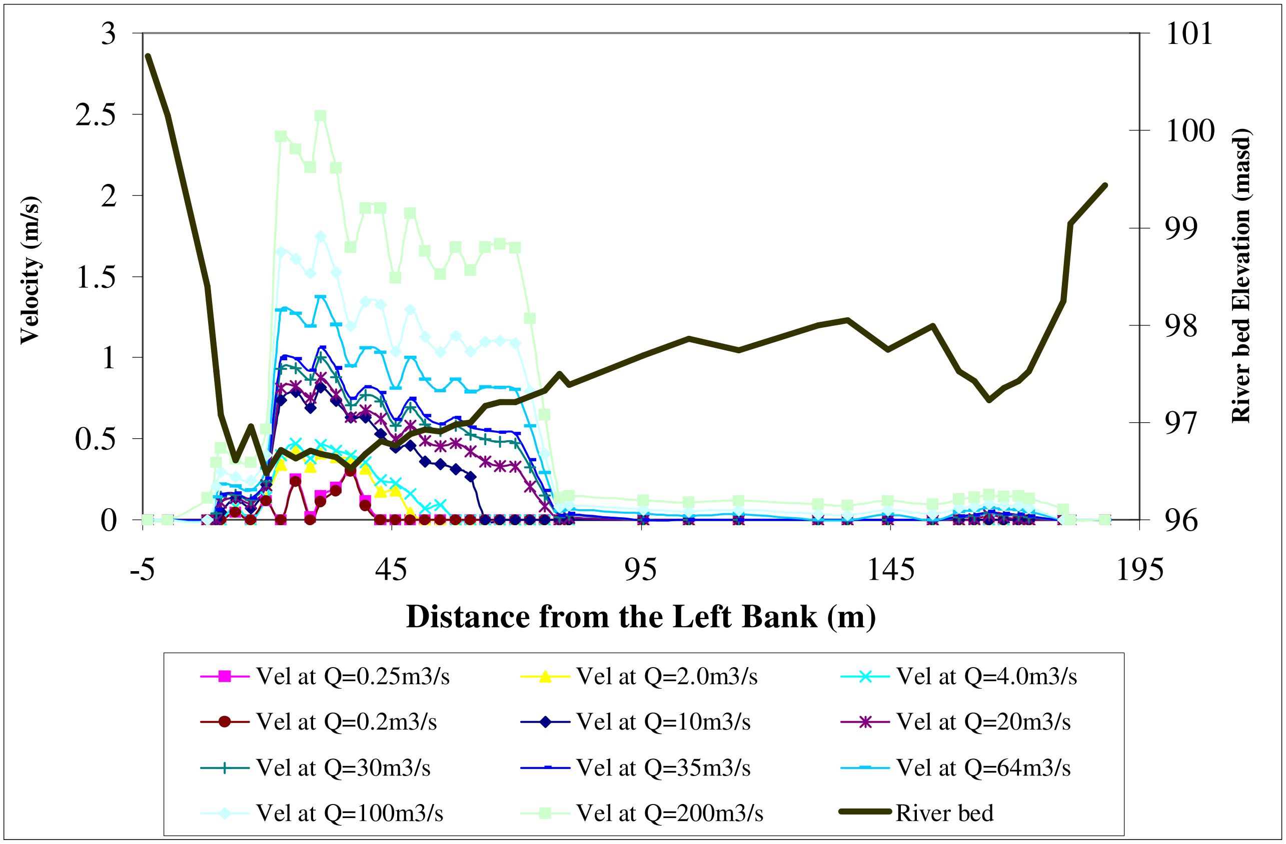


**Figure 13: Velocities at various flow volumes at BBM1**

## Dry season low flows for maintenance years (November)

Table 20 describes the requirement for each indicator at dry season low flows in a maintenance year, in terms of velocity, depth, and discharge. The motivation for each flow and the consequences of not providing them is described for each indicator.

**Table 20: Dry season low flows for maintenance years (November) at BBM1**

| Indicator | Max Velocity (m/s) | Max Depth (m) | Discharge ($m^3/s$) | Motivation | Consequences of not providing this flow |
|---|---|---|---|---|---|
| Fish* | 0.44 | 0.454 | 2.5 | The low flows during the driest month of a maintenance year are required to<br>• inundate more riffle sections to increase habitat diversity and therefore fish species diversity<br>• maintain active channel flows to inundate benches and sustain emergent vegetation that fish need for shelter/cover<br>• permit more fish passage over obstacles<br>• flush out pools to improve water quality (more favourable habitats for fish).<br>The primary motivation for maintaining low flow flows in a dry season of the maintenance year would be to inundate the main channel (especially vast area of riffles and benches) to provide a variety of habitats for resident fish species.<br>The recommended discharge results in an average hydraulic depth which is enough to cover appreciable portion of mid-channel riffles. The resultant maximum velocity is also suitable for *Chiloglanis* and juveniles of other species which need appreciable inundated vegetation for cover/shelter and feeding. | Will curtail optimal growth rate of many species and present diversity.<br>It may result in lowering fish standing biomass in that reach of the river. |

| | | | | | |
|---|---|---|---|---|---|
| | | | | N.B These motivations are similar to those written for the wet season low flows in a drought year. | |
| Invertebrates | | | | The velocities and discharges described for fish are well above the requirements of most macroinvertebrate species found at the site, including the most sensitive species. | |
| Riparian vegetation** | | 0.454 | 2.5 | This flow will support population expansion of the permanent flow dependent riparian species *Leersia hexandra* and *Pennisetum purpreum* and the survival of woody species at the bank such *as A.albida, T. indica, C.apiculata* and *Diospyros fischeri*<br>This flow will allow the riparian woody species at the bank to get enough water for survival.<br>The permanent flow dependent species can regenerate in the channels, and the roots of woody species in the bank can continue getting water for physiological functions and hence survival. Even though the flow is on only one side of the channel, the water below the sands can still be available for flow dependent species, since they have average root length of 30cm which can still source water.<br>NB: These motivations are similar to those for wet season low flows for drought years. | |
| Geomorphology | | | | There are no geomorphological considerations at this flow level. | |

### Wet season low flows for maintenance years (April)

Table 21 describes the requirement for each indicator at wet season low flows in a maintenance year, in terms of velocity, depth, and discharge. The motivation for each flow and the consequences of not providing them is described for each indicator.

**Table 21: Wet season low flows for maintenance years (April) at BBM1**

| Indicator | Ave Velocity (m/s) | Ave Depth (m) | Discharge ($m^3/s$) | Motivation | Consequences of not providing this flow |
|---|---|---|---|---|---|
| Fish* | 0.52 | 0.47 | 19 | The low flows during the wettest month of a maintenance year are required to<br>• provide cue for migration and spawning in fishes.<br>• inundate macrophytes and emergent vegetation along banks (some fish and invertebrates need vegetation to deposit their eggs).<br>• displace dominant competitors (e.g. *oligochaetes* for invertebrates) and allow drift of species into new habitats<br>The primary motivation for having low flows in a wet season of the maintenance year would be to inundate the vast area of the channel (including lower bank aquatic vegetation – sedges) and increase habitat diversity.<br>Increased habitat diversity would provide ample resources (shelter, food, hiding from predators, etc) enabling fish to attain good body condition index, fast growth rates and accumulate enough energy for successful spawning in the coming season. | Will curtail optimal growth rate for all fish species in the river reach and resulting in stunting growth and low fish standing biomass.<br>Will affect successful recruitment in the next spawning season. Adult fish which are poorly fed during resting period would have poor spawning and therefore poor recruitment success. |
| Invertebrates | | | | | |
| Riparian vegetation** | | 0.473 | 19 | This flow will:<br>• help to supply nutrients to the riparian vegetation to enable it to perform best in this season and to supply sufficient | The performance of most of the plant species can be affected, due to the lack of nutrients. Vegetation that is inundated in the stream cannot recover rapidly from |

| | | | | | |
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| | | | | forage for the aquatic life.<br>• inundate roots of woody riparian plant species in the bank to provide sufficient water and nutrients for the development of reproductive structures.<br>• wash plant debris into the stream as a nutrient source for invertebrates and fish.<br>This flow is above the requirement for the survival and regeneration of all the riparian vegetation (e.g. Permanent flow dependent species including *Leersia hexandra, Schoenoplectus corymbosus* and *Phragmites mauritianum* as well as the regenerants of *A.albida, T. indica, C.apiculata* are likely to perform well at this flow and expand their populations. | herbivorous fish. Fish breed in this season and need sufficient food for the rapid growth of their young. |
| Geomorphology | .345 | .547 | 4.25 | There are pools and runs formed due to rocky potholes. The flow is needed to remove sandy material in pools when during the low flows. Therefore riffles and pools, important ecological habitats are maintained. | Infilling of pools and obliteration of ecological units will remove the refuge sites for that on which both terrestrial and river fauna depends when the flows are highly reduced in the GRR. |

### Wet season high flows for maintenance years (April)

Table 22 describes the requirement for each indicator at wet season high flows in a maintenance year, in terms of velocity, depth, and discharge. The motivation for each flow and the consequences of not providing them is described for each indicator.

**Table 22: Wet season high flows for maintenance years (April) at BBM1**

| Indicator | Max Velocity (m/s) | Ave Depth (m) | Discharge ($m^3/s$) | Motivation | Consequences of not providing this flow |
|---|---|---|---|---|---|
| Fish* | 0.65 | 0.65 | 70 | NB!! 2 times in March (one-time breeders) and another one in mid-wet season (April-May) for repeated breeders.<br>This flow is required to:<br>• maintain macro channel features and provide diversity of physical habitats for many species of fish found in the GRR<br>• scour and flush the bed of sediment deposits to expose riffles which were clogged with sediments. Riffles are preferred habitats of the most sensitive species such as *Chiloglanis*<br>• cue spawning migrants such as *Labeo* to start upstream spawning migration.<br>• inundate and recharge larger higher banks, allowing for nutrient transfer into the main river channel (increase primary productivity).<br>Two of the three fish species caught at this site (*Labeo* and *Barbus*) have one breeding season a year that is closely linked to peak flows. *Labeo* and *Barbus* also rely on increased flow as cues for migration and maturation. For these species, one flood would be necessary at the beginning of rainy | Failure in recruitment success of the resident fish species.<br>Less physical habitat due to sediment deposition on the river channel bed. |

| | | | | | |
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| | | | | season to bring about maturation of gonads and trigger upstream spawning migration into suitable spawning grounds (e.g. small tributaries for Labeo). Another flood towards the end of wet season will be necessary to allow spawners and their young to drift back into the main river channel<br><br>The third type of species caught at this site (*Oreochromis* sp) are generally repeat breeders, although in drought years may even breed during low flow phases of the hydrograph. For *Oreochromis*, 2 flood flows in the wet season would be advantageous for their repeated spawning habits. | |
| Invertebrates | | | | | |
| Riparian vegetation** | | 1.92 | 435, with 1350 once in five years | (This is a stronger motivation than for BBM2). This flow is needed once every five years.<br><br>This flow will:<br>• inundate the fans created due to the shift of the river course to the left bank during the el Nino period in 1998.<br>• provide nutrients to favour the expansion of riparian habitats beyond to the bank and the recently created fans.<br>• favour the regeneration of woody species from propagules (seeds) in the banks and the fans where they can get sufficient moisture and nutrients to germinate and grow sufficiently.<br>• soak the soil in the bank to favour most of the woody species at the banks such as *Acacia albida, Tamarindu indica, Combretum apiculata* and *Diospyros fischeri)* and the recovery of *Pennisetum purpreum* which was found | Lack of this flow is limiting the regeneration of woody species which are important for bank stabilization.<br><br>Loss of stabilising vegetation will result in changes in the water course. |

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| | | | | retreating in the sand deposits.<br>• allow seeds in the banks to germinate without being swept away into the stream, facilitating the population expansion of woody species | |
| Geomorphology | 2.92 | 2.93 | 425 | 1 in 5 year flood.<br>The flow is needed to<br>• move sandy point bars<br>• prevent lateral erosion of the left bank, and<br>• release suspended sediments into the river.<br>The river at this site is meandering and eroding the left bank due to deposition sand on the left bank | Continuous erosion of the left bank and release of suspended sediments that reduce the quality of water downstream due to increased turbidity. |

### Dry season low flows for drought years (November)

Table 23 describes the requirement for each indicator at Dry season low flows in a drought year, in terms of velocity, depth, and discharge. The motivation for each flow and the consequences of not providing them is described for each indicator.

**Table 23: Dry season low flows for drought years (November) at BBM1**

| Indicator | Max Velocity (m/s) | Ave Depth (m) | Discharge ($m^3/s$) | Motivation | Consequences of not providing this flow |
|---|---|---|---|---|---|
| Fish | 0.327 | 0.128 | 0.85 | The low flow during the driest month of a drought year are required to:<br>• maintain hydrological connectivity in the system (upstream-downstream)<br>• maintain inundation of critical habitats (eg., riffles) in order to sustain flow-sensitive species (e.g. *Chiloglanis* sp)<br>• provide natural habitats variability to maintain diverse species assemblage<br>Most of the EFA studies in Africa have used *Chiloglanis* sp as the most sensitive species and therefore used as the basis for recommending flows for respective river basins. *Chiloglanis* has very high requirement of fast flowing water in riffles with recommended minimal flow for survival given as ≥ 0.3 m/s. The velocity provided for this BBM site provide enough depth to fully inundate the riffles, which are concentrated on the incised left bank<br>*Chiloglanis* and *Amphilius* were caught only from this site | Could have catastrophic effect on the survival of sensitive species such as *Chiloglanis* and *Amphilius*.<br>*Chiloglanis* do not tolerate pools and once inundation of riffles and channel connectivity is not maintained their survival is threatened. |
| Invertebrates | | | | | |
| Riparian vegetation** | | 0.128 | 0.85 | This flow allows the flow dependent riparian vegetation such as *Leersia hexandra* and *Pennisetum purpreum* to perform their functions in the channel, and supports the survival of woody species in the bank. Only two of the most sensitive | |

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|---|---|---|---|---|---|
| | | | | species were found at this site, and the surviving woody species at this site included *Acacia albida, T. indica, C.apiculata* and *Diospyros fischeri*. | |
| Geomorphology | | | | | |

## Wet season low flows for drought years (April)

Table 24 describes the requirement for each indicator at wet season low flows in a drought year, in terms of velocity, depth, and discharge. The motivation for each flow and the consequences of not providing them is described for each indicator.

**Table 24: Wet season low flows for drought years (April) at BBM1**

| Indicator | Max Velocity (m/s) | Ave Depth (m) | Discharge ($m^3/s$) | Motivation | Consequences of not providing this flow |
|---|---|---|---|---|---|
| Fish* | .44 | 0.454 | 2.5 | The low flows during the wettest month of a drought year are required to<br>• inundate more riffle sections to increase habitat diversity<br>• maintain active channel flows to inundate benches and sustain emergent vegetation<br>• permit more fish passage over obstacles<br>• • inundate pools to improve water quality (more favourable habitats for fish).<br>The primary motivation for maintaining reasonably higher low flows in a wet season of the drought year would be to inundate the main channel (especially riffles and benches) to provide a variety of habitats for resident fish species. This would provide more resources (space, food, etc) than that available during the dry season. This allows fish to grow faster.<br>The recommended discharge would result in an average hydraulic depth that would cover an appreciable portion of mid-channel riffles. The resultant average velocity would be suitable for | Limit available habitats for *Labeo* and juveniles of *Barbus* sps occurring in that part of the river. It may result in lowering fish and macroinvertebrate standing biomass in that reach of the river. |

| | | | | | |
|---|---|---|---|---|---|
| | | | | *Chiloglanis* and juveniles of other species which need appreciable inundated vegetation for cover/shelter and feeding. | |
| Invertebrates | | | | These velocities and discharges are well above the requirements of most macroinvertebrate species found at the site. | |
| Riparian vegetation** | | 0.199 | 2.5 | This flow will support population expansion of the permanent flow dependent riparian species *Leersia hexandra* and *Pennisetum purpreum* and the survival of woody species at the bank such as *A.albida, T. indica, C.apiculata* and *Diospyros fischeri*<br>This flow will allow the roots of the woody species at the bank to access enough water for physiological functions and hence survival.<br>At this flow also, the expanding population of permanently flow dependent species provides energy and protein food resources.<br>NB: The permanent flow dependent species can regenerate in the channels. Even though there is flow in only one side of the channel, the water below the sands is still available for flow dependent species since they have average root length of 30cm which can still source water. | |
| Geomorphology | | | | | |

## Wet season high flows for drought years (April)

Table 25 describes the requirement for each indicator at wet season high flows in a drought year, in terms of velocity, depth, and discharge. The motivation for each flow and the consequences of not providing them is described for each indicator.

**Table 25: Wet season high flows for drought years (April) at BBM1**

| Indicator | Ave Velocity (m/s) | Ave Depth (m) | Discharge ($m^3/s$) | Motivation | Consequences of not providing this flow |
|---|---|---|---|---|---|
| Fish* | 0.6 | 0.59 | 50 | Small pulses of high flow that occur in the drier months are necessary to:<br>• prevent sediment build-up on river bed, thus increasing habitat variability for fish and invertebrates<br>• maintain active channel features<br>• flush out organic matter, thus improving water quality<br>• facilitate nutrient transfer between floodplains and the river<br>Some small floods are necessary in the wet season of a drought year, to inundate areas of the channel above the riffles in order to provide additional habitats for near-optimal growth of fish species.<br>The floods will also help to flush out organic matter deposited on lower banks and small pools that would otherwise impact on water quality. | Curtail optimal growth rates of fish in terms of less living habitats and poor water quality. |
| Invertebrates | | | | | |
| Riparian vegetation** | | 1.0 | 21 | This flow is important for the survival of the woody species, in addition population expansion. At this point most of the exposed roots of the woody plant species at the bank will be inundated in water, allowing them to access water for | |

| | | | | | |
|---|---|---|---|---|---|
| | | | | photosynthesis and population expansion.<br>At this flow water has already reached to the shoots of the woody species and the soil underneath. The riparian plant species that can survive at this flow include *A. albida, T. indica, C. apiculata.* They can take over once the flow has increased.<br>NB. This flow is needed only for short periods during the rain season. | |
| Geomorphology | | | | | |

### 4.4.2. BBM Site 2

### Hydrology

Figure 14 and Figure 15 illustrate the recommended flows for BBM2

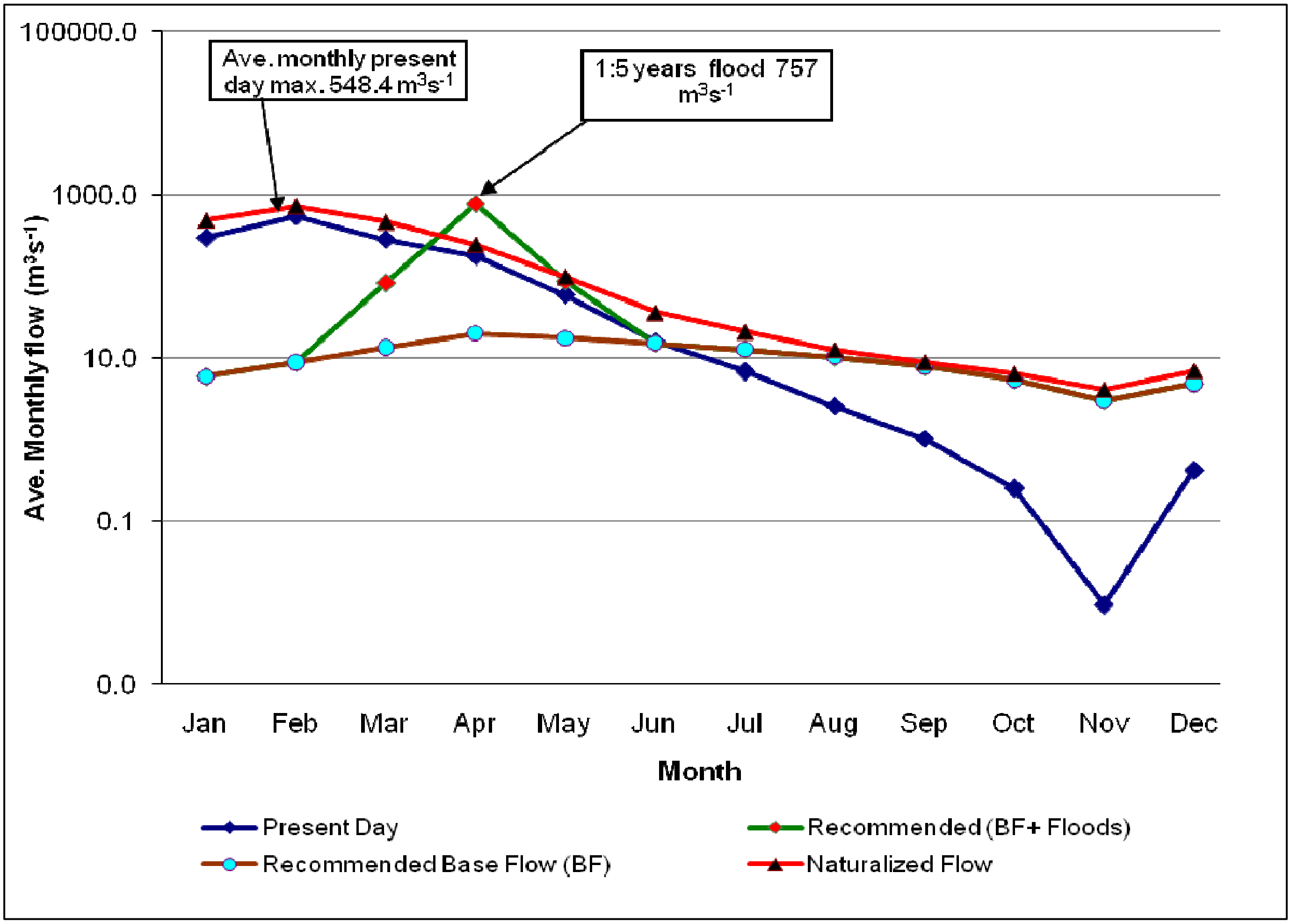



**Figure 14: Recommended maintenance flow against present day and naturalized flow for BBM2**

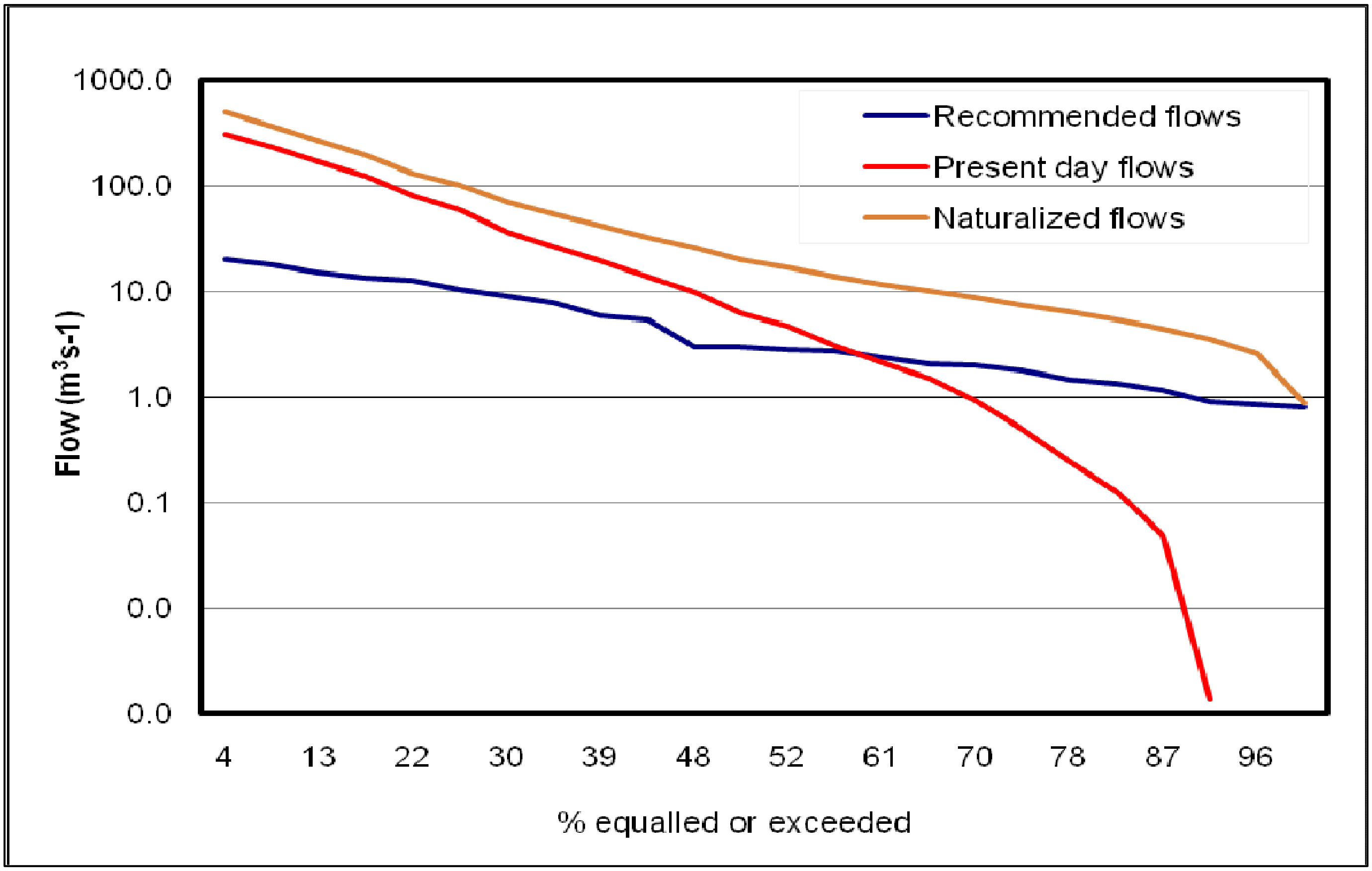



**Figure 15: Flow duration curve for recommended maintenance and drought flow for BBM2**

Table 26 shows the summary of recommended flows for BBM2

**Table 26: Summary of recommended flows for BBM2**

| | |
|---|---|
| Natural MAR | 3154 MCM |
| Present MAR | 2193 MCM |
| Long term average annual requirement for environmental flows | 324 MCM |
| Environmental flow requirement as a percentage of natural MAR | 10.3% |
| Environmental flow requirement as a percentage of present MAR | 15.0% |

## Hydraulics

Figure 16 shows the water surface level for the various required flow volumes specified during the EFA workshop.

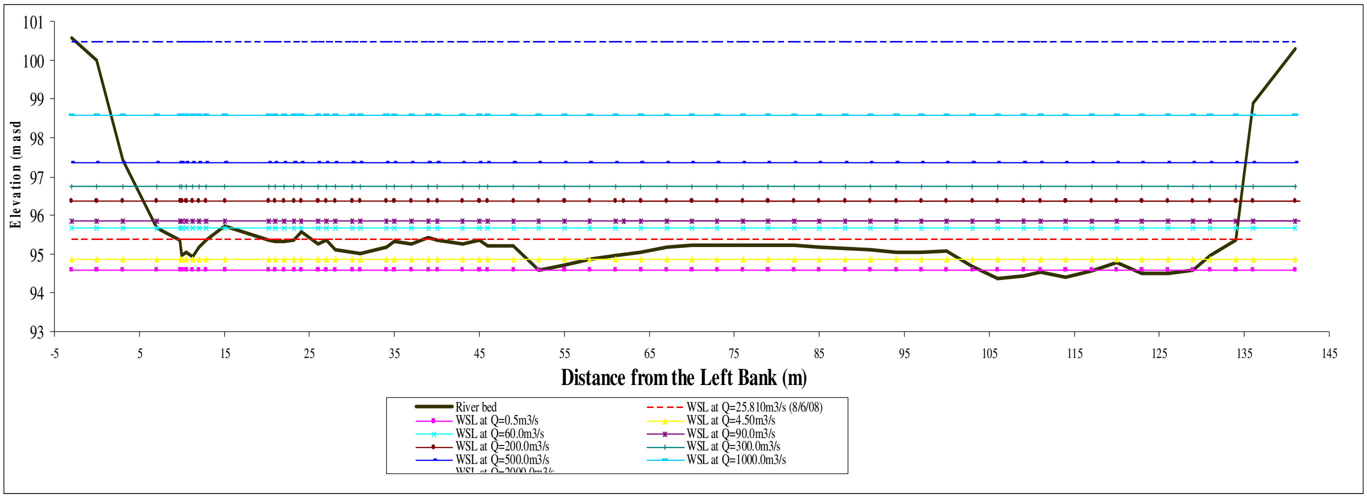



**Figure 16: Water surface levels at BBM2 for various required flow volumes**

Figure 17 depicts velocities at the flow volumes specified during the EFA workshop for BBM2

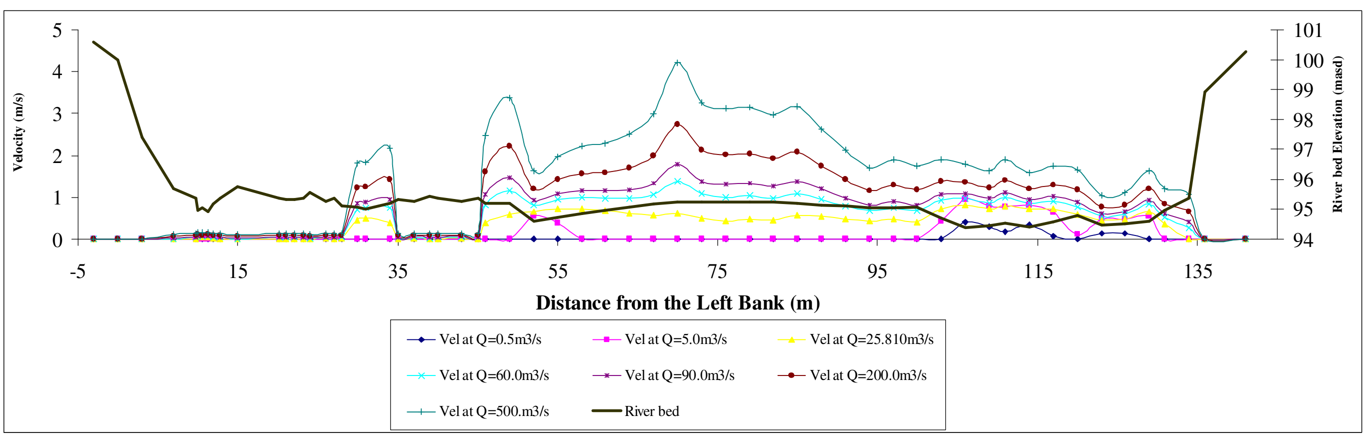



**Figure 17: Velocities of required flows at BBM2**

## Dry season low flows for maintenance years (November)

Table 27 describes the requirement for each indicator at dry season low flows in a maintenance year, in terms of velocity, depth, and discharge. The motivation for each flow and the consequences of not providing them is described for each indicator.

**Table 27: Dry season low flows for maintenance years (November) at BBM2**

| **Indicator** | **Max Velocity (m/s)** | **Max Depth (m)** | **Discharge ($m^3/s$)** | **Motivation** | **Consequences of not providing this flow** |
|---|---|---|---|---|---|
| Fish* | 0.6 | 0.428 | 3 | These flows are required to:<br>• Inundate more riffle sections to increase habitat diversity<br>• maintain active channel flows to inundate benches and sustain emergent vegetation<br>• permit more fish passage over obstacles<br>• Flush out pools to improve water quality (more favourable habitats for fish).<br>The primary motivation for maintaining low flows in the dry season of a maintenance year would be to inundate the main channel (especially the vast area of riffles and benches) to provide a variety of habitats for resident fish species.<br>The recommended discharge would result in sufficient hydraulic depth to cover an appreciable portion of the mid-channel riffles. The resultant average velocity is also suitable for *Labeo,* and juveniles of other species which need appreciable inundated vegetation for cover/shelter and feeding. | Will curtail optimal growth rate of many species and present diversity.<br>It may result in lowering fish standing biomass in that reach of the river. |
| Invertebrates | | | | These velocities and discharges are well | |

| | | | | | |
|---|---|---|---|---|---|
| | | | | above the requirements of most macroinvertebrate species found at the site including the most sensitive species. | |
| Riparian vegetation** | | 0.428 | 3.0 | This flow is likely to cause a population expansion of both in-stream and bank plant species.<br>The roots of regenerating woody riparian plant species in the bank can access sufficient water to perform, and retain soil clods for bank stability, and provide sufficient forage for aquatic and terrestrial biota.<br>This flow is above the requirement for the survival and reproduction of all the riparian vegetation (e.g. permanent flow dependent species including *Leersia hexandra, Schoenoplectus corymbosus* and *Phragmites mauritianum,* as well as the regenerants of *A.albida, T. indica,* and *C.apiculata* | |
| Geomorphology | | | | | |

## Wet season low flows for maintenance years (April)

Table 28 describes the requirement for each indicator at wet season low flows in a maintenance year, in terms of velocity, depth, and discharge. The motivation for each flow and the consequences of not providing them is described for each indicator.

**Table 28: Wet season low flows for maintenance years (April) at BBM2**

| Indicator | Max Velocity (m/s) | Ave Depth (m) | Discharge ($m^3/s$) | Motivation | Consequences of not providing this flow |
|---|---|---|---|---|---|
| Fish* | .69 | 0353 | 20 | • cue fish migration and spawning<br>• inundate macrophytes and emergent vegetation along banks (some fish and invertebrates need vegetation to deposit their eggs).<br>• displace dominant competitors (e.g. *oligochaetes* for invertebrates), and allow drift of species into new habitats<br>The primary motivation for having low flows in the wet season of a maintenance year would be to inundate the vast area of the channel (including lower bank aquatic vegetation – sedges) and increase habitat diversity.<br>Increased habitat diversity would provide ample resources (shelter, food, hiding from predators, etc) enabling fish to attain good body condition index, fast growth rates and accumulate enough energy for successful spawning in the coming season. | • Curtail optimal growth rate for all fish species in the river reach and resulting in stunting growth and low fish standing biomass.<br>• Affect successful recruitment in the next spawning season. Adult fish which are poorly fed during the resting period would have poor spawning and therefore poor recruitment success. |
| Invertebrates | | | | | |
| Riparian vegetation** | | 0.353 | 20 | This flow will is required to:<br>• supply nutrients to the riparian vegetation to allow them to perform best in this season and be able to | |

| | | | | | |
|---|---|---|---|---|---|
| | | | | supply sufficient forage for the aquatic life.<br>• inundate the roots of woody riparian plant species in the bank with sufficient water and nutrients for development of reproductive structures.<br>• wash debris into the stream as a food source for invertebrates and fish.<br>This flow is above the requirement for the survival and reproduction of all the riparian vegetation (e.g. Permanent flow dependent species including *Leersia hexandra, Schoenoplectus corymbosus* and *Phragmites mauritianum*, and the regenerants of *A.albida, T. indica,* and *C.apiculata.*<br>NB: If this flow is not available, the performance of the most of the plant species can be affected due to the lack of nutrients. The vegetation inundated in the stream cannot recover rapidly from herbivores. | |
| Geomorphology | .45 | 0.496 | 4.5 | Redistribution and movement of sand size material in channel and maintain of riffles and pools. | Infilling of pools and obliteration of ecological units |

### Wet season high flows for maintenance years (April)

Table 29 describes the requirement for each indicator at wet season high flows in a maintenance year, in terms of velocity, depth, and discharge. The motivation for each flow and the consequences of not providing them is described for each indicator.

**Table 29: Wet season high flows for maintenance years (April) at BBM2**

| Indicator | Max Velocity (m/s) | Ave Depth (m) | Discharge ($m^3/s$) | Motivation | Consequences of not providing this flow |
|---|---|---|---|---|---|
| Fish* | .804 | .685 | 70 | Wet. width: 127 m<br>This high flow is required twice: in March (one-time breeders) and again in the mid-wet season (April-May) for repeated breeders.<br>These flows will:<br>• maintain macro channel features and provide diversity of physical habitats<br>• scour and flush the bed of sediment deposits to expose riffles which were clogged with sediments<br>• Provide a cue for spawning migrants such as *Labeo* to start upstream spawning migration.<br>• inundate and recharge larger higher banks, allowing for nutrient transfer into the main river channel (increase primary productivity).<br>Two of the three fish species caught at this site (*Labeo* and *Barbus*) have one breeding season a year that is closely linked to peak flows and they rely on increased flow as cues for migration and | • Failure in recruitment success of the resident fish species.<br>• Less physical habitats due to sediment deposition on the river channel bed. |

| | | | | | |
|---|---|---|---|---|---|
| | | | | maturation.<br>For these species one of the floods at the beginning of rain season would be necessary to bring about maturation of gonads and trigger upstream spawning migration into suitable spawning grounds (e.g. small tributaries for *Labeo*).<br>Another flood towards the end of wet season will be necessary to allow spawners and their young to drift back into the main river channel<br>The third type of species caught at this site (*Oreochromis* sp) are generally repeat breeders, although in drought years they may even breed during low flow phases of the hydrograph. For *Oreochromis*, two flood flows in the wet season would be advantageous for their repeated spawning habits. | |
| Invertebrates | | | | | |
| Riparian vegetation** | 4.067 Once in five years | | 1350<br>Once in five years | This flow will favour expansion of riparian habitats up to the bank full. The riparian vegetation in the banks will be provided with nutrients to perform and expands their communities beyond the banks.<br>This flow will also favour regeneration from propagules (seeds) in the banks allowing them to germinate and grow sufficiently. This flow will soak the soil in the bank and favour most of the woody species there such as *Acacia albida, Tamarindu indica, Combretum apiculata* and *Diospyros fischeri)*<br>Consequences:<br>This flow is suitable for woody riparian vegetation regeneration from seeds in the banks. At this depth, it is possible for | Lack of this flow limits the regeneration of woody species which are important for bank stabilisation. |

| | | | | | |
|---|---|---|---|---|---|
| | | | | seeds to germinate without being swept away into the stream. This can facilitate expansion of woody species populations.<br>This flow is needed once every five years. | |
| Geomorphology | | | | | |

### Dry season low flows for drought years (November)

Table 30 describes the requirement for each indicator at dry season low flows in a drought year, in terms of velocity, depth, and discharge. The motivation for each flow and the consequences of not providing them is described for each indicator.

**Table 30: Dry season low flows for drought years (November) at BBM2**

| Indicator | Ave Velocity (m/s) | Ave Depth (m) | Discharge ($m^3/s$) | Motivation | Consequences of not providing this flow |
|---|---|---|---|---|---|
| Fish* | 0.271 | 0.137 | 0.85 | These flows are required to:<br>• maintain hydrological connectivity in the system<br>• maintain inundation of critical habitats (e.g., riffles)<br>• sustain flow-sensitive species (e.g. *Chiloglanis* sp.)<br>• provide natural variability to maintain diverse species assemblage<br>Most of the EFA studies in Africa have used *Chiloglanis* sp as the most sensitive species for the basis for recommending flows for respective river basins. *Chiloglanis* has a very high requirement of fast flowing water in riffles, with recommended minimal flow for survival given as > 0.3 m/s.<br>In a fish sampling expedition conducted by WCS in the RNP *Chiloglanis* and *Amphilius* were also caught in different stretches of the river.Although *Chiloglanis* was not caught at BBM2, we assume that it exists along the entire river. Being the most sensitive species we would want to provide favourable conditions for its survival at all sites. | Could have catastrophic effect on the survival of sensitive species such as *Chiloglanis* and *Amphilius*. *Chiloglanis* do not tolerate pools and once inundation of riffles and channel connectivity is not maintained their survival is threatened. |

| | | | | | |
|---|---|---|---|---|---|
| Invertebrates | | | | | |
| Riparian vegetation** | 0.27 | 0.137 | 0.85 | Reasons for recommending this flow:<br>This flow is likely to favour propagules to regenerate by providing sufficient moisture to the woody species at the bank.<br>Moreover, there is a direct link between the duration of flows and reproductive cycle of the plant species. Reproductive lifecycles of most of the flow dependent riparian plant species have been modified to be completed within a short inundation period.<br>Most of the listed riparian plant species sensitive to flows have been used to make recommendations of the required flows in Tanzania. This includes *Leersia hexandra Schoenoplectus corymbosus, Phragmites mauritianum, A.albida, T. indica,*and *C.apiculata* | |
| Geomorphology | | | | | |

### Wet season low flows for drought years (April)

Table 31 describes the requirement for each indicator at wet season low flows in a drought year, in terms of velocity, depth, and discharge. The motivation for each flow and the consequences of not providing them is described for each indicator.

**Table 31: Wet season low flows for drought years (April) at BBM2**

| Indicator | Max Velocity (m/s) | Ave Depth (m) | Discharge ($m^3/s$) | Motivation | Consequences of not providing this flow |
|---|---|---|---|---|---|
| Fish* | 0.6 | 0.43 | 3 | These flows are required to:<br>• Inundate more riffle sections to increase habitat diversity<br>• maintain active channel flows to inundate benches and sustain emergent vegetation<br>• permit more fish passage over obstacles<br>• Flush out pools to improve water quality (more favourable habitats for fish).<br>The primary motivation for maintaining reasonably high low flows in the wet season of a drought year would be to inundate the main channel (especially riffles and benches) to provide a variety of habitats for resident fish species.<br>The recommended discharge would result in average hydraulic depth that is enough to cover an appreciable portion of mid-channel riffles. The resultant maximum velocity is suitable for *Labeo* and juveniles of other species which need appreciable inundated vegetation for cover/shelter and feeding. | Limit available habitats for *Labeo* and juveniles of *Barbus* sps occurring in that part of the river. It may result in lowering fish and macroinvertebrate standing biomass in that reach of the river. |

| | | | | | |
|---|---|---|---|---|---|
| Invertebrates | | | | These velocities and discharges are well above the requirements of most macroinvertebrate species found at the site. | |
| Riparian vegetation** | | 0.278cm | 4.5m$^3$/s | This flow is likely to favour the population expansion of both in stream and bank plant species. The roots of regenerating woody riparian plant species in the bank can access moisture to perform, clog the soil clods for bank stability, and provide sufficient forage for aquatic and terrestrial biota. This is suitable for the survival and reproduction of all the riparian vegetation (e.g. Permanently flow dependent species including *Leersia hexandra, Schoenoplectus corymbosus* and *Phragmites mauritianum* as well as the regenerants of *A.albida, T. indica,* and *C.apiculata*) | |
| Geomorphology | | | | | |

## Wet season high flows for drought years (April)

Table 32 describes the requirement for each indicator at wet season high flows in a drought year, in terms of velocity, depth, and discharge. The motivation for each flow and the consequences of not providing them is described for each indicator.

**Table 32: Wet season high flows for drought years (April) at BBM2**

| Indicator | Max Velocity (m/s) | Ave Depth (m) | Discharge ($m^3/s$) | Motivation | Consequences of not providing this flow |
|---|---|---|---|---|---|
| Fish* | 0.718 | 0.565 | 50 | These flows are required to:<br>• prevent sediment build-up on river bed, thus increasing habitat variability for fish and invertebrates<br>• maintain active channel features<br>• flush out organic matter, thus improving water quality<br>• facilitate nutrient transfer between floodplains and the river<br>A few small floods are necessary in the wet season of a drought year to inundate areas of the channel above the riffles in order to provide additional habitats for near-optimal growth of fish species.<br>The floods will also help to flush out organic matter deposited on lower banks and small pools that would otherwise impact on water quality. | Curtail optimal growth rates of fish in terms of less living habitats and poor water quality |
| Invertebrates | | | | | |
| Riparian vegetation** | | 0.43 | 3 | This flow is important for the survival of the woody species in the banks.<br>At this point most of the exposed roots of the woody plant species will be inundated to continue to provide water for photosynthesis and population expansion. | |

| | | | | | |
|---|---|---|---|---|---|
| | | | | The riparian plant species that can survive at this flow include all of the flow dependent species and the bank species such *as A. albida, T. indica,* and *C. apiculata)*. They can take over once the flow has increased.<br><br>NB. This flow is only needed for short periods in the rainy season | |
| Geomorphology | | | | | |

## 4.5. *Confidence in the assessment*

**BBM1**

Table 33 Shows the level of confidence expressed by each specialist in the EFA carried out at BBM1 Confidence is rated on a scale of 1 to 5 where 5 represents a very high degree of confidence, whilst 1 represents a very low degree of confidence.

**Table 33: Confidence in the EFA assessment at BBM 1**

| | Confidence rating | Motivation |
|---|---|---|
| Hydrology | 4 | Absence of automatic recordings of the flood peaks has influence on the floods could be a real problem in providing very realistic flood peaks.<br>However, the flow data used in this assessment was representative in terms of long-term average with less reliability on the higher peaks as might have been observed than was found in the historical records.<br>Despite that, the hydrological data is considered sufficiently accurate adequate for the analysis |
| Hydraulics | 4 | A riffle site was captured as a strong and reliable hydraulics control |
| Geomorphology | 4 | The maintenance flow recommended to move sediments are usually superimposed to the extreme/extraordinary conditions that may be involved in moving large load than maintenance flows |
| Riparian vegetation | 4 | The information present explains sufficiently the riparian ecology in the GRR. However, due to browsing some died back seedling or stumps remaining were not easily identified. But the present species are representative as such.<br>The flows recommended in this site therefore are required to maintain the current ecological conditions and probably restoring the modified habitat in the riparian ecosystem |
| Fish<br>Invertebrates | 3<br>5 | Fish sampling (data collection) was complicated by presence of hippos moving up and down the river. Nets were destroyed and their use had to be discontinued.<br>Just one season was sampled and few hours (less than 5 hours) were spent in sampling. Experience in Tanzania show that there are more fish in rivers to catch during early wet season as many spawning migrants move about in the river looking for suitable sites to spawn. |

**BBM2**

Table 34 Shows the level of confidence expressed by each specialist in the EFA carried out at BBM2.

**Table 34: Confidence in the EFA assessment at BBM 2**

| | Confidence rating | Motivation |
|---|---|---|
| Hydrology | 5 | Absence of automatic recordings of the flood peaks has influence on the floods could be a real problem in providing very realistic flood peaks.<br>However, the flow data used in this assessment was representative in terms of long-term average with less reliability on the higher peaks as might have been observed than was found in the historical records.<br>Despite that, the hydrological data is considered sufficiently accurate adequate for the analysis |
| Hydraulics | 3 | Absence of stong hydraulic controls |
| Geomorphology | 4 | The maintenance flow recommended to movie sediments are usually superimposed to the extreme/extraordinary conditions that may be involved in moving large load than maintenance flows |
| Riparian vegetation | 4 | As explained in BBM1, the information present explains sufficiently the riparian ecology in the GRR. This is because the representative permanent flow dependent riparian plant species were exhaustively identified and are comparable the composition of the same from other river in Tanzania.<br>Therefore the minimum flows recommended at this study sites are carefully considered the needs of the flow dependent species and those which needs short term inundations |
| Fish<br>Invertebrates | 3<br>3 | Just one season (flow) was sampled and only few hours spent in sampling. |

## *4.6. Priorities for further information*

### General

Two further BBM sites should be established, one on the rejuvenated high gradient zone downstream of BBM2, and the other on the braided floodplain section upstream of the Mtera inflow as identified by the geomorphologist during this study and detailed in the geomorphology starter report which is available from WWF TCO and RBWO. The purpose of these further sites is to check that the recommended flows for BBM1 and 2 will also meet the objectives for the river downstream.

### Hydraulics

As the sampling was conducted during medium flows, another sampling programme in low flow seasons is recommended. During the latter season it is expected to adequately capture the micro-topography of the hydraulic controls and critical low flow conditions for the aquatic life.

### Hydrology

Rating information for high flows at the source site (Msembe gauging station), and flow data at the selected BBM sites (both high and low flows), are still needed.

### Geomorphology

Information regarding extreme conditions (extraordinary high flows) is needed in order to determine how often or at what intervals when extraordinarily changes of channel morphology occur.

### Riparian vegetation

Further sampling is required to gain a more comprehensive understanding of riparian vegetation dynamics with relation to flow.

### Fish and invertebrates

Sampling in different flows (wet and low flows in a calendar year) is still required, as well as more sampling (possibly 2 days of sampling spent in one site)

## *4.7. Way forward*

The following actions were agreed in order to be able to apply the information derived from this EFA study and restore flows to the GRR:

- The survey boat will be repaired and the wetland assessment will be undertaken
- The feasibility study for all options needs to be undertaken but may be challenging. The transfer option is preferred and could give a quick solution to the problem of restoring flows. It may be possible to try and obtain WWF funding for this.
- An EFA of the Eastern wetlands should be undertaken.
- The socio-economic study to accompany EFA findings needs to be looked into.

- The coordination of ecological data capture and distribution, and collaboration between WWF, Natparks etc., will be looked into by WWF. A scoping study and a website for networking were suggested.
- The possibility of a study to disaggregate anthropogenic impact from climate impact, i.e. a vulnerability assessment to assist with planning will be looked into.
- The issue of an EFA co-ordinator will be discussed soon.
- Meetings will take place to see how to share information and conduct EFAs in a nationally more coordinated manner. This will be discussed soon, to decide if each basin should have a co-ordinator and with whom they would liaise.
- Stakeholders must read the reports they receive, make comments and use the opportunity to be informed and involved
- The specialists recommended that Dr Rashid Tamatamah of the University of Dar es Salaam should be appointed coordinator of EFA activities for future assessments. This will mean that Tanzania now has a complete team capable of planning and carrying out EFA projects for its rivers. More specialists, such as hydrologists, ecologists, etc. need training in the EFA methodologies. This should not be too expensive or take too long.

# 5. Identification and assessment of options to restore flows to the Great Ruaha River in the Ruaha National Park (February 2009)

## *5.1. Background*

### 5.1.1. Introduction

This section focusses on ways to maintain environmental flows within the RNP during the low flow periods, without undermining the importance of the other problems experienced within the Usangu catchment and beyond. Solutions that may solve more than one problem are ideal – nevertheless, the primary focus of this work is on the drying of the GRR in the RNP.

### 5.1.2. Problem summary

The fundamental problem is a cessation of flow within the GRR in the RNP. Preliminary EF investigations suggest that minimum flows in the GRR within the RNP of 0.5 cumecs are required, with low flows of 1 cumec preferred. Given the extensive water losses in the ihefu swamp, this corresponds to inflows to the swamps of 7 – 8 cumecs.

The reality is that achieving such inflows through a reduction of use is particularly difficult, given the economic and social requirements for water abstraction in the Usangu Plains. While various water savings could be achieved through improved irrigation and canal management, nevertheless, a total reduction of 65-90% of current dry-season abstraction would be required to achieve the necessary ihefu inflows. Given that Tanzania has prioritised irrigation agriculture in her key economic growth and poverty reduction strategies, and given that current global commodity booms will reflect into local Tanzanian food markets driving increased agricultural activity in fertile and accessible areas such as Usangu, attempts to achieve the 65%+ reductions in water consumption in the Usangu Plains are going to meet with resistance and is probably not feasible.

Accordingly, an alternative solution to this problem must be sought, which may include engaging with irrigation to increase efficiencies and reduce abstraction. It is important to highlight that total annual flows in the GRR are significantly greater than annual water requirements and that opportunities for extending productive water use exist, either during the wet season or through improved management of MAR.

## *5.2. Options to restore low flows*

Options to restore low flows in the RNP to achieve 0.85 – 3.0 cumec dry-season flow in the GRR downstream of Ng'iriama.can broadly be classed into a number of categories:

- Technical (engineering) options: these are engineering based options that require the construction of infrastructure and are related to the construction of storage, the development of transfer schemes or the abstraction of groundwater;
- Institutional options: these are linked to the management of the resource through the development of particular institutional arrangements and the development / deployment of water resource management instruments;
- Environmental options: related to the management of land or land-use to retain environmental services and functions;
- Agricultural options: relate to the management of agricultural activity and adaptation of agricultural practices; and
- Economic options: these are options linked to economic development and the provision of alternatives to current economic practices.

### 5.2.1. Transmission losses in the Great Ruaha River

Before considering the options to restore flows to the GRR, the issue of transmission losses in the system as water flows through the RNP must be addressed.

A first-order desk-top assessment of transmission losses, based on the Manning's Equation was undertaken, although ideally, these losses would be quantified through field analyses combined with hydrological modelling. It was felt that this was a useful indication of transmission losses and therefore water requirements at Ng'iriama.

The input and output for the Manning's Equation are shown in Figure 18.

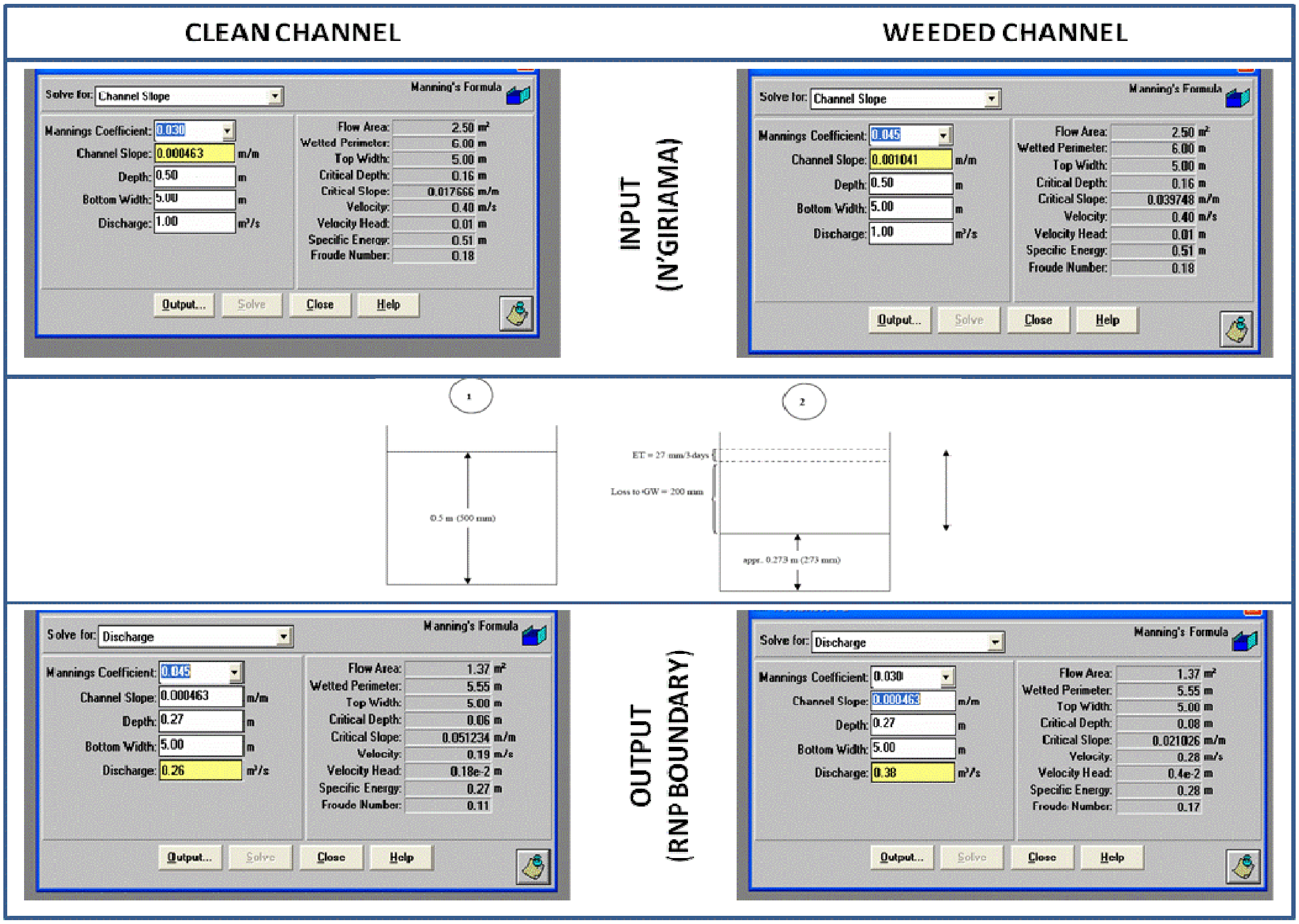



**Figure 18: Model input and output for the desk-top determination of transmission losses in the GRR between Ng'iriama and the RNP boundary (100km downstream)**

The key finding is that 1 cumec released at Ng'iriama results in flows at Lunga (RNP boundary) of 0.26 – 0.38 cumec, depending on key channel characteristics. Alternatively, 0.5 cumec at Lunga implies 0.85 cumecs at BBM 2 (see the EFA report for location and description of BBM 2) and requires a release of 1.5 cumecs at Ng'iriama.

In summary, a first-order assessment of the transmission losses suggests the following:

- To get some water to flow through the RNP, a release of 0.6 cumecs at Ng'iriama is required; and
- To get the required 0.85 cumecs at BBM2, a release of 1.5 cumecs at Ng'iriama is required.

### 5.2.2. Technical options

Technical options applicable to the GRR problem include:

- Storage options:
  - impoundment in the uplands / tributaries (e.g. Ndembera River)
  - increased storage in the wetland (Usangu)
  - small-scale, off-channel storage in fans
  - impoundment on a tributary in the RNP (e.g. Njongomero River)
  - groundwater storage through artificial recharge
- Transfer options
  - Transfer from Nyalunga to Ng'iriama
  - Transfer over the sill at Ng'iriama
  - Inter-catchment transfer from upland catchment
  - Inter-basin transfer (e.g. Pangani River)
  - Channelisation of the wetland to ensure short-circuiting
- Groundwater options
  - Groundwater abstraction as alternative to river abstraction for irrigation
  - Groundwater abstraction to provide domestic (tail-end) use
  - Groundwater abstraction to maintain dry-season GRR flow

#### Upland impoundment

Impoundment of one of the larger highland rivers will enable storage of rainy season runoff that can be released during the dry-season to augment flows into the eastern wetland. In theory, MAR stored in the impoundment is released during the dry season to ensure flows into ihefu of 8 cumecs or more, thereby enabling outflow from the swamp at Ng'iriama of 1 cumec.

The Ndembera River is an ideal choice for impoundment, for four reasons:

1. it flows directly into the eastern wetland (it is the only perennial river to do so);
2. it has significant MAR - about 15% of inflow into the eastern wetland or approximately 500Mm$^3$;
3. impounding the Ndembera River was extensively studied as part of the feasibility of the Madibira Rice Scheme; and
4. various additional benefits can be derived from this impoundment, including the generation of power (feasibility on a 2MW hydropower plant has been undertaken), the storage of water for additional irrigation, aquaculture and recreation / tourism.

Operating rules will have to be carefully developed to ensure that the various (possibly conflicting) uses of water are supplied.

### Increased wetland storage

Increasing wetland storage is achieved through raising the sill at Ng'iriama using an artificial structure (weir), which will capture some of the flood flows currently flowing over the ihefu outflow and will increase the size of the permanent swamp. This increased storage is released during the dry season through operation of the weir, draining the enlarged ihefu of 1 cumec of flow until flood waters again flood the eastern wetland (and the weir). Cursory analysis suggests that raising the sill by 1m will increase storage sufficiently that a 1 cumec dry season flow from ihefu can be maintained, without dropping the water level below the height of the natural sill.

A key issue to consider is the feasibility of the construction, as the natural granite sill may not be easily raised - the apex of the sill is almost certainly not a straight line and may extend across the outflow for some distance, requiring a complex and extensive structure.

### Off-channel storage in the fans

Given the high MAR in the south-eastern highland rivers and the south-eastern fans, this option explores constructing off-channel storage facilities (off-channel dams) to capture some of these high flows. This stored water is then used as an alternative to river abstractions in the dry season and feeds the major irrigation off-takes.

Key issues to consider include suitable sites for such off-channel storage, financing and ownership, and institutional-operational arrangements to ensure adequate flow for all users, including tail-enders.

### RNP tributary impoundment

Impoundment of one of the tributaries of the GRR in the RNP introduces an interesting option for restoring flows to the GRR in the RNP. In particular, this option would require a far smaller impoundment than any above the eastern wetland, given the extensive loss of water from the swamp through evapotranspiration - an impoundment above the eastern wetland has to release circa 8 cumecs into ihefu to achieve a 1 cumec discharge at Ng'iriama, while an impoundment on a tributary within the RNP would only release 1 cumec to achieve the same flow in the GRR. However, such an impoundment does not offer the additional opportunities for productive use of the water, that an impoundment in the Usangu Catchment enables. It appears that there have been some discussions within TANAPA regarding impoundments in RNP, to provide dry-season water to wildlife.

The Njongomero River appears a possible choice, although further investigation of suitable tributaries must be undertaken. Such investigation should consider:

- Sufficient MAR to support dry-season flow;
- Suitable sites for impoundment;
- Location within the RNP – the tributary should be relatively close to Ng'iriama;
- Environmental impacts of impoundment in the national park; and
- Issues of sediment transport and siltation of the impoundment.

### Groundwater storage

Artificial recharge of groundwater uses flood flows to recharge aquifers, for abstraction during the dry-season. Such recharge requires a sound understanding of the aquifer, high hydraulic conductivity and well established well fields. Accordingly, such recharge is possible within the alluvial soils of the fans, and could be linked with extensive groundwater abstraction systems used in conjunction with surface water abstraction (conjunctive use schemes). However, very little is known about the groundwater situation in the fans and it is not clear that abstraction rates sufficient to support large-scale irrigation could be achieved, without massive capital investment.

### Transfer from Nyaluhanga to Ng'iriama

This option entails a transfer scheme, either a pipeline or a canal, from Nyaluhanga to Ng'iriama, diverting 1 cumec at Nyaluhanga for discharge into the GRR below Ng'iriama. Direct distance from

Nyaluhanga to Ng'iriama is about 30 km, with the transfer crossing the Usangu Plains to the north-west of the eastern wetland and crossing the Kimbi River.

While this option reduces flow into the ihefu swamp, these impacts are probably less than the benefits received from restoring flows to the GRR. Few other benefits could be derived from this scheme, unless more water than that required for the GRR low flow is diverted, with the additional diversion used for the expansion of irrigation or domestic / livestock use.

Important considerations include technical feasibility of constructing the transfer, operational issues such as protection from vandalism or abstraction, and the availability of water at Nyaluhanga, given that zero flows from the western wetland are said to occur during the dry season.

### Transfer over the sill

A second transfer option is to directly transfer 1 cumec over the sill. A short pipeline would be required, with the outflow beyond the sill placed at a lower elevation than the intake placed within a deep portion of ihefu near Ng'iriama. The pipeline would be constructed to allow 1 cumec of flow at all times – such flow would be insignificant during the flood flows, but would support EFs in the GRR during the dry season. The pipeline would ensure that flow into the GRR continues even if the water level in ihefu drops below the level of the granite sill.

Important considerations include technical feasibility of the transfer (particularly requirements to protect the pipeline during flood flows), operational issues such as blockage of the intake, and environmental impacts on the ihefu swamp, although these should be negligible.

### Inter-catchment and inter-basin transfers

These options are variations on the transfer from Nyaluhanga to Ng'iriama, either sourcing the required water from an upland (highland) catchment through diversions from one of the perennial rivers, or through inter-basin transfers from the Pangani Catchment. Feasibility based on cost and technical issues is limited in the latter option. However, an inter-catchment transfer from the Ndembera River catchment or the Kimbi River catchment to Ng'iriama may be feasible.

Transfer from the Ndembera River is particularly attractive, given its perennial flow and the proximity of the lower reaches to the ihefu outflow at Ng'iriama (a few Km). A partial flow diversion would suffice, given that only 1 cumec is required  and would probably only require the construction of a simply weir structure and a diversion pipeline. Diversion of the Kimbi River is not as attractive, as the river is not described as perennial and the diversion pipeline would be longer.

Whilst a potentially attractive option, a number of technical issues remain to be resolved regarding the feasibility of the inter-catchment transfer.

### Ihefu channelisation

One of the causes of flow cessation within the GRR is said to be blockage of channels within the swamp, resulting in retardation of free water and ponding (with increased evapotranspiration). Historically canals were kept open by macro-fauna (hippopotami) and later by fishermen and livestock. However, recent changes to the management of swamp have excluded the fishermen and pastoralists, and hippo have not yet returned. Accordingly, an option exists to open channels within the swamp and to maintain open channels, particularly during the dry-season.

While it is unlikely that this measure alone will support adequate flow from ihefu through the dry season, it may be a useful adjunct to other options. A community-based approach to channel management may also have local economic benefits.

### Groundwater abstraction

Groundwater is poorly utilised in the Usangu catchment and the RNP. Accordingly, this option explores the use of groundwater as an alternative to irrigation abstraction from the rivers in the fans, as an alternative to domestic requirements by tail-enders on the irrigation canals, or as an alternative means to source 1 cumec of flow within the RNP.

- Alternative to irrigation from surface water abstraction: a small groundwater study undertaken through SMUWC suggested that a significant aquifer exists within the fans, but that hydraulic conductivity is probably too low to support large-scale irrigation from groundwater. However, very little information on the aquifer is available and no detailed hydrogeological study has been undertaken. Nevertheless, it seems unlikely that significant irrigation savings could be achieved through conjunctive use.
- Alternative to tail-enders: diversions in the irrigation canals are maintained even when irrigation demand is limited (or absent) during the dry season, to provide water to tail-enders for domestic use. Shifting such domestic use to groundwater may enable stricter management of canal diversions. Groundwater studies undertaken during SMUWC suggest groundwater quality and aquifer quantity in the Usangu catchment is adequate for domestic use and possible livestock watering.

- GRR low flows restored through groundwater abstraction: no studies of the hydrogeology of the RNP have been undertaken and as such groundwater within the park is unknown. This option explores using groundwater to augment flows within the GRR, through abstraction groundwater and discharging into the river channel. However, a significant well field would have to be constructed, with 1 cumec of flow (1000 l/s) equivalent to at least 50 wells (at an average of 20 l/s) and probably a field of several hundred wells. Costs, technical feasibility and large areas of uncertainty regarding supply and recharge make this option unlikely.

### 5.2.3. Institutional options

The generic management cycle as applied to water resources is described in Figure 19

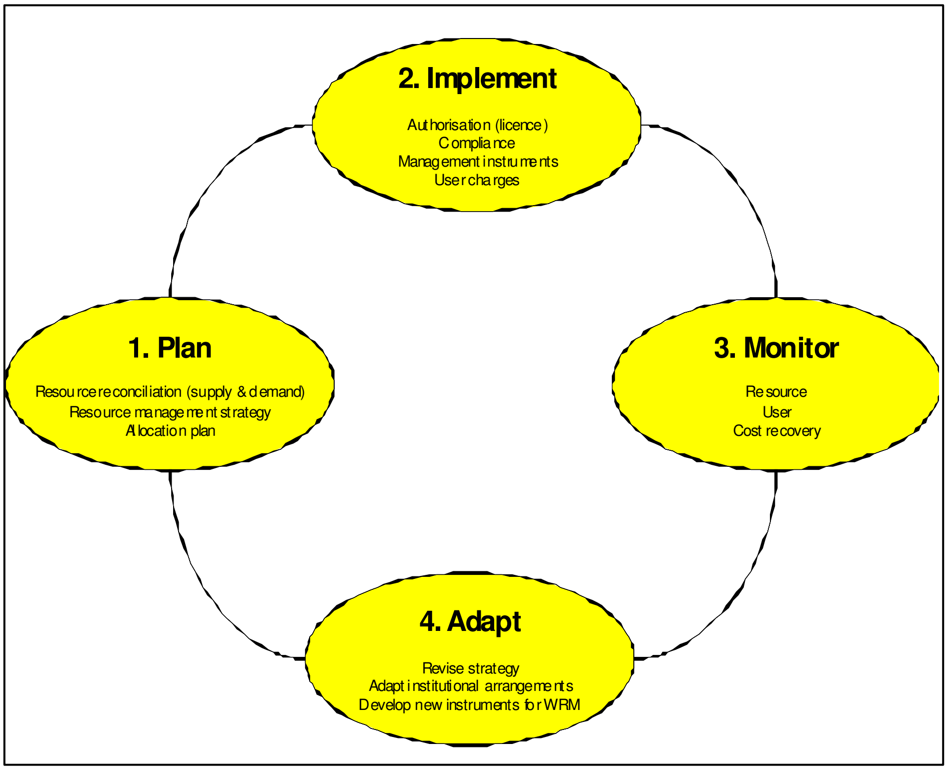



**Figure 19: The water resources management cycle**

- Planning requires understanding the catchment – water availability and quality, water use requirements and appropriate allocation to competing users – and enables the development of management plans based on that understanding;
- Implementation gives effect to the plans, by authorising water use (licences), ensuring compliance with licence conditions, implementing management interventions (e.g. awareness

programmes, economic instruments, demand-management, etc.) and recovering management charges;

- Monitoring enables a dynamic understanding of the system to be developed, based on monitoring of the resource (availability and quality), monitoring of use (demand and distribution) and monitoring cost recovery (financial viability); and
- Based on a dynamic understanding of the resource, new planning can be undertaken and strategies and management approaches adapted (adaptive management).

All these elements must be in place, to achieve efficient and effective water resources management (WRM). Accordingly, it is worth noting that appropriate institutional arrangements are central to the effective management of a stressed water resource, and therefore the question is not whether these measures should or should not be implemented – improved WRM through appropriate institutional arrangements and management instrument is clearly required given the extent of the problem encountered in the catchment. The question here is whether these instruments will restore dry-season flows to the GRR, and how feasible or realistic the required (ideal) institutional arrangements are?

Based on the cycle described above, the key areas were additional focus is required are:

- Allocation planning and scheduling of abstraction (planning)
- Reducing illegal abstraction (authorisation)
- Increased compliance with existing regulations, licence conditions and agreements (compliance)
- Pricing and economic instruments (pricing to drive efficiency and water trading to enable purchase of water use rights)

Various studies on the Usangu Catchment have developed a relatively good understanding of many elements of the system. Nevertheless, some components of the system are still largely unknown, including the highlands and groundwater, and a detailed systems analysis has not been undertaken. Accordingly, a consistent challenge facing the responsible authority is the allocation of resources and the issuing of further licences – significant demand exists but it is unclear what the impact of such allocation will be on the resource (in the absence of a detailed systems analysis). In addition, various pressures and drivers within the catchment are placing increasing pressure on the responsible authority to allocate more water for productive purposes. A need exists for detailed allocation planning based on a detailed understanding of water demand and availability within the system. In addition, allocation scheduling and the concept of "assurance of supply" introduce an opportunity to spread the scarce resource more widely and reflect the marked variability in run-off, both intra-annually and inter-annually.

Evidence suggests that significant illegal abstraction of water is taking place, either from the diversion canals or directly from the resource. Such illegal abstraction undermines the ability of the responsible authority to effectively manage the resource, or perform appropriate planning. Linked to the issue of illegal abstraction is the need to ensure enforcement of licence conditions and allocation schedules. Accordingly, a significant need exists to improve compliance, based on appropriate monitoring and a legal framework that supports enforcement.

Finally, an opportunity exists to explore economic and pricing instruments to drive increased efficiency of water use, demand-management and market mechanisms to enable the transfer of water use rights. However, such mechanisms require strong institutional environments to function effectively and are plagued by perverse outcomes where the institutional environment fails. Accordingly, their applicability to the Usangu catchment and the GRR is questionable.

Key issues to consider are the availability of appropriate information, necessary legal and institutional frameworks, and resource constraints – human, financial and technical.

### 5.2.4. Environmental options

Environmental options relate specifically to the highlands, and the management of land to reduce soil losses, land degradation and stream-flow reduction activities. Accordingly, these options seek to restore or maintain ecosystem goods and services, and have been shown to be effective mechanisms in managing water resource quality and quality problem in other parts of the world.

However, evidence from SWUMC and other studies suggest that land degradation and environmental change have not resulted in significant flow reduction in the highlands, and that environmental change on the fans is linked to agricultural activity that cannot be readily reversed. Accordingly, it would appear that environmental management is unlikely to be significant in restoring low flows. Nevertheless, the importance of sound management of the environment should not be underestimated in improved water resources management, and further work in the highlands in particular may highlight environmental management options that are currently not evident.

### 5.2.5. Agricultural options

These options relate to the management of agricultural activities and agricultural practices. In particular, the following opportunities can be described:

- Increased efficiency of irrigation practises

- Alternative crop use
- Cessation of dry-season irrigation

### Increased efficiency of irrigation

Irrigation efficiency on the Usangu Plains was extensively studied under SMUWC and RIPARWIN. A number of practices result is very low dry season water use efficiency:

- The irrigation and canal system (involving a lack of sufficient density of secondary and tertiary canals) requires that water passes through harvested rice fields to reach more distant rice fields, resulting in considerable waste;
- The use of sunken tertiary canals in the NAFCO farms which leads to very high dosages of water per irrigation;
- Towards the end of the dry season, water is used for field preparation for early plantings of the next season's crop;
- Flow is also maintained in the primary and secondary canals to provide for domestic uses, particularly on the large-scale commercial farms. While total domestic demand is very small, meeting them involves significant conveyance losses; and
- Large 'unaccountable' losses remain, even after the losses described above have been imputed.

As a result, it was demonstrated that efficiency during the dry season is low, in the order of 20% efficiency estimated by SMUWC. In total, SMUWC estimated that 50% of dry-season diversions could be retained in the river, without affecting agricultural productivity on the Usangu Plains. This is particularly the case where alternative water is provided to tail-enders and domestic use. SMUWC estimated that 2 - 5 cumecs of flow could be retained in the rivers through improved canal management, while RIPARWIN estimated that 2 – 7 cumecs could be retained through closure of the canals during the dry season. However, these are average figures and savings during the late dry season (October and November) are significantly lower, averaging below 2 cumecs. Nevertheless, it is clear that efficiencies in irrigation in the Usangu Plains should be improved and these represent significant savings. The critical issue is to retain water in the rivers through reduced abstraction, rather than the common practices of passing water through irrigated fields with the expectation that farmers return drainage to the rivers (institutionally more complex and involves unmanageable losses en-route).

Key issues with increasing efficiency of agricultural usage include compliance and alternative productive uses for the water freed-up through the increased efficiency (e.g. alternative crops or increased dry-season irrigation). Institutional arrangements for WRM in the Usangu Catchment will have to be well established to ensure that water savings achieved through improved agricultural water use efficiency are not used to grow additional crops or diverted to other productive uses, but are left within the GRR. Delivering higher efficiency is not easy – one approach might be for farmers in different parts of an irrigation system or sub-catchment to share ideas regarding their water management. Thus tail-enders are usually able to obtain 2-3 tonnes of rice per 900-1000 mm of water, while top-enders do only marginally better while using 25-40% more water. Sharing ideas was the main design aim of the river basin game (RUBADA – see RIPARWIN), a dialogue tool for farmers used with good outcomes in the Usangu.

**Other agricultural adaptation**

Other agricultural adaptation could be considered, such as changing crop type or moving to short-season (120 day) basmati types (requiring less flooding). Moreover, it is possible that other livelihood strategies (even livestock husbandry) may result in greater economic return, which could underpin changes in livelihood strategies away from irrigation. However, the reality is that existing market structures, technical support systems, infrastructure investment, knowledge and social practices make such changes unlikely and largely unfeasible. Therefore, although these options are theoretically feasible and should possibly inform long-term water allocation planning and land-use planning, dramatic changes to current land-use within the catchment are unlikely.

A further option worth considering is the use of the floating plant, Azolla sp., to reduce evaporative losses from the rice paddies – Azolla is said to reduce water loss from free water surfaces by up to 50%. It has the added advantage that it fixes nitrogen and is a useful natural fertilise. Azolla has been used in SE Asia to reduce water loss from rice paddy systems. Several indigenous species of Azolla are reported to occur in Tanzania, potentially reducing the environmental impact of widespread usage of this plant. However, the literature contains mixed reports on the success of Azolla and significantly further investigation of this option is required before it could realistically be deployed.

### 5.2.6. Economic options

Economic options are included here for completeness sake – they refer to providing alternatives to current water use practices, to increase productivity of water use and find mechanisms to restore flows without jeopardising household income or geographic product. However, within the Usangu Catchment such alternatives are limited. Brick-making, livestock and tourism are the principal, realistic options, and it is highly unlikely that these activities could ever significantly replace agriculture in the catchment, particularly given national and global drivers for agricultural expansion already discussed above. Accordingly, it is unlikely that significant opportunity exists to fundamentally shift the economic activities of the Usangu Catchment, at least in the short- to medium term.

## 5.3. Evaluation of options

### 5.3.1. Criteria

Criteria are required through which options can be compared, to enable identification of a list of preferred options (short-list).

#### Qualifying criteria

Overarching, qualifying criteria can be described (Table 35) – ability to achieve the objective of restoring flows (i.e. does the option put the required 1 cumec back into the GRR throughout the dry season) and sustainability of the option to maintain the sustained flow (i.e. will the option continue to put 1 cumec of water back into the GRR for years to come). These qualifying criteria inform the first level of analysis (first filter), which determines whether an option qualifies for further investigation.

**Table 35: Qualifying criteria**

| Qualifying Criteria | Disqualify | Qualify |
|---|---|---|
| Objective: flow restoration | *Does not achieve objective* | *Achieves objective* |
| Sustainability | *Unsustainable* | *Sustainable* |

#### Viability criteria

Viability criteria are the second level of analysis (second filter), and can largely be grouped into assessment criteria that address whether the option is feasible (i.e. is the option "doable") and whether the option is implementable (i.e. is the option "workable"). The following viability criteria were identified (Table 36).

**Table 36: Viability criteria**

| Feasibility Criteria | Score | | |
|---|---|---|---|
| | -1 | 0 | +1 |
| Technical feasibility | *Not feasible* | *Feasible* | *Highly feasible* |
| Financial feasibility | *Not feasible* | *Feasible* | *Highly feasible* |

| | | | |
|---|---|---|---|
| Economic impacts | *Negative impacts* | *No net impacts* | *Positive impacts* |
| Environmental impacts | *Negative impacts* | *No net impacts* | *Positive impacts* |
| Institutional simplicity | *Highly complex* | *Complex* | *Simple* |
| Operational requirements | *Highly complex* | *Complex* | *Simple* |
| Stakeholder acceptability | *Unacceptable* | *Acceptable* | *Highly acceptable* |
| Rollout requirements | *Complex implement.* | *Moderate implement.* | *Simple implement.* |

***Technical feasibility***

This relates primarily to technical interventions and reflects the extent to which the option is technically feasible given the likely constraints.

***Financial feasibility***

This refers to the capital cost of the option and the likelihood of finding funding or financing to implement the initiative.

***Economic and strategic impacts***

This criterion refers to the direct economic impacts of the option, for example employment opportunities (short- or long-term), livelihood changes, local economic development and diversification, etc. It also refers to broader strategic and economic national objectives that the option supports, besides the restoration of low flows in the RNP.

***Environmental impacts***

This criterion refers to the possible environmental impacts of implementing the option (excluding the impacts of restoring flows).

***Institutional simplicity***

This criterion refers to the institutional complexity that the option introduces, and links to the presence of an enabling legal framework and to the institutional and organisational arrangements demanded by the option – the simpler the institutional arrangements, the more attractive the option.

***Operational / management requirements***

This criterion assesses the simplicity of operation or management of the option – the simpler an option to operate, manage or administer, the more attractive that option.

***Stakeholder acceptability***

This criterion refers to the extent to which the option is likely to be acceptable to the various stakeholders in the catchment.

***Roll-out requirements***

This criterion refers to the measures required before the option can be effected and the parallel processes required for rollout. Where the implementation process is complex, lengthy and fraught with various political, administrative or other hurdles, implementability is undermined. This criteria therefore refers to how quickly environmental flows can be achieved within the GRR.

Scoring against the criteria is according to a three-point system:- +1 for a positive attribute; 0 for a neutral attribute; -1 for a negative attribute

Where a criterion is not applicable, a neutral attribute score (i.e. 0) is applied. In addition, criteria are subjectively described as critical or as important.

### 5.3.2. Qualifying criteria analysis

Each of the options are assessed against the two qualifying criteria:- (1) does the option by itself achieve the objective of restored dry season flow (1 cumec) to the GRR, and (2) is the flow restoration achieved through the option sustainable (i.e. will flow restoration by the option be maintained).

### Ndembera impoundment

The Ndembera Impoundment option both achieves the objective of restoring flow to the GRR during the low flow periods and is sustainable in the long term. Studies conducted on a dam on the Ndembera River to support agricultural development in the catchment started in 1987 and a suitable site has been identified at Lugoda Village. The site is sufficiently large to ensure sustained release of at least 8 cumecs during the low flow periods (significantly more water can be stored, allowing for additional productive and consumptive users of water to be explored).

Sustainability of the dam is considered good in the long term, given that the site is good, siltation problems are not as severe as elsewhere in the catchment, and long-term operational, management and maintenance requirements are relatively simple. The proposed Lugoda Dam is significantly multi-purpose – it will support expansion of irrigation at Madibira (Madibira Phase II) by 3600 ha, it will produce energy through the construction of a 2 MW hydropower facility at Maluluma Falls, it will support fishing and a recreational industry, and it will providing storage to meet environmental flow requirements. Construction of the Lugoda Dam have been repeated proposed by the Tanzanian Government as part of irrigation expansion at Madibira (Madibira Phase II proposals).

The Ndembera Impoundment option qualifies in terms of the first filter qualifying criteria.

### Increased Ihefu storage

Conceptually this option achieves the objective of meeting the low flow EF requirements of the GRR. Increasing storage within Ihefu by artificially raising the level of the sill by 1m creates sufficient additional storage within the system to enable a 1 cumec drawdown during the 5 month low flow period (including accounting for evapotranspiration).

Artificially raising the sill through an engineered wall structure would require sluices at the base of the wall that enable a constant release of 1 cumec. Such a design implies that operational issues are limited to ensuring that the sluices are functional, and long term maintenance and management is simple. Accordingly, sustainability of the option is good in the long-term, assuming a feasible concept.

The increased Ihefu storage option qualifies in terms of the first filter qualifying criteria.

### Off-channel storage in the fans

Off-channel storage in the fans is unlikely to achieve the objective of restored low flow EF requirements for three reasons:

1. Significant storage is required and the topography of the fans does not lend itself to such storage – superficial evaluation suggests that only shallow dams could be constructed on the fans, which implies that siltation and evaporation losses are a problem;
2. Institutional arrangements related to these dams would be very complex – only the largest water users could afford to build such dams, which does not address the issues of the smaller users requiring the water for early season planting and domestic use (tail-enders); and
3. It is not clear that the water freed-up would not simply be utilised elsewhere in the system for additional agriculture.

Accordingly, in the absence of a very strong water resources management institutional environment, it is evident that this option will not support downstream flows. However in the presence of strong institution, this option may be attractive to manage complex water allocation related issues, and may be a mechanisms through which productive use of water is increased in the Usangu plain, without jeopardising EFs.

Off-channel storage does not qualify in terms of the first filter criteria as an option to restore flows to the GRR. However, it should be stressed that the option should be explored by the responsible authority as a means of improving WRM in the Usangu catchment.

### RNP tributary impoundment

The impoundment of a tributary of the GRR, downstream of the sill at Ng'iriama is attractive because significantly less water storage, compared to impounding the Ndembera River impoundment option, is required to achieve the low flow EF requirements in the GRR (i.e. a smaller impoundment will suffice). Three rivers potentially come into contention – the Itiku, the Mdonya and the Mwagusi Rivers – as these have significant wet season flow, large enough to fill an impoundment that will sustain a dry season 1 – 2 cumec release. This option therefore achieves the objective, at least in the short term.

However, sustainability of the option fails for three reasons:

1. All of the potential rivers for impoundment are seasonal streams that carry very high sediment loads during the rainy season flood flow events. Accordingly, the impoundment would receive very high sediment loads and would rapidly fill with sediment;
2. Very few suitable dam sites are available within the RNP, with most sites implying a large, shallow dam that would not only silt up rapidly, as described in 1 above, but would also lose significant water through evaporation from the large surface area; and
3. Various environmental impacts would be experienced. Providing permanent water within a seasonal stream affects aquatic and riparian ecology and biodiversity, and changes the migration patterns of fauna within the national park. Moreover, given that a large, shall dam would be required, an unacceptably large surface area of riparian vegetation would possibly be inundated.

Accordingly, on the basis of the poor sustainability of the option, impoundment of a tributary within the RNP is disqualified from further investigation.

### Groundwater storage

Groundwater storage is unlikely to achieve the objective of restored low flows in the GRR for three reasons:

1. While the hydrogeology of the Usangu catchment and the RNP remains largely unknown, preliminary studies suggest that the alluvial sediments of the fans are the only likely aquifer of remotely significant proportion in terms of storage capacity – storage outside of the fans (e.g.

within the RNP) is not feasible, given that the presence of suitable aquifers has not been demonstrated. Hydraulic conductivity within the aquifer is important to enable rapid infiltration of water into the aquifer, and to enable rapid abstraction to support the major water use activities in the catchment – irrigation. While the fans as a whole could support a significant aquifer, hydraulic conductivity in the fans is almost certainly inadequate to enable abstraction for irrigation and is probably inadequate to enable sufficient artificial recharge using flood-flows from the high-lands;

2. Groundwater quality within the fans aquifer is largely unknown – there is some evidence of poor quality saline water and some other evidence of reasonably good quality water. Artificial recharge is only feasible where the geochemistry of the aquifer will yield water of sufficient quality to enable irrigation and live-stock watering – it is not abundantly clear that this would be the case should artificial recharge be practices in the fans; and

3. While artificial recharge of aquifers is a developed practice in certain parts of the world (Western US, Australia and the Middle East, amongst others), the technology and expertise require are poorly developed in Tanzania (throughout most of sub-Saharan Africa) and the technical design and institutional management of the system would be a significant challenge.

Moreover, sustainability of the option is unlikely, for two reasons:

1. Institutional arrangements for the construction, maintenance and management of a large scale artificial recharge and abstraction scheme on the Usangu fans are highly complex and it is unlikely that the multiple stakeholder arrangements that would be required could be sustained; and

2. Technical maintenance of the system would be complicated, given the requirements for infrastructure, power and hydraulic technology.

Accordingly, it is clear that artificial recharge of groundwater (groundwater storage) within the Usangu Catchment does not qualify for further investigation.

### Transfer: Nyaluhanga to Ng'iriama

Is it doubtful that this option will achieve the objective of restored low flows within the GRR for two reasons:

1. In recent years, flow from the western to the eastern wetland has ceased during the late dry season – i.e. there is no flow at Nyaluhanga to divert to Ng'iriama; and

2. A long transfer scheme (pipeline or canal) would be required (in the order of 25 km for a pipeline, 40 km for a canal). This transfer would have to cross much of the northern plains bordering the eastern wetland (including various small rivers), introducing significant technical complexity.

Sustainability of the option is also questionable:

1. Operation and maintenance of the long transfer scheme is complicated, and damage leading to failure is likely, particularly at the Kimbi River; and
2. Diversion of the entire flow at Nyaluhanga is likely to have unacceptable impacts on the eastern wetland and Ihefu.

This transfer option does not qualify for further investigation.

### Transfer of wetland water over the sill (Ng'iriama)

This option will achieve the objective of restoring flows, as it draws the required volume of water out of the Ihefu and transfers it over the sill into the GRR channel at Ng'iriama. Technical complexity is limited to identifying a suitably deep portion of Ihefu near the sill to place the transfer pipe and maintaining the transfer pipe open (unobstructed) and damage free. A floating intake, gravity flow and relatively simple construction should achieve these objectives.

The sustainability of the option is good, as simple design and limited maintenance is required to maintain the transfer in working order. However, it must be stressed that given the extensive flooding of the wetland and the sill, the transfer will have to be constructed robustly with the necessary engineering design to enable the transfer to withstand the flooding. Encasing of the transfer within concrete that is anchored on bed-rock may be required. This option assumes that a suitably deep pool for abstraction and transfer over the sill can be found close to the sill - if such a location cannot be found (during field visits) the feasibility and sustainability of the option is questionable.

Despite this qualification, the option of transfer over the sill at Ng'iriama qualifies for further investigation.

### Ndembera River transfer

This option achieves the objective of restored flow to the GRR. A relatively simple construction design (diversion weir leading into a transfer pipe or canal) will suffice. Distance of transfer is short, further supporting this option. Flow within the Ndembera River exceeds the required 1 cumec throughout the year implying that a simple transfer scheme will suffice, without the need for storage to augment flows in the late dry season.

Sustainability of the transfer is considered good, given that a simple design and limited maintenance is required to achieve the desired transfer. Flow within the Ndembera River is adequate even in the dry season to support the 1 cumec flow requirements in the GRR, and climate change impacts are unlikely to reduce this flow to such a point that transfers are no longer viable. The environmental impact of the transfer requires further consideration, but it is anticipated that this impact will be small, given the low volume of water transferred out of the system and the low point on the river where transfer would take place (the most significant impact would be reduced flows into the Ihefu during the dry season).

The Ndembera River transfer qualifies for further investigation.

### Ihefu channelisation

Whilst it has been mentioned in some reports on the hydrology of the Usangu wetland that blockage of wetland channels contributes to water spreading and increased evapotranspiration and therefore reduced dry season flows in the GRR, it is not clear that channelisation of the wetland will restore flows without other measures being put in place. It has not been demonstrated that current wetland evapotranspiration losses are equivalent to the additional flow required at Ng'iriama to sustain dry season flow

Despite the fact that the option will unlikely result in restoration of flows by itself, opening up of the old drainage channels within Ihefu will almost certainly help to resolve the problem. Since the RNP has been extended to include the Usangu wetland it is probable that the establishment of a hippo population within the wetland will restore many of the old drainage channels (the role of mega-fauna (hippo and elephant) in the hydrology, drainage and ecological dynamics of wetlands has been well demonstrated from, amongst other, the Okavango delta). Evidence from the ground already shows a rapid increase in the numbers of hippo in Ihefu. This option is therefore highly sustainable, as long as a natural population of mega-fauna is allowed to establish.

Given that the option by itself is unlikely to restore flows and as it is anticipated that the re-establishment of mega-fauna within Ihefu will resolve the blockages naturally, this option does not qualify for further investigation. However, the re-establishment of channels in Ihefu should be closely monitored (easily achieved using remote sensing data) – if it is shown that channels are not being restored by the increasing number of mega-fauna, options for co-management of the wetland should be explored.

### Groundwater abstraction

Three ways in which groundwater may be utilised within the system to contribute towards the restoration of dry season flows within the GRR have been identified: - as an alternative to irrigation abstraction, as an alternative source of domestic water for tail-enders and as a source of dry season flows within the RNP.

Any of the three approaches is highly unlikely to achieve the objective for four reasons:

1. The hydrogeology of the basin is largely unknown, both in terms of groundwater quantity and quality;
2. Limited work undertaken through SMUWC suggests that the only reasonable aquifer lies within the alluvial sediments of the fans, where pumping tests have shown abstraction rates of 1-5l/s. Multiple boreholes would be required to achieve any level of sustainable irrigation at such low abstraction rates;
3. Groundwater availability in the RNP is unknown, but assuming abstraction potential similar to the fans, several hundred boreholes would be required to achieve the required 1 cumec flow; and
4. Infrastructural limitations in terms of borehole drilling and, more significantly, power to drive the pumps, are serious limiting factors in terms of cost and availability.

Sustainability of the option is also highly questionable, given the cost of energy required, the maintenance cost of the large number of boreholes required and water quality related impacts associated with the extensive abstraction required. Finally, the environmental impact of several hundred boreholes in the RNP makes this option entirely unfeasible.

However, one element of this option is feasible – namely the provision of groundwater sources for domestic use by tail-enders. If such sources could be established and developed, this would negate the need for continued surface water abstraction (canal abstraction) to meet the dry-season water needs of tail-enders. Given the nature of this particular manner for groundwater use (improved canal management), it will be incorporated into the discussion on improved irrigation efficiency below.

Given that groundwater abstraction neither meets the objective nor is sustainable, this option clearly does not qualify for further investigation.

### Institutional options: improved water resources management

It is difficult to assess how much water could be saved through appropriate institutional arrangements, as some water losses are likely to occur and as a system that is fully compliant and controlled is unlikely to be achievable within the currently resource constraints experienced by the Rufiji Basin Water Office. Despite these concerns, at a conceptual level it is clear that good water resources management in the

Usangu will result in the objective of restoring flows to the GRR being met. Achieving this will require a combination of good understanding of the system (availability and use), appropriate allocation (allocation planning), good licensing and compliance, and appropriate pricing and cost recovery.

Sustainability of appropriate water resources management in the Usangu (and the wider Rufiji-Ruaha basin generally) ultimately depends on the strength of the institutions and the availability of the requisite capacity – human resources, infrastructure and financial. It is worth noting that significant work has been undertaken in the Usangu and that much is known about the system. In addition, an IWRM plan for the basin (Rufiji Basin) has been tendered. Accordingly, understanding of the system and allocation planning are good or being addressed. This implies that the key issue remains the sustainability of the WRM institution and the available resources to enable it to deliver on its mandate. Financial resources through adequate pricing and cost recovery, and through government appropriation (and donor contributions) is a key element of sustainability. Significant advances in this regard in recent times suggest that sustainability of this option is good, if certain measures are implemented.

It is clear that no matter which technical option is deployed to restore flows within the GRR in the short-term, institutional options will be required in the long-term (i.e. strong and appropriate water resources management) to ensure the sustainability of the restored flows. Accordingly, this option qualifies for further investigation.

### Environmental management

It is not clear that environmental management options in the highlands will restore flows within the GRR, for two reasons:

1. Evidence in SMUWC and RIPARWIN suggest that flow from the highlands is not significantly reduced. This information is dated and flow may in fact be reduced today, owning to evidence of recent extensive degradation of the highlands. However, SMUWC and RIPARWIN clearly demonstrated that degradation of the highlands was not the primary cause of the flow reductions experienced in the GRR. Nevertheless, they are almost certainly an additional stressor and management of the highlands to halt or even reverse the trend in degradation is urgently required.
2. Even if more water was made available through improved management of the highlands, this additional water may very well be consumed by additional agriculture in the plains.

Environmental management interventions in the highlands are closely linked to good IWRM practices and strong WRM institutions in the catchment. Accordingly, these management interventions may very well be sustainable, if strong and capacitated institutions are in place to manage the catchment's water and land use.

Because improved environmental management of the highlands will not, but itself, restore dry season flows to the GRR, this option is excluded from further investigation. However, this does not mean that environmental management of the highlands is not a priority for improved water resources managed in the Usangu catchment, in line with the principles of IWRM. It is likely that unless such improved management through institutional responses is achieved, the long-term sustainability of flow restoration in the GRR through technical interventions is doubtful. As a result, this option is grouped with the institutional option described above (improved WRM).

### Increased efficiency of irrigation

From data collected during SMUWC and RIPARWIN, it is clear that irrigation in the Usangu Plains is the chief cause of reduced dry season flows into the eastern wetland, and the cessation of flow at Ng'iriama. Increased efficiency effectively refers to reduced irrigation water use during the critical dry season months. As described elsewhere, significant wastage occurs through flooding of unused fields, in-field conveyance losses, early paddy preparation, and "unaccounted" losses – possibly illegal abstractions. Increased efficiency is fundamentally an institutional issue, as an institutional response is required to address this issue (allocation planning, licensing and compliance, and a supportive engagement with illegal abstractors). Accordingly, its separation from the discussion on institutional options above (improved WRM) is slightly artificial. Nevertheless, it appears that addressing the dry season irrigation wastages through improved crop diversification and zoning, management of the canals, providing alternative water sources to domestic users in tail-end areas (by using groundwater and/or piped conveyance) and through managing wasteful abstractions may well retain sufficient water within the GRR through the dry season. Although RIPARWIN and SMUWC estimated that late dry season (October and November) water savings through improved irrigation efficiency is relatively small (1 – 3 cumecs), the additional storage created within Ihefu through sustained flows into the eastern wetland during June to September should enable flow at Ng'iriama to be maintained. Accordingly, it appears that increasing the efficiency of irrigation, as defined here, should achieve the objective of restored dry season flows in the RNP.

Sustainability of this option is good, where strong institutions and good WRM prevails. As discussed above, this option is closely linked to the broader option of improved WRM discussed above, and it is unlikely that the one will succeed without the other. Accordingly, it is presumed here that sustainability of this option can be ensures, with the caveat that strong institutional arrangements are maintained.

Increased irrigation efficiency qualifies for further investigation.

### Other agricultural adaptation

This option relates to significant changes to agricultural practices within the Usangu. While theoretically this option could achieve the objective, such wholesale agricultural adaptation in the Usangu would be required to make this option unrealistic. The reality is that paddy production is an important source of income in the Usangu and is practiced by several thousand households, some with significant economic and political power. Accordingly, the level of agricultural adaptation required to achieve the objective is not considered realistic and, therefore is not explored further here.

### Economic options

Economic options refer to the provision of alternatives to agriculture in the Usangu, to reduce irrigation water use within the catchment. Data suggests that the per litre income from livestock, fish-farming, some manufacturing activities (brick-making in particular), and other arts and crafts, is significantly greater than that from irrigation. If alternative sources of livelihoods could be found, this would reduce the amount of water usage through irrigation. However, as with the option on significantly altering the agricultural practices (crop types) above, this option is not realistic given the scale of rice farming systems in the Usangu. It is hoped that as Tanzania develops, diversification of the Usangu economy can occur moving from an agrarian economy to an industrial / manufacturing economy. The development of ecotourism is also an important element of this evolution. However, such changes will take time and will bring with them other challenges for the land and water of the Usangu and GRR. In the short- to medium-term, it is clear that agriculture will be the dominant economic activity within the Usangu catchment, and irrigated agriculture will be the dominant activity within the Plains (and a highly sought after activity within the catchment). Accordingly, the option of developing alternative economic livelihoods is unrealistic as a means of restoring flows to the GRR in the short- to medium-term, and is not explored further here.

### Summary of qualification criteria

The first filter aims to separate the realistic and unrealistic options, thereby identifying the real opportunities that warrant further investigation through the feasibility criteria analysis (Table 37). It is clear from the qualification criteria results described above that although many option theoretically or conceptually exist, most of these options are not realistic as they either do not achieve the objective, or are not sustainable, or both.

**Table 37: Summary of qualifying criteria assessment**

| Option | Qualifying criteria | | Qualifies |
|---|---|---|---|
| | Flow restoration | Sustainability | |
| 1. Ndembera impoundment | *qualify* | *qualify* | **YES** |
| 2. Increased *Ihefu* storage | *qualify* | *qualify* | **YES** |
| 3. Off-channel storage in the fans | *disqualify* | *qualify* | NO |
| 4. RNP tributary impoundment | *qualify* | *disqualify* | NO |
| 5. Groundwater storage | *disqualify* | *disqualify* | NO |
| 6. Transfer: Nyaluhanga to Ng'iriama | *disqualify* | *disqualify* | NO |
| 7. Transfer over the sill (Ng'iriama) | *qualify* | *qualify* | **YES** |
| 8. Ndembera River transfer | *qualify* | *qualify* | **YES** |
| 9. *Ihefu* canalisation | *disqualify* | *qualify* | NO |
| 10. Groundwater abstraction | *disqualify* | *disqualify* | NO |
| 11. Institutional options: improved WRM | *qualify* | *qualify* | **YES** |
| 12. Environmental management | *disqualify* | *qualify* | NO |
| 13. Increased efficiency of irrigation | *qualify* | *qualify* | **YES** |
| 14. Other agricultural adaptation | *disqualify* | *disqualify* | NO |
| 15. Economic options | *disqualify* | *disqualify* | NO |

Of the 15 broad options identified through the Options Identification task, application of the qualification criteria has described 6 options that both achieve the objectives of restoring flow to the GRR and that are sustainable in the medium to long term. Two other options – provision of groundwater for domestic use by tail-enders and improved environmental management of the highlands – are important contributors to the qualification of improved irrigation efficiency and institutional arrangements (improved WRM) respectively.

The second filter – the viability criteria – will be applied to the 6 options that were identified through the qualification process.

### 5.3.3. Viability criteria analysis

The viability analysis applies the eight viability criteria which address the two key feasibility issues:-

1. is the option “feasible”, and
2. is the option “implementable”.

### Ndembera impoundment

Much work has been undertaken on the impoundment of the Ndembera River near Lugoda village. First proposed in 1987 as part of a feasibility assessment of an expansion to the Madibira Rice Scheme, the Lugoda Dam has recently been highlighted again by the Tanzanian Government for development funding.

A full feasibility assessment was undertaken on Lugoda Dam in 1987 (Halcrow, UK). This feasibility demonstrated that the dam was technically and financially feasible (1, 1), particularly where the impoundment was used for multiple purposes. Expansion of rice production at Madibira (circa 3600 ha), hydropower production at Maluluma Falls, small-scale flood irrigation in Lugoda village and surrounds, establishment of a fishery and recreational use of the impoundment are envisaged, implying positive long-term economic impacts from the scheme (1). In addition, sufficient water could be stored in the impoundment to ensure an environmental release to support dry season flow within the RNP.

Given this understanding of the proposed impoundment, the Lugoda Dam is regarded as highly technical and financially feasible, and contributes significantly to economic development. However, the option has negative environmental impacts typically associated with dams in terms of the transport of sediment, migration of fish, flooding of riparian habitats and flow modulation (-1). This assessment given the Lugoda Dam a feasibility score of 2.

The dam is institutionally relatively simple (0), but operationally complex (-1), given that operating rules will have to be carefully developed to achieve environmental flows, adequate flows for hydropower production, flows for irrigation demand, and to retain as far as possible the natural characteristics of the Ndembera River hydrograph. Given the increased livelihood options that the dam offers and the investment associated with the dam construction, this option is considered as highly acceptable to stakeholders (1). Construction of this impoundment of course has roll-out timing implications, probably of several years (0). However, it is assumed that implementation will be moderately simple and relatively rapid, following a technical construction process. Accordingly, this option is awarded 0 points on balance for implementability.

Overall, the option is awarded 2 points for viability (the option is viable, with some implementation complexity).

### Increased wetland storage

This option requires the raising of the granite sill at Ng'iriama, through the construction of a wall along the length of the sill. This option has been proposed by a number of other studies, including SMUWC and RIPARWIN.

Whilst conceptually sound, this option is in reality very complex, as the sill is not clearly defined and is discontinuous. Accordingly, wall construction would be technically difficult and a dam wall of between 500m and 1km in length would be required (-1). Given the strength of the floods over the wall, specialised construction and foundation would be required, to ensure that annual flooding does not damage the infrastructure. A construction of this nature would also require significant financial resources (-1), particularly as the construction would serve an environmental purpose only (as opposed to mixed use derived from, for example, the Lugoda Dam development). Economic impacts are limited (0). Environmental impacts would need to be established although the impact is not considered very great (0) – raising of the water table in Ihefu of approximately 1m is all that is required and this, in fact, may have a positive impact on Ihefu which used to have greater surface area and depth than it presently does. Given these considerations, this option is awarded -2 points for feasibility.

Institutionally the option is very simple (1), as it is a passive mechanism that simply enables the defined flow all year round (floods would exceed the wall, with much greater flows out of Ihefu). The option has some operational complexity (0), given the need for maintenance of the structure and protection from flood damage and blockages. Stakeholder acceptability is neither positive nor negative (0), as the option has little impact on stakeholders (besides stakeholders interested in the restoration of flow). Rollout requirements are also moderately complex (0), given the technical engineering design and construction of the wall, implying significant time required between conceptualisation and the restoration of flows (probably several years). The option is awarded 1 point for implementability, implying that if it could be constructed (technically and financially), it would be a workable option.

On balance the option is awarded -1 points for viability, owing to the questions regarding feasibility. Solutions to the feasibility (technical and financial) of the option should be sought before the option can be considered for implementation.

### Transfer over the sill at Ng'iriama

This option implies a simple transfer over the granite sill at Ng'iriama, using a pipeline located within a deeper pool in IhefuI as the intake and outflow taking place at a lower point beyond Ng'iriama. Flow through the transfer would be passive, given gravity feed, and would be continuous (1 cumec throughout the year). A transfer of 1 – 2 km would suffice.

This option is difficult to assess, as it is not clear where the closest suitable pool for abstraction is located (probably within 500m of the sill). Even if the pool is located relatively close to the sill, significant engineering design and construction will be required to build and anchor the transfer within the wetland, and to protect it from damage during the floods (-1). Financial feasibility is also poor, given the extensive design and complex construction required, and as the option would be single purpose – environmental flow restoration (-1).

Like the wall along the sill, this option only supports restored dry season flows in the RNP and therefore does not have significant additional economic impacts (0). Environmental impacts are significant, given that 1 cumec (1m$^3$.s-1) will be drawn from Ihefu and owing to damage to the wetland during construction (-1). It should be noted that during the dry season, Ihefu has been described as consisting of a series of connected ponds, and it is not clear whether sufficient water is contained within lowest pond to support the 1 cumec flow – connection of ponds further upstream in the wetland may be required. On this basis, this option is awarded -3 point for feasibility.

Institutionally this option is very simple (1). Operationally, this option is neutral as some maintenance of the transfer is required to ensure blockages do not occur and to prevent damage (0). Stakeholder acceptability is neutral (0), given that the option does not affect most stakeholders (as with the wall at Ng'iriama). Rollout considerations are mixed, given the technical and financial complexity (0). An implementability score of 1 is awarded.

This option is awarded -2 points on overall viability, primarily because of significant concerns regarding feasibility. This is premised on the critical feasibility assessment, and a different result would be received should technical and financial feasibility prove significant simpler than anticipated here.

### Ndembera River transfer

This option describes the transfer of 1 cumec from the Ndembera River into the GRR downstream of Ng'iriama. Given the flow of the Ndembera, several possible sites exist (upstream of Madibira) were a transfer pipeline of approximately 25 km would be required. An offtake weir and simple gravity flow will suffice for this transfer.

Technically and financially this option is highly feasible (1, 1). Construction design is simple and cost is significantly lower than the larger-scale engineering works required for the Ng'iriama wall or the Lugoda Dam. Several of the complexities encountered with the Ng'iriama transfer – flood damage and hippo damage in particular – are largely avoided with this option. The option is largely single purpose, and therefore has limited economic advantages (0), unless the transfer also serves to the small-scale irrigated agriculture and domestic water use en route (good agricultural land exists on the opposite bank of the Ndembera River at Madibira). Similarly, it could be argued that environmental impacts are less than those anticipated with the transfer across the sill, given that this option does not significantly affect the water level of the Ihefu swamp. From a feasibility perspective, this option is awarded 2 points.

Institutionally the option is very simple (1). Operational complexity is neutral (0), given that some maintenance is required to ensure that blockage and damage of the transfer is prevented. Medium- to long-term siltation of the weir will need to be evaluated, although the silt load of the Ndembera River is not as great as that of other river in the basin. Period clearing of the weir may be required. Stakeholder acceptability for this option is similar to that for the transfer at Ng'iriama (0), although it may be considered more acceptable where additional benefits are introduced (i.e. where water use en route is explored). Rollout requirements are simple (1), given the simple engineering design and construction, and environmental flows in the GRR would be rapidly restored where this option is pursued. The option is awarded 2 points on implementability.

Overall, this option is awarded 4 points for viability, reflecting the positive feasibility and implementability scores.

### Institutional options: improved water resources management

Institutional options refers to the suit of elements of improved WRM, including detailed understanding of the system, allocation planning and scheduling, licensing and conditionality on water use, monitoring and enforcement (compliance and prevention of illegal water use), improved environmental and land-use management, and the development of non-regulatory tools (awareness and education, and economic instruments) to support the management of the water resource of the catchment (basin). The critical institution in this regard is the RWBO. Local and traditional institutions are also important in monitoring, enforcement and regulation, and awareness, and civil society plays an important role in education and awareness, monitoring and compliance, and the sourcing of resources for targeted interventions.

Five elements are particularly critical for achieving improved WRM:- a strong legislative and regulatory framework, the provision of adequate information, building of capacity within the management institutions, provision of adequate resources to enable appropriate management, and creating awareness and building stakeholder support for IWRM.

- Tanzania has progressive water legislation and strong regulations. Accordingly, the formal legal and regulatory framework is strong – the key challenge is that the framework lacks implementation. Further projects focussed on harmonising water sector policy and strategy are underway (tender process is underway), which will result in alignment and further strengthening of the framework. However, one challenge that the framework does experience is the existence of legal pluralism, with traditional water rights system in place and actively practiced in parts of the catchment. This traditional system is in some cases at variance with the formal legislative and regulatory framework.
- Information on the Usangu catchment is good, following the extensive studies undertaken through SMUWC and RIPARWIN, and the development of decision-support tools such as RUBADA. The proposed IWRM plan for the Rufiji Basin will further strengthen the technical understanding of the Usangu catchment.
- Building capacity within the management institutions is a key area of focus. The RBWO has some very good capacity in its human resources, but these resources are too few to enable the level of management required in the Rufiji Basin (and the Usangu catchment in particular). Given that many of the areas are not easily accessible, the limited human resources implies that monitoring and enforcement is difficult to implement. Moreover, the infrastructural capacity of the institutions is relatively weak, with only a small number of vehicles, field-equipment and other technical needs for integrated management.
- A key challenge is finding sufficient financial resources to enable the intensive management required in the Usangu catchment (and the wider Rufiji Basin). Dependence on donor funding is unfeasible, as such funding is sporadic and uneven. A predictable and adequate flow of finances must be established, through a combination of government (fiscal) appropriation and the collection of water user charges. Several processes are underway to estimate the financial requirement of WRM in Tanzania and the Rufiji IWRM plan should also include an evaluation of financial requirements and means of collection.
- Awareness creation and stakeholder engagement are critical elements of IWRM, and are central to the long-term success of institutions managing water resources in water-stressed environments. It also helps to address issues of legal pluralism, with the IWRM approach reflecting the stakeholder understanding of water rights and allocation, and vice versa. A key challenge in this regard is creation the institutional structures and relationships that enable stakeholder participation, and that build stakeholder understanding and capacity for IWRM.

Dedicated organisational structures and financial resources are required to ensure that this core elements of IWRM is supported.

Based on the discussion above, it is clear that the technical feasibility of the institutional option is relatively simple (1), particularly given that much information is already available and further information will be generated shortly. Financial feasibility, although complicated by the need to establish reliable financial sources from government and water users, is good where successful management is implemented (1). Economic and environmental impacts of improved WRM in the Usangu catchment (and wider Rufiji Basin) is clearly positive (1, 1), given the improved utilisation of limited water resources (increased efficiency) and the attention to environmental and land-use practices (including considerations of environmental flows). Accordingly, feasibility of the institutional option of improved WRM is awarded 4 points for feasibility, reflecting the emerging global consensus on feasibility of IWRM.

Institutional complexity of this option is obviously significant (-1), particularly around the issues of legal pluralism, water allocation planning and licensing, monitoring and compliance, and the recovery of charges (and management costs). The need for detailed cooperative arrangements with local stakeholder institutions adds a further layer of complexity to achieving improved WRM. This extensive institutional and operational complexity (-1) undermines the viability of this option to achieve restored flows within the RNP.

From a stakeholder perspective, improved WRM is neutral (0), because while it implies more efficient and effective management of the scarce resource, it also implies that water will have to be taken away from some users and allocated to other uses (e.g. environment). Some stakeholders may not be as supportive, as they are benefiting under the status quo arrangements (e.g. existing large users).

Finally, rollout considerations are complex and time intensive (-1), given the changing management regimes and the need to build institutional and financial capacity, systems and processes. Stakeholder engagement, planning, and the authorisation (licensing and compliance) further complicate rollout. Accordingly, this option will not restore flows in the GRR in the short-term.

Based on the reasoning above, the option of improved WRM scores -3 points on implementability, reflecting emerging global concerns regarding on the implementation of IWRM principles. However, it must be stressed that improved institutional arrangements and institutional strengthening for IWRM are paramount to any lasting solution to the low flow problems in the GRR. It is, therefore, in effect a meta-layer overlying the short-term options for restored dry-season flow – without proper institutional arrangements for improved WRM in the Usangu catchment (and the Rufiji Basin more widely), none of the short- to medium-term options for restoring flows in the RNP will be sustainable. Fortunately this imperative has been widely recognised, leading to various initiatives (e.g. Rufiji IWRM plan, financing WRM project, etc) that will lead to strengthened institutions in the long-term.

### Increased irrigation efficiency

This option refers to increasing irrigation efficiency through reduced transmission losses, changes in irrigation practice (pre-season wetting and other innovative mechanisms to reduce water losses), and alternative sources of water to tail-enders. It does not refer to illegal abstractions, as these are addressed through improved water resources management (discussed above).

Much work has been done through SMUWC and particularly RIPARWIN on the technical interventions to improve irrigation efficiency. This includes the practices of closing the major canals from a certain date during the dry season onwards (e.g. 1st August). Accordingly, the technical feasibility of achieving improved irrigation efficiency is good (1). Similarly, the financial feasibility is good (1), given that the interventions are not financially intensive and that water conservation is financially sustainable. A few technical construction interventions may be required (to reduce transmission losses in particular). Economic impacts are considered positive (1), as increased water use efficiency typically leads to improved crop yields and increased farm revenue. In addition, better management of the irrigation will free up water for alternative productive use and provide the benchmark for widespread improvement in agricultural practices and production. Environmental impacts of the interventions are considered negligible (0), as management responses are primarily involved. However, utilisation of evaporation reducing plants, such as Azolla, may have an environmental impact and will need to be considered carefully before implementation. The option is awarded 3 points on feasibility.

The institutional complexity of this option is considered high (-1), as operating rules will have to be established, management practices will need to be adapted, and enforcement and compliance will have to be ensured. The RBWO has already undertaken some of these activities, with promising results. However, dry season flow within the GRR has continued to deteriorate, despite improved canal management. Accordingly, for this option to restore dry season flows in the RNP, large-scale adaptation of irrigation practices will be required, which implies significant institutional complexity.

Operationally the option is neutral (0), given that clear rules of operation must be developed, and monitoring and enforcement systems established. Stakeholder acceptability and rollout requirements are both neutral (0, 0), given the level of stakeholder buy-in required and the institutional complexity associated with this option. The option is awarded -1 point on implementability.

The overall viability of this option is awarded 2 points. This implies that the option is viable, but viability is undermined by the complexity of implementation. In fact, it can reasonably be assumed that improved management of the water resources of the Usangu catchment (Rufiji Basin) will lead to improved efficiency of irrigation. Accordingly, this option is effectively subsumed into the institutional option described above, as part of the long-term approach to ensuring sustainability of the system as a whole and long-term maintenance of environmental flows within the GRR.

### 5.3.4. Further considerations based on stakeholder engagement

Stakeholders were actively engaged on each of these options and raised a number of key issues that further inform the short-listing process:

***Lugoda Dam***

Lugoda Dam is highly favourable as a mixed development initiative, with the Government of Tanzania currently actively pursuing this option. This initiative requires significant planning and design, leading to construction of the impoundment, hydropower and irrigation scheme. This implies significant time before this option is implemented. Accordingly, while Lugoda Dam is clearly a preferred option, it is being explored through other channels (Ministry) and should not be explored further through this process (to prevent duplication).

***Raising the sill***

It should be noted that key local stakeholders are highly sceptical of this option based on feasibility and implementability concerns. Therefore, it is highly unlikely to receive the required support from the key institutional players – Ministry of Water and irrigation, and the Rufiji Basin Water Office. On this basis, this option is excluded from further investigation, as it is clear that it will not receive the requisite support for implementation.

***Transfer over the sill***

Significant concern was expressed on this option, based on the unknown factors such as likely location of the transfer, engineering requirements and impact on the Ihefu. Accordingly, while it was recognised that this option may be worth exploring further in the future, it is not a preferred option at present and should be discarded from further investigation through this process.

***Institutional options and irrigation efficiency***

Key stakeholders agreed combining these options into a single conceptual option, based on an integrated approach to improved WRM in the Usangu catchment (and wider Rufiji Basin). Irrigation efficiency is part of a water conservation and demand management strategy, and is achieved through improved allocation, compliance and enforcement, and the use of pricing and economic instruments.

This option is clearly necessary for any meaningful, long-term resolution of the water stress issues in the Usangu catchment. It was recognised that related processes initiated by government (Ministry of Water and Irrigation) are focussing on improved WRM and institutional strengthening in the Rufiji Basin. It was also recognised that these changes take significant time to implement. Accordingly, while the central significance of improved WRM and institutional strengthening in the Usangu catchment was recognised, it was felt that this option should not be explored further through this process.

***Ndembera River transfer***

This option was clearly recognised as the most implementable and workable option on the table. A broad stakeholder grouping agreed that this option should be explored in detail through this process, with the intention of preparing the option for a full feasibility study.

### 5.3.5. Conclusions of the options assessment

The options screening analysis has assessed options against two sets of criteria: firstly whether the option will achieve the objective of restored dry season flows to the GRR in the RNP (Table 37), and will continue to achieve this objective over time; and secondly whether the option is viable (Table 38).

**Table 38: Summary of viability criteria assessment**

| Option | | 1. | 2. | 3. | 4. | 5. | 6. |
|---|---|---|---|---|---|---|---|
| | | **Ndembera impoundment** | **Increased wetland storage** | **Transfer over the sill (Ng'iriama)** | **Ndembera River transfer** | **Institutional options: improved WRM** | **Increased efficiency of irrigation** |
| Feasibility criteria | Technical feasibility | 1 | -1 | -1 | 1 | 1 | 1 |
| | Financial feasibility | 1 | -1 | -1 | 1 | 1 | 1 |
| | Economic impact | 1 | 0 | 0 | 0 | 1 | 1 |
| | Environmental impact | -1 | 0 | -1 | 0 | 1 | 0 |
| | Institutional complexity | 0 | 1 | 1 | 1 | -1 | -1 |
| | Operational complexity | -1 | 0 | 0 | 0 | -1 | 0 |
| | Stakeholder acceptability | 1 | 0 | 0 | 0 | 0 | 0 |
| | Rollout considerations | 0 | 0 | 0 | 1 | -1 | 0 |

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| Results | "Feasibility" | 2 | -2 | -3 | 2 | 4 | 3 |
| | "Implementability" | 0 | 1 | 1 | 2 | -3 | -1 |
| | **Overall Viability** | **2** | **-1** | **-2** | **4** | **1** | **2** |

This distinction is critical, as many options that theoretically exist do not, in reality, achieve the objectives sustainably. Accordingly, of the broadly 15 options outlined through the Options Identification task, only 6 were considered realistic and, therefore, qualified for further investigation (viability assessment).

Based on rigorous assessment and engagement with a broad range of stakeholders, three options emerge as viable:

1. Institutional strengthening and support to ensure improved water resources management;
2. Construction of an impoundment on the Ndembera River (Lugoda Dam); and
3. Transfer from the Ndembera River.

Of these three options, Options 1 and 2 is the focus of significant work being undertaken by the MoWI (Water Sector Development Programme and others). Little further value can be added to that process through this study. However, Option 3 (Ndembera Transfer) is currently not being explored in any detail by the mandated institutions. As this option is principally focussed on returning flows to the GRR (with some potential for small-scale agricultural production en route), it is entirely suited to this project (and the mandate of WWF) and possible follow-up phases.

It is critical to recognise that the improved WRM option is central to the long-term sustainability of any approach to restore flow within the GRR in the short- to medium-term. Without appropriate institutional arrangements and improved management of the scarce water resources of the Usangu Catchment, any gains achieved in the short-term in terms of flow within the GRR will likely be negated through increased abstraction, and unsustainable agricultural and land-use development of the Usangu catchment (highlands and plains).

It is also recognised that water availability in the catchment, when viewed over an annual cycle, far exceeds current use (and demand). Given the drive for poverty reduction and economic growth through expansion in irrigated agriculture, and given the high agricultural potential of the Usangu catchment, it is clear that development of the catchment's water resources is urgently required. To this end, the Lugoda Dam is a priority development, particularly given the dam's multi-use potential.

Accordingly, it is acknowledged here that strengthening the water resource management institutions, creating the appropriate environment for IWRM, and development of the catchment's water resources (Lugoda Dam and possibly others) is crucial to the long-term success of any initiative to restore flows in the GRR. However, this study also acknowledges that such an institutional response and infrastructure development takes time, that it is the focus of various other pieces of work currently being commissioned by the Ministry of Waster and Irrigation, and that it is beyond the financial and time constraints placed upon this project. Whilst this project will investigate the Ndembera River transfer option further (to develop it for full feasibility assessment), this is with the full knowledge and acknowledgement that this options will only succeed where appropriate and strong institutional arrangements for water resources management in the Usangu catchment are created.

## *5.4. Further investigation of the Ndembera transfer*

### 5.4.1. Hydrology and available water within the Ndembera River

The Ndembera River arises in the north-east of the Usangu Catchment and drains directly into the eastern wetland, near Ng'iriama (Figure 20). The main water use in the basin is at Madibira Rice scheme, on the north-eastern margins of the Ihefu. The Ndembera River catchment is largely unchanged, with some small scale agriculture in the upper reaches.

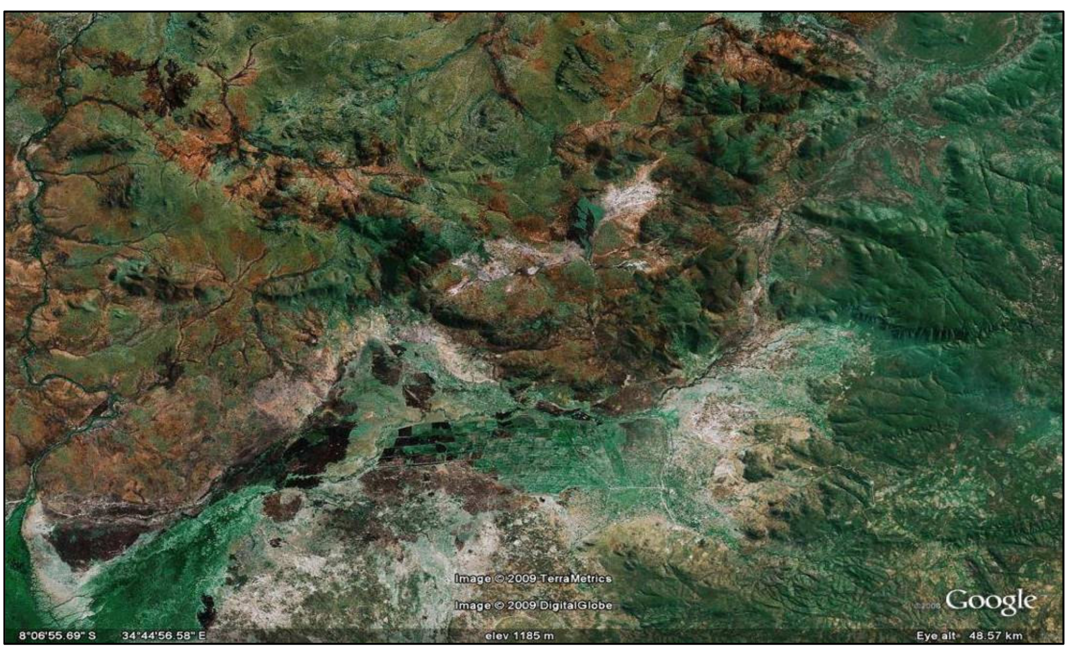



**Figure 20: Satellite image of the lower Ndembera River and GRR at the Ng'iriama outflow**

Reliable hydrological data from the catchment is found at a site half-way up the catchment . MAR at this point is 224Mm$^3$ or 10% of MAR of the GRR at Msembe Bridge. Studies have suggested that MAR for the Ndembera River is closer to 15% of GRR MAR (360Mm$^3$), which may be attributed to contributions of tributaries below the gauging weir. This, however, would have to be confirmed. Regardless of the exact amount, it is clear that the Ndembera River has significant storage potential, particularly given that a number of good dam sites exist within the upper catchment.

Hydrology of the Ndembera River is shown in Figure 21.

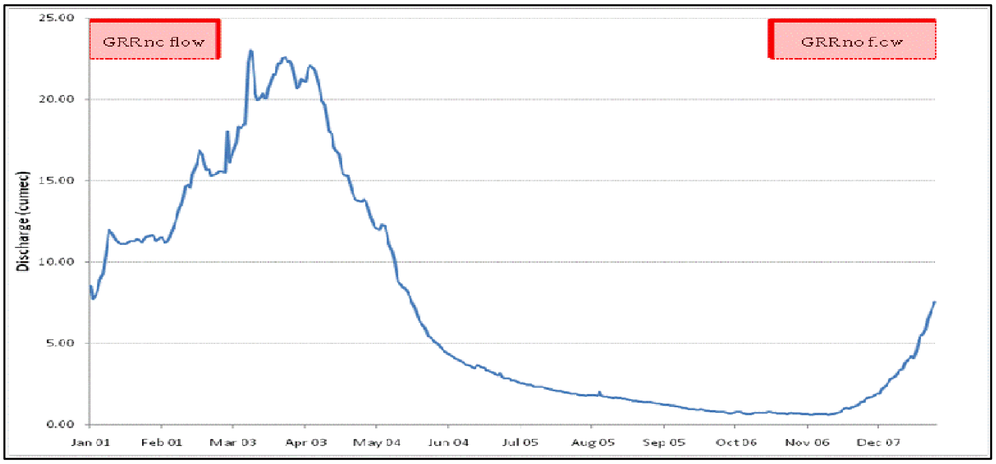



**Figure 21: Mean daily discharge for the Ndembera River 1961 – 1990. Source: RBWO**

The hydrograph is characteristic of a headwater river with flashy run-off during the rainy season, steep flow recession during the dry season and low base-flow through the dry-season, probably maintained by limited groundwater input from the crystalline aquifers and through wetland seepage. Figure 22 focuses on the dry season and shows the critical period of no-flows within the GRR.

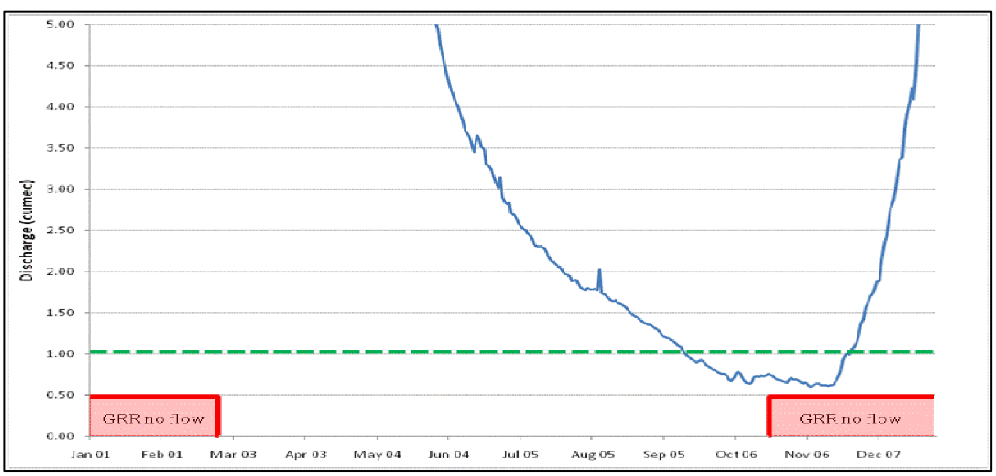



**Figure 22: Hydrograph for the Ndembera River showing no-flow period in the GRR and the 1 cumec discharge threshold**

Low flows appear to reduce to around 0.8 cumec during the mid to late dry season, although significant variability around this mean is expected, reflecting the rainfall variation characteristic of the catchment.

Another significant characteristic of the hydrograph (Figure 22) is the rapid response to the onset of rains, with run-off rapidly rising to beyond 5 cumec, typically in early December. This high flow (10 to 20 cumec) is maintained through the rainy season, receding from late April onwards.

Based on this understanding of the hydrology of the Ndembera River, a few critical conclusions can be formulated:

- Late dry season flow in the Ndembera River is not sufficient to achieve a 1 cumec discharge at Ng'iriama, even if the entire flow within the Ndembera River is transferred into the GRR;
- Nevertheless, diversion of some flow from the Ndembera River into the GRR during the late dry season (e.g. 0.5 cumec) would maintain some flow within the GRR and would delay the onset of no flows, and may in fact maintain flows throughout the dry season (albeit very low flows);
- Once significant flows within the Ndembera River resume (early December onwards), a full transfer of 1.5 to 2 cumecs could be diverted into the GRR, returning flows within the RNP and beyond to their required levels (as defined by the Environmental Flow Assessment), thus significantly reducing the length of the no-flows period within the GRR; and
- Impoundment of the Ndembera River could ensure that sufficient environmental allocations are released from the dam to ensure the required 1.5 to 2 cumecs flow at Ng'iriama throughout the dry season (Figure 23).

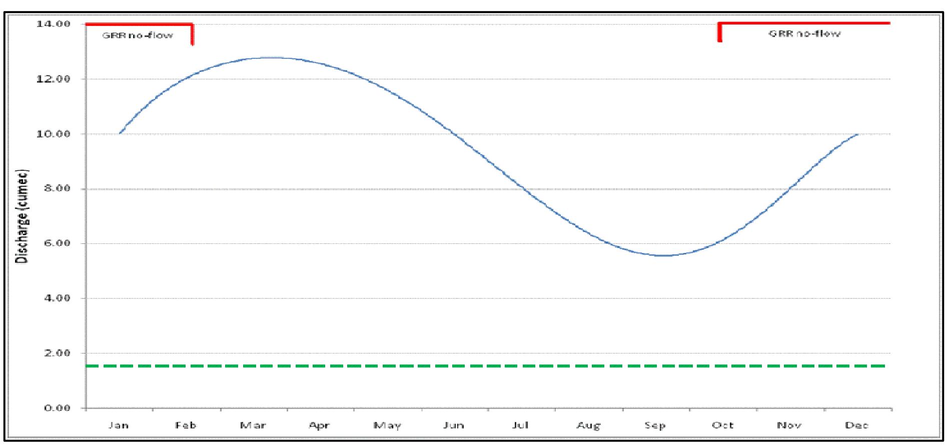



**Figure 23: Hypothetical flow releases from the proposed Lugoda Dam, showing available water for the full environmental transfer**

### 5.4.2. Design of the transfer

This study is not intended to examine in detail the design of the transfer – a pre-feasibility study is required to explore the design and cost implications of the option. Nevertheless, some important design issues can be outlined here:

- The transfer should be a closed conduit (pipe), to enable the transfer to cover changes in elevation, to prevent illegal abstraction and to maintain head;
- An off-take weir should be constructed that splits low flows or enables off-take beyond a certain minimum flow to be retained within the Ndembera River;
- Transfer construction should enable passive management of the system – i.e. should not require the opening or closing of sluices, or the alteration in volume transfer (design should be a fixed transfer). This will prevent tampering with the system and minimise management and institutional complexity;
- Off-take should be above the Madibira Rice Scheme off-take, to prevent wasteful abstraction at the rice farms to impact on the volume of transfer – this implies a transfer of some 28km (Figure 24); and
- Additional uses for the transfer should be considered – e.g. construction of a smaller off-take on the transfer to support small-scale irrigation production;

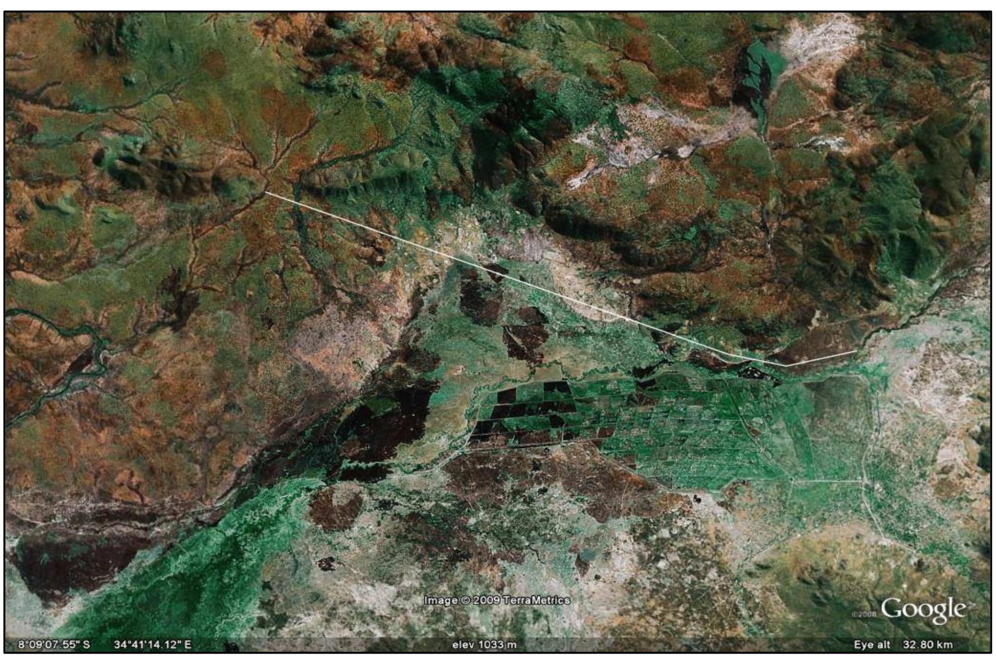



**Figure 24: Satellite image of the lower Ndembera River showing the proposed Ndembera transfer**

## 5.5. Findings

This study of the options to restore flows to the GRR within the RNP was undertaken in parallel with a study assessing the environmental flow requirements of the GRR in the RNP. That study suggested flows of 0.85 – 3 cumecs dry-season flow at BBM 2, some km downstream of Msembe Bridge.

This report provides a summary of the findings of significant previous works on the Usangu Catchment, identifying water use for irrigated agriculture in the Usangu (and particularly rice production in the Usangu Plains) as the predominant reason for reduced dry season flows into the Ihefu and cessation of dry season flows in the GRR downstream of Ihefu (Ng'iriama).

The report investigates a number of options to restore flows to the GRR, following a rigorous analysis and stakeholder consultation process.

The report finds three options attractive for the restoration of flows in the GRR:

1. Institutional strengthening and support to ensure improved water resources management. Including improved management of irrigation water;
2. Construction of an impoundment on the Ndembera River (Lugoda Dam); and
3. Transfer from the Ndembera River.

It is recognised that all three options must be implemented concurrently to achieve fully restored flows to the GRR. However, it is also recognised that options 1 and 2 are only likely to achieve this objective within the medium- to long-term, and that an intervention is required urgently to prevent further degradation of the GRR and loss of natural (and financial) capital within the RNP.

Accordingly, the third option – transfer from the Ndembera River – is highlighted as the most likely to restore flows in the short-term.

## 5.6. Recommendations

It is recommended that the Ndembera Transfer option be the subject of detailed economic and financial analyses, to demonstrate full feasibility of the transfer. Whilst the other two options are already the subject of significant planned work within the basin, the transfer option has not yet been given due consideration and requires incorporation into the TOR for the Rufiji IWRM Strategy project, the Lugoda Dam Pre-Feasibility study or should form the focus of a dedicated study of its own.

# 6. Environmental Flow Assessment of the Eastern Wetlands

## *6.1. Background*

Because of the interconnected nature of river systems, interventions that are made in one portion of the river basin implicitly impact those living downstream. The study of options to restore flow (See Section 5) to the GRR where it flows through the RNP highlighted three interventions which could impact on the wetland.

1. Institutional strengthening and support to ensure improved water resources management, including improved management of irrigation water;
2. Construction of an impoundment on the Ndembera River (Lugoda Dam); and
3. Transfer from the Ndembera River.

At the conclusion of the GRR River EFA, when these options were presented to stakeholders, it was recommended that a wetland EFA be undertaken specifically to investigate the likely impact, and the feasibility in terms of wetland flows, of these options on the Usangu wetland.

The Usangu Wetland EFA programme was launched with an initial reconnaissance visit to Usangu which took place on 16th December 2009. This visit was aimed at gaining a synoptic view of the extent of the wetland habitats and selecting suitable/representative sampling sites, and finalising logistical arrangements prior to conducting the field work. The field sampling and assessments were then carried out between 20th and 27th March 2010.

## *6.2. Study area*

See Section 2.3.1

## *6.3. Objectives*

### 6.3.1. Overall objectives

The objective of the wetland assessment is to determine the response of the wetland to changing flow regimes, not only those caused by upstream abstraction, but also with respect to proposed engineering modifications:

- The construction of the Lugoda Dam
- The Ndembera transfer option.

Among other things, this study looked into how these alterations might affect wetland size and geology, and the consequences of this on biodiversity and ecosystem services.

### 6.3.2. Specialist objectives

#### Classification of Sites: Present Ecological State, Ecological Importance and sensitivity, and Ecological Management Category

In order to use the EFA process in targeting management strategies, the sites were ranked according to their present and desired ecological state. Present Ecological State (PES) recognises the natural, or reference, conditions at each site and includes a judgment of how far each site has changed from those conditions.

Sites were ranked from A (natural) to F (critical/extremely modified). Then sites were assigned a Trajectory of Change, indicating whether each component was getting better or worse under the current wetland management regime.

Sites were also classified according to their Ecological Importance and Sensitivity (EIS), indicating their importance for maintenance of ecological diversity and system functioning on local and wider scales, their ability to resist disturbance and their capability to recover from disturbance.

Finally, sites were assigned an Ecological Management Category (EMC), summarising the overall objective or desired state for each site. Sites were ranked from A (natural) to D (largely modified); as categories E and F were not considered sustainable, they were not included in the EMCs.

#### WBBM1: Nyaluhanga

***Riparian vegetation***

The PES is slightly/moderately modified.

The trajectory of change is positive.

The EIS is High.

The EMC is B.

*Objectives and motivations for riparian vegetation*

The riparian vegetation community at Nyaluhanga contains the lowest proportion of flow-sensitive plant species. There was a low diversity of plant species in Nyaluhanga due to a substantial decrease in flow.

The general objectives are to maintain low flows in both the dry and wet season. Table 39 and

Table 40 provide the specific objectives and motivations for wetland vegetation (in drought and maintenance years respectively), derived at Nyaluhanga.

**Table 39: Specific objectives and motivations for riparian vegetation (drought year) derived at Nyaluhanga**

| Objectives | Reasons/ motivation |
|---|---|
| To maintain low flows during the dry seasons | Most of the flow-dependent riparian plant species can survive with low flows. The hydrophilic plants perform better in the channel low flows than in high flows. Low flows at depth of 0.53m (5.87$m^3$/s) are sufficient for the performance of flow-dependent plant species and the survival of trees and shrubs in the banks. |
| Maintain the duration of low flows | There is a direct link between the duration of flows and reproductive cycle of the plant species; flows are required that can provide sufficient inundation for the performance of flow-dependent riparian vegetation. |
| Maintain low flows in drought years | Low flows are required in the driest years to allow the permanent flow-dependent riparian plant species to survive and support aquatic life. The roots of plan species which are found at the banks can still access water. |
| Maintain high flows in the wet season | High flows allow propagules (seeds) to germinate for community regeneration, and supply nutrients to the woody species at the bank and the wetland. These flows also flush debris from the bank into the channel, to provide food source for fish and invertebrates. |

**Table 40: Specific objectives and motivations for riparian vegetation (maintenance year) derived at Nyaluhanga**

| Objectives | Reasons/ motivation |
|---|---|
| To maintain low flows during the dry seasons | Most of the flow-dependent riparian plant species can survive with low flows. The hydrophilic plants perform better in the channel low flows than in high flows. Low flows at depth of 1.11m (40$m^3$/s) are sufficient for the performance of flow-dependent plant species and the survival of trees and shrubs in the banks. |
| Maintain the duration of low flows | There is a direct link between the duration of flows and reproductive cycle of the plant species; flows are required that can provide sufficient inundation for the performance of flow-dependent riparian vegetation. |
| Maintain low flows in maintenance years | Low flows are required in the driest years to allow the permanent flow-dependent riparian plant species to survive and support aquatic life. The roots of plan species which are found at the banks can still access water. |
| Maintain high flows in the wet season | High flows allow propagules (seeds) to germinate for community regeneration, and supply nutrients to the woody species at the bank. The flow at depth of 0.8m. This flow also provide food to fish and invertebrates in the channel and pools |

*Target indicators for riparian vegetation*

The plant species for follow up purposes include *Vosia cuspidata, Polygonum senegalensis Phragmites mauritianun, Azolla nilotica, Ipomoea aquatica* and *Ceratophylum demerseum* to survive in the channel, and woody species in the bank, as well as flushing down stream of water cabbages in the freshwater pools.

***Fish and invertebrates***

The PES is classified as: A/B: Pristine to slightly modified, evidenced by the following:

- All moderately flow sensitive species including *Labeo* were caught at this site.
- A good number of the fish species reported to be resident in Usangu wetland were caught at this site (14 out of 19).
- The site had the highest fish species diversity index (H' score =1.51).

The trajectory of change is negative, evidenced by:

- A good number of the fish species reported to be resident in GRR are still present (14 out of 19). A negative value is given to indicate that the component is possibly slightly changed from natural conditions.

The EIS is high due to the following reasons:

- A good number of fish species caught at this site have some level of conservation priority, creating the need to maintain their presence in the Usangu Wetland. *Barbus jacksonii* and *B. paludinosus* are listed as threatened and declining species according to the Tanzanian fish conservation ranking system.
- The borders of the RNP were recently extended to include the Usangu Wetland (i.e. the site falls within the RNP boundaries).

The EMC is set at A/B, Pristine to slightly modified (the same level as the PES) in order to maintain the present good conditions.

*Objectives and motivations for fish*

Fish communities should include a large proportion of fairly flow-sensitive taxa including *Labeo cylindricus* and *Barbus* sp (*Barbus paludinosus, Barbus jacksonii*, and *Barbus macrolepis*). Fish species diversity should = $H' \geq 2$ i.e. even distribution of individuals among species. Table 41 provides details of specific objectives and motivations for fish, derived at Nyaluhanga.

**Table 41: Specific objectives and motivations for fish derived at WBBM1.**

| Objective | Motivation |
|---|---|
| Maintain the low flow requirements during the driest month of a drought year. | • inundate an appreciable area of the wetland habitats (e.g. channels and pools), to sustain fairly flow-sensitive species of fish such as *Labeo cylindricus* and *Barbus* sp. |
| Maintain the low flow requirements during the wettest month of a drought year. | • inundate more wetland habitats to increase habitat diversity<br>• inundate a greater area of the wetland channels to permit fish passage over obstacles. |
| Maintain the low flow requirements during the driest month of a maintenance year. | • inundate more habitats to provide natural variability to maintain diverse fish species assemblage<br>• maintain active channel flows to inundate benches and sustain emergent vegetation<br>• permit more fish passage over obstacles<br>• Inundate pools to improve water quality (DO, temperature, etc). |
| Maintain the low flow requirements during the wettest month of a maintenance year. | • provide cue for migration in spawning migrant fishes such as *Labeo* and *Schilbe*.<br>• inundate macrophytes and emergent vegetation along banks to provide more habitats (shelter, feeding) for fishes especially juvenile stages |
| Maintain the higher flow requirements during the wettest month of a drought year. | • prevent sediment build-up on river bed, thus increasing habitat variability for fish and invertebrates<br>• flush out organic matter, thus improving water quality for fish<br>• facilitate nutrient transfer between floodplains and the main wetland channel. This will increase primary productivity and food for fishes. |
| Maintain the higher flow requirements during the wettest month of a wet year. | • maintain macro channel features and provide diversity of physical habitats for fish<br>• scour and flush bed of sediment deposits to expose wetland habitats which were clogged with sediments<br>• Cue for spawning migrant fishes such as *Labeo* to start upstream spawning migration.<br>• inundate and recharge larger area of the wetland, allowing for nutrient transfer into the main wetland channel (increase primary productivity).<br>• inundate higher bank vegetation to provide more habitat (shelter, feeding, breeding) for fishes. |

*Target indicators for fish*

The following species were used as indicators, with the objective of maintaining abundances comparable to reference conditions:

- *Labeo* (Lotic guild)
- *Brycinus, Barbus* and *Synodontis* (pool guild)

*Objectives and motivations for invertebrates*

The ASPT score improved from the present 4.6 to ≥ 6. The invertebrate community should include a large proportion of sensitive taxa such as *Baetidae*, *Actyidae*, and *Elmidae*, with lower relative abundances of *Chironomidae*. Community diversity should = H' ≥ 2 i.e. an even distribution of individuals amongst species, reflected by a low gradient rank-abundance curve. Table 42 provides details of specific objectives and motivations for invertebrates derived at Nyaluhanga site.

**Table 42: Specific objectives and motivations for invertebrates derived at Nyaluhanga**

| Objective | Motivation |
|---|---|
| Maintain the low flow requirements during the driest month of a drought year | • to inundate appreciable area of the critical wetland habitats to, at least, sustain moderately flow-sensitive species of macroinvertebrates such as freshwater shrimps (*Actyidae*), creeping water bugs (*Naucoridae*) and small minnow flies (*Baetidae*) which were collected from this site |
| Maintain a major flood at the beginning of the wet season i.e. March/April, and several more during the wet season | • The first major flood resets the wetland to the wet season conditions, flushing away fine sediments and pollution tolerant species such as *Chironomidae* which were collected at this site. Subsequent floods sort and rework sediments maintaining physical heterogeneity of the wetland channels. |
| Maintain small pulses/freshes of higher flow that occur in the drier months | • Enhance downstream drift of animals and flush out areas of poor quality water accumulated during dry season low flow. |
| Mimic natural pattern of average monthly flows | • Different species are adapted to react to different flow cues for life history stages. |

*Target indicators for invertebrates*

The following target taxa will be used as indicators with the objective of maintaining abundances comparable to reference wetland conditions: *Actyidae, Naucoridae* and *Baetidae*. Being a wetland habitat it is unlikely that highly flow sensitive taxa such as stoneflies (*Perlidae*) and mayflies (*Oligoneuridae* and *Leprophlebiidae*) were ever been present in the reference conditions.

## WBBM2: Ruaha Ponds

### *Riparian vegetation*

The PES is classified as B, slightly modified

The trajectory of change is positive

The EIS is High

The EMC is B

*Objectives and motivations for riparian vegetation*

The vegetation community at perennial swamps contains the highest proportion of flow-sensitive plant species. There was a high diversity of plant species in the perennial swamps, particularly at the Lyang'ulage swamps, than at the seasonally flooded area, upper reach and lower reach, due to persistence of suitable microhabitat conditions. However, population and abundance were low due to denied required flows, caused by disturbances. The abundance of many species of the woody community that includes *Aeschynomene elaphroxylon* has decreased because of disturbance. This community, however, may be used as guide for future observation.

The general objectives are to maintain low flows in both dry and the wet season. Table 43 and Table 44 provide specific objectives and motivations for wetland vegetation (in drought and maintenance years respectively) derived at perennial swamps

**Table 43: Specific objectives and motivations for riparian vegetation (drought years) derived at perennial swamps**

| Objectives | Reasons/ motivation |
|---|---|
| To maintain low flows during the dry and wet seasons | Most of the flow-dependent plant species can survive at these low flows during drought years. The hydrophytes can persist in the channel or swamp however, without increasing in abundance, due to narrowing of area coverage. Some species can survive better at low flows than at high flows. Low flows above **0.52m** are sufficient for the survival of flow-dependent plant species in the perennial swamps. |
| Maintain the duration of low flows | Flow durations are required that can provide sufficient inundation for the performance of flow-dependent riparian vegetation. Below this flow, some of the sensitive species die and can be lost from the wetlands. The low flows can serve as a refuge for hydrophytes and fish with a high tolerance to harsh conditions. |
| Maintain low flows in the driest years | Low flows are required in the driest years to allow the permanent flow-dependent riparian plant species to survive and to support aquatic life. However, recovery from herbivory can be low, due to unfavourable habitat conditions. The plants species in perennial |

| | |
|---|---|
| | swamps can still support herbivores and reducing the heating effects of the sun on open water. |
| Maintain high flows in the wet season | High flows allow expansion of populations through vegetative regeneration in the wetlands, and supply enough food materials to aquatic organisms. These flows help to dilute the concentration of wastes in the pools. |

**Table 44: Specific objectives and motivations for riparian vegetation (maintenance years) derived at perennial swamps**

| Objectives | Reasons/ motivation |
|---|---|
| To maintain low flows during the dry and wet seasons | Most of the flow-dependent plant species can survive at these low flows during drought years. The hydrophytes can persist on the channel or swamp, however, without increasing in abundance, due to narrowing of area coverage. Some species can survive better at low flows than at high flows. Low flows above **0.64m** ($5m^3$) are sufficient for the survival of flow-dependent plant species in the perennial swamps. |
| Maintain the duration of low flows | Flow durations are required that can provide sufficient inundation for the performance of flow-dependent riparian vegetation. Below this flow, some of the sensitive species die and can be lost from the wetlands. The low flows can serve as refuge for hydrophytes and fish that have a high tolerance for harsh conditions. |
| Maintain low flows in the normal years | Low flows are required in the driest years to allow the permanent flow-dependent riparian plant species to survive and to support aquatic life. Whilst recovery from herbivory can be low, due to unfavourable habitat conditions, the plant species in perennial swamps can still support herbivores and reduce the heating effects of the sun on open water. |
| Maintain high flows in the wet season of the maintenance yr | High flows allow expansion of populations through vegetative regeneration in the wetlands, and supply enough food materials to aquatic organisms. These flows help to dilute concentration of wastes in the pools and expand habitat and area cover for the expansion of water lilies. |

*Target indicators for wetland vegetation*

Indicator species for change in perennial swamps includes *Urena lobata, Trapa natans, Utricularia foliosa, Aeschynomene elaphroxylon, Cyperus mundtii, Fuirena Aeschynomene cristata, Nymphaea noutchali, Ceratophyllum demersum Centrostachys aquatica Fimbristylis ovata Fimbristylis hispidula Fuirena ciliaris, Fuirena ochresta Fuirena stricta.*

***Fish and invertebrates***

The PES is classified as B, slightly modified, evidenced by the following:

- Only 2 of the 19 resident species of fish were caught, making it the site with the lowest fish species diversity index score.
- None of the moderately flow sensitive species were caught from this site, but instead it is dominated by most flow insensitive/tolerant species such as *Clarias gariepinus* and *Oreochromis* sp.

The trajectory of change is slightly negative, evidenced by:

- Total catch of only 2 species of fish. A negative value is given to indicate that the component is possibly slightly changed from natural conditions.

The EIS is high, due to the following factors:

- Presence of *Oreochromis urolepis*, which is endemic to the GRR basin provides strong motivation for maintaining or improving the present river management regime.
- *Oreochromis urolepis* has a peculiar sex determination (monosex) trait.
- The presence of a conservation area (RNP) downstream of the Usangu wetland.

The EMC is set at B, slightly modified, (the same level as the PES) in order to improve the state of this site.

*Objectives and motivations for fish*

The fish community should include a good proportion of resident fish species in the Usangu wetland. Fish species diversity = H' ≥ 2 i.e. even distribution of individuals among species. Table 45 details the specific objectives and associated motivations for fish species at Ruaha Ponds.

**Table 45: Specific objectives and associated motivations for fish species at WBBM2**

| Objective | Motivation |
|---|---|
| Maintain the low flow requirements during the driest month of a drought year | • to inundate appreciable area of the channel to sustain fish species such as *Oreochromis rukwaensis* caught at this site. |
| Maintain the low flow requirements during the wettest month of a drought year | • to inundate more sections of the wetland to increase habitat diversity<br>• to inundate more area of the channel to permit fish passage over obstacles. |

| | |
|---|---|
| Maintain the low flow requirements during the driest month of a maintenance year | • inundate more habitats to provide natural variability to maintain diverse fish species assemblage<br>• maintain active channel flows to inundate benches and sustain emergent vegetation<br>• permit more fish passage over obstacles<br>• Inundate pools to improve water quality (DO, temperature, etc). |
| Maintain the low flow requirements during the wettest month of a maintenance year | • inundate macrophytes and emergent vegetation along banks to provide more habitats (shelter, feeding) for fishes especially juvenile stages |
| Maintain the higher flow requirements during the wettest month of a drought year. | • prevent sediment build-up on river bed, thus increasing habitat variability for fish and invertebrates<br>• flush out organic matter, thus improving water quality for fish<br>• facilitate nutrient transfer between floodplains and the main wetland channel. This will increase primary productivity and food for fishes. |
| Maintain the higher flow requirements during the wettest month of a wet year. | • maintain macro channel features and provide diversity of physical habitats for fish<br>• scour and flush bed of sediment deposits to expose riffles which were clogged with sediments<br>• inundate and recharge larger higher banks, allowing for nutrient transfer into the main river channel (increase primary productivity).<br>• inundate higher bank vegetation to provide more habitat (shelter, feeding, breeding) for fishes. |

*Target indicators for fish*

The following target species were used as indicators with the objective of maintaining abundances comparable to reference conditions:

- *Brycinus, Synodontis, Bagrus* (**pool guild**)
- *Barbus, Schilbe* (**Lotic guild**)

*Objectives and motivations for macroinvertebrates*

The ASPT score improved from the present 4.6 to ≥ 6. The invertebrate community should include a large proportion of sensitive taxa such as *Helodidae* and with lower relative abundances of *Chironimidae*. Invertebrate community diversity should = H' ≥ 2 i.e. displaying an even distribution of individuals amongst species, reflected low gradient rank-abundance curve. Table 46 outlines the specific objectives and associated motivations for invertebrate species derived at Ruaha Ponds.

**Table 46: Specific objectives and associated motivations for invertebrate species derived at WBBM2**

| Objective | Motivation |
|---|---|
| Maintain the low flow requirements during the driest month of a drought year | • to inundate appreciable area of the critical wetland habitats to sustain highly flow-sensitive species of macroinvertebrates which was only caught at this site - *Helodidae*. |
| Maintain a major flood at the beginning of the wet season i.e. March/april and several more during the wet season | • The first major flood resets the river to the wet season conditions, flushing away fine sediments and pollution tolerant species such as Chironomidae collected at this site. Subsequent floods sort and rework sediments maintaining physical heterogeneity of the channel |
| Maintain small pulses/freshes of higher flow that occur in the drier months | • Enhance downstream drift of animals and flush out areas of poor quality water accumulated during dry season lowflow |
| Mimic natural pattern of average monthly flows | • Different species are adapted to react to different flow cues for life history stages. |

*Target indicators*

The following target taxa were used as indicators with the objective of maintaining abundances comparable to reference conditions:

- *Helodidae* (Highly flow-sensitive)
- *Ecnomidae* (moderately flow-sensitive).

## WBBM3: Ng'iriama

***Riparian vegetation***

The Present ecological state classified as C: moderately modified

The trajectory of change is negative

The EIS is Low

The EMC is C

*Objectives and motivations for riparian vegetation*

The vegetation community in the lower reach areas contains fewer plant species that are sensitive to flows. The diversity of flow-dependent species was low, and this can only be improved if the reqiured flow can be achieved.

Objectives: To have a maintained level of flows in the wet season. Table 47 and Table 48 provide specific objectives and motivations for wetland vegetation (in drought and maintenance years respectively) derived at Ng'iriama

**Table 47: Specific objectives and motivations for riparian vegetation (drought years) derived at Ng'iriama**

| Objectives | Reasons/ motivation |
|---|---|
| To maintain low flows during the dry and wet seasons | Most of the wetland plant species can adapt and survive in low flows better than in high flows. The water lilies and hydrophilic plants perform better in the channel low flows than in high flows. The depth of 0.28m (4.10m3/s) is suitable for sustaining plants at Ng'iriama during the dry season |
| Maintain duration of low flows | The productivity of many flow-dependent wetland plant species is high in this season.<br>This implies that there is a direct link between the levels of flows and productivity of perennial and seasonally flooded plant species in Usangu wetland |
| Maintain high flows in the wet season | High flows favour perennial wetland species to reproduce and expand in their communities to regenerate and supply nutrients to the woody species at the bank. |

Target indicators for wetland vegetation change at Ng'iriama include *Aeschynomene indica, Nymphaea capensis, Schoenoplectus nodiflorum,Centrostachys aquatica* and *Orzya longistaminata*

**Table 48: Specific objectives and motivations for riparian vegetation (maintenance years) derived at Ng'iriama**

| Objectives | Reasons/ motivation |
|---|---|
| To maintain low flows during the dry and wet seasons | Most of the wetland plant species can adapt and survive in low flows better than in high flows.. The water lilies and hydrophilic plants perform better in the channel low flows than in high flows. |
| Maintain duration of low flows in maintenance year | The productivity of many flow dependent wetland plant species is high in this season.<br>This implies that, there is a direct link between the levels of flows and productivity of perennial and seasonally flooded plant species in Usangu wetland |
| Maintain high flows in the wet season | High flows favour perennial wetland species to reproduce and expand in their communities to regenerate and supply nutrients to the woody species at the bank. |

Target indicators for wetland vegetation change at Ng'iriama include *Urena lobata, Nymphaea capensis, Schoenoplectus nodiflorum* and *Aeschynomene indica.*

***Fish and invertebrates***

The PES is classified as B, slightly modified, evidenced by the following:

- Only 2 of the 19 resident species of fish were caught, making it the site with the lowest fish species diversity index score.
- None of the moderately flow sensitive species were caught from this site, but instead it is dominated by most flow insensitive/tolerant species such as *Clarias gariepinus* and *Oreochromis* sp.

The trajectory of change is slightly negative, evidenced by:

- Total catch of only 2 species of fish. A negative value is given to indicate that the component is possibly slightly changed from natural conditions.

The EIS is high, due to the following factors:

- Presence of *Oreochromis urolepis*, which is endemic to the GRR basin provides strong motivation for maintaining or improving the present river management regime.
- *Oreochromis urolepis* has a peculiar sex determination (monosex) trait.
- The presence of a conservation area (RNP) downstream of the Usangu wetland.

The EMC is set at B, slightly modified, (the same level as the PES) in order to improve the state of this site.

*Objectives and motivations for fish*

The fish community should include a good proportion of resident fish species in the Usangu wetland. Fish species diversity = H' ≥ 2 i.e. even distribution of individuals among species. Table 49 details the specific objectives and associated motivations for fish species at Ng'iriama.

**Table 49: Specific objectives and associated motivations for fish species at BBM3**

| Objective | Motivation |
|---|---|
| Maintain the low flow requirements during the driest month of a drought year | • to inundate appreciable area of the channel to sustain fish species such as *Oreochromis urolepis* caught at this site.. |
| Maintain the low flow requirements during the wettest month of a drought year | • to inundate more sections of the wetland to increase habitat diversity<br>• to inundate more area of the channel to permit fish passage over obstacles. |

| | |
|---|---|
| Maintain the low flow requirements during the driest month of a maintenance year | • inundate more habitats to provide natural variability to maintain diverse fish species assemblage<br>• maintain active channel flows to inundate benches and sustain emergent vegetation<br>• permit more fish passage over obstacles<br>• Inundate pools to improve water quality (DO, temperature, etc). |
| Maintain the low flow requirements during the wettest month of a maintenance year | • inundate macrophytes and emergent vegetation along banks to provide more habitats (shelter, feeding) for fishes especially juvenile stages |
| Maintain the higher flow requirements during the wettest month of a drought year. | • prevent sediment build-up on river bed, thus increasing habitat variability for fish and invertebrates<br>• flush out organic matter, thus improving water quality for fish<br>• facilitate nutrient transfer between floodplains and the main wetland channel. This will increase primary productivity and food for fishes. |
| Maintain the higher flow requirements during the wettest month of a wet year. | • maintain macro channel features and provide diversity of physical habitats for fish<br>• scour and flush bed of sediment deposits to expose riffles which were clogged with sediments<br>• inundate and recharge larger higher banks, allowing for nutrient transfer into the main river channel (increase primary productivity).<br>• inundate higher bank vegetation to provide more habitat (shelter, feeding, breeding) for fishes. |

*Target indicators for fish*

The following target species were used as indicators with the objective of maintaining abundances comparable to reference conditions:

- *Brycinus, Synodontis, Bagrus* (pool guild)
- *Barbus, Schilbe* (Lotic guild)

*Objectives and motivations for macroinvertebrates*

The ASPT score improved from the present 4.6 to ≥ 6. The invertebrate community should include a large proportion of moderately flow sensitive taxa such as *Elmidae*, *Hydracarina* and *Baetidae* with lower relative abundances of *Oligochaeta* and Chironimidae. Invertebrate community diversity should = H' ≥2 i.e. displaying an even distribution of individuals amongst species, reflected low gradient rank-abundance curve. Table 50 outlines the specific objectives and associated motivations for invertebrate species derived at Ng'iriama.

**Table 50: Specific objectives and associated motivations for invertebrate species derived at WBBM3**

| Objective | Motivation |
|---|---|
| Maintain the low flow requirements during the driest month of a drought year | • to inundate appreciable area of the critical wetland habitats to sustain moderately flow-sensitive species of macroinvertebrates such as *Elmidae*, *Hydracarina* and *Baetidae*. |
| Maintain a major flood at the beginning of the wet season i.e. March/april and several more during the wet season | • The first major flood resets the river to the wet season conditions, flushing away fine sediments and pollution tolerant species such as *Oligochaeta* and *Chironomidae* collected at this site. Subsequent floods sort and rework sediments maintaining physical heterogeneity of the channel |
| Maintain small pulses/freshes of higher flow that occur in the drier months | • Enhance downstream drift of animals and flush out areas of poor quality water accumulated during dry season low flow |
| Mimic natural pattern of average monthly flows | • Different species are adapted to react to different flow cues for life history stages. |

*Target indicators*

The following target taxa were used as indicators with the objective of maintaining abundances comparable to reference conditions:

- *Elmidae, Hydracarina* and *Baetidae* (moderately flow-sensitive).

## *6.4. Description of preparatory work*

### 6.4.1. Selection of study sites

During initial field visit to the study area (16th December 2009), the multidisciplinary group of specialists chose three broadly representative Building Block Methodology (WBBM1, 2, and 3) sites where sampling would be conducted by the various specilaists:

- WBBM1 Nyaluhanga,
- WBBM2 Ruaha Ponds and
- WBBM3 Ng'iriama

The location of these sites are shown in Figure 25.

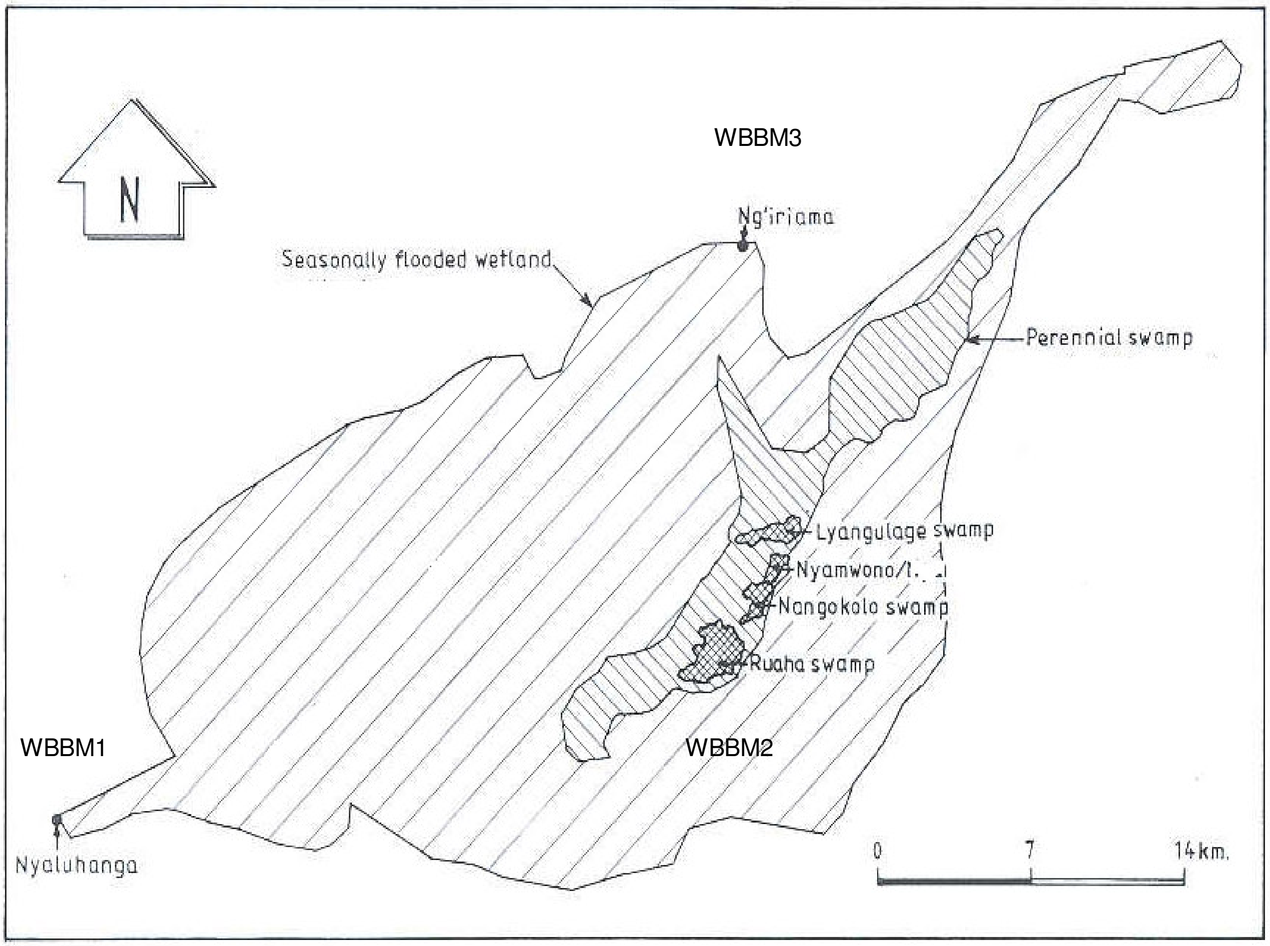



**Figure 25: Map of Usangu Plain and its Wetland, showing the three sampling areas**

Photographic views of the three sampling sites are shown in Figure 26, Figure 27 and Figure 28 .

**Figure 26: Photographic view of Nyaluhanga**

**Figure 27: Photographic view of Ruaha Ponds**

**Figure 28: Photographic view of Ng'iriama**

### 6.4.2. Hydrology

#### Introduction

***Objectives***

The specific objective of this component was to carry out a hydrological analysis of the Ihefu wetlands that would characterise the wetlands hydrology, to assist in the EFA of the Usangu wetlands.

***Tasks***

The ToR for the hydrology study of the Ihefu wetlands outlined the following main tasks:

(i) Review information and data from previous studies (e.g. RIPARWIN, SMUWC)

(ii) Participate in pre-wetlands survey meeting

(iii) Conduct spot measurements of inflows and outflows from Ihefu wetlands

(iv) Define wetlands size and bathymetry change during the dry season

(v) Conduct wetlands water balance

(vi) Assess historical changes of inundated wetlands area

(vii) Describe impacts of flow reduction of wetlands size and effects of permanent change (increase or decrease) of the wetlands

(viii) Prepare a study document that provide information on study findings

(ix) Attend EFA workshop to discuss the results

## Data and methodology

### *Water balance model*

*General equation*

Sequential routing is used to estimate the different components of the water of the Ihefu wetlands, using the available information of some components. This sequential routing provides information on linkages between inflows, wetlands level/storage and wetlands outflows. Sequential wetlands routing uses the relationship shown in Equation 1:

$$\Delta S_{t,t-1} = I_t - O_t$$

**Equation 1**

Where $\Delta S_{t,t-1}$ is the change of wetlands storage between day $t$ and previous day $t-1$ while $It$ and $Ot$ are total wetlands inflow and outflow volumes respectively in day $t$.

To use Equation 1, reliable data is needed that describes wetlands storage, elevation, area, inflows and outflows. With respect to the Ihefu wetlands system configuration, inflows ($It$) and outflows ($Ot$) comprise several components. The components of the wetlands inflows include:

i) GRR discharge at Nyaluhanga ($Q_{nyaluhanga}$)

ii) Ndembera river discharge at Madibira ($Q_{ndembera}$)

iii) Kioga river discharge ($Q_{kioga}$)

iv) Kimbi river discharge ($Q_{kimbi}$)

v) Surface runoff from wetlands immediate catchment ($V_{runoff}$)

vi) Rainfall over the wetlands area ($R_{wetlands}$)

vii) Subsurface inflow ($Q_{sub,in}$)

The wetlands outflows comprise

i) GRR outflow discharge at Ng'iriama ($Q_{Ng'iriama}$)

ii) Wetlands evapotranspiration ($ET$)

iii) Subsurface outflow ($Q_{sub,out}$)

Expanding Equation 1 to include these components of wetlands inflows and outflows results in Equation 2:

$$\Delta S_{t,t-1} = (Q_{nyaluhanga} + Q_{ndembera} + Q_{kioga} + Q_{kimbi} + V_{runoff} + R_{wetlands} + Q_{sub,in}) - (Q_{Ng'iriama} + ET + Q_{sub,out})$$

**Equation 2**

These different component inputs are, however, provided in different units, and therefore could not be directly used in Equation 2. These components and their unit conversions are presented and discussed in the subsequent sections.

*Wetlands storage*

Wetlands storages are estimated from average water surface elevation, using established elevation-storage equations. The information on the elevation-storage and elevation-area was taken from Kashaigili (2008). The relationships are given in Table 51.

**Table 51: Elevation-area and elevation-storage relationships for Ihefu wetlands (Kashaigili, 2008)**

| Elevation (m) | Area ($\times 10^6$ m$^2$) | Storage ($\times 10^6$ m$^3$) |
|---|---|---|
| 1008 < El ≤ 1009.477 | Area = 43.38253(Elev – 1008) | Storage = 7.9073812(Elev – 1008) |
| 1009.477 < Elev ≤ 1009.657 | Area = 64.076 + 250(Elev – 1009.477) | Storage = 11.68 + 70(Elev – 1009.477) |
| 1009.657 < Elev ≤ 1011.027 | Area = 110.675 + 108(Elev – 1009.657) | Storage = 25.73 + 76(Elev – 1009.657) |
| 1011.027 < Elev ≤ 1011.577 | Area = 261.618 + 370(Elev – 1011.027) | Storage = 134.57 + 232(Elev – 1011.027) |
| 1011.577 < Elev ≤ 1011.967 | Area = 465.153 + 360(Elev – 1011.577) | Storage = 263.05 + 720(Elev – 1011.577) |
| El > 1011.967 | Area = 610.967 + 17(Elev – 1011.967) | Storage = 562.57 + 6(Elev – 1011.967) |

Ndomba (2010) produced another set of elevation-area and elevation-storage relationships. The relationships, however, give comparable estimates of wetlands areas and storages to those established by Kashaigili (2008).

Daily wetlands storage changes are therefore computed as the difference between storages in consecutive days as shown in Equation 3:

$$\Delta S_{t,t-1} = S_t - S_{t-1}$$

**Equation 3**

where $S_t$ and $S_{t-1}$ are storages in day $t$ and $t-1$ respectively.

*Wetlands inflow volume*

*River flows:* The main inflows to the Ihefu wetlands are from rivers mainly perennial rivers (GRR and Ndembera) and seasonal rivers (Kioga and Kimbi). Whilst discharge is expressed in $m^3/s$, the volumetric daily flow volume is computed as shown in Equation 4:

$$V_{x,t} = Q_{x,t} \times 86400$$

**Equation 4**

where $V_{x,t}$ and $Q_{x,t}$ are total flow volume and average daily discharge of a river at location $x$ in day $t$ respectively.

*Surface runoff:* The catchment configuration indicates that not all water entering the wetlands is draining through rivers into the wetlands. A certain portion of inflows into the wetlands comes as surface runoff generated by rainfall falling on the catchment area immediate to the wetlands. The total volume of this runoff ($V_{runoff}$) is estimated from Equation 5:

$$V_{runoff} = R_{catchment} \times A_{catchment}$$

**Equation 5**

where $R_{catchment}$ is rainfall amount over an area on the catchment ($A_{catchment}$) contributing to surface runoff entering directly into the wetlands.

*Rainfall over wetlands:* The catchment configuration indicates that not all water entering the wetlands is draining through rivers into the wetlands. A certain portion of inflows into the wetlands comes as surface runoff generated by rainfall falling on catchment area immediate to the wetlands. The total volume of this runoff ($V_{runoff}$) is estimated from Equation 6:

$$V_{wetlands} = R_{wetlands} \times A_{wetlands}$$

**Equation 6**

where $R_{wetlands}$ is rainfall amount falling on wetlands surface ($A_{wetlands}$) contributing to surface runoff entering directly into the wetlands.

Subsurface inflows: Subsurface inflows are hard to measure and consequently the subsurface inflow volumes will be estimated from water balance Equation 2.

*Wetlands outflow volume*

*Outflow volumes:* The only surface outflow from the Ihefu wetland is from the GRR at Ng'iriama. The rocky outlet makes the wetland behave like a huge "bucket" discharging through an upper hole. Consequently, wetland surface outflow is the function of wetland water level and is assumed to be the estimated (routed) total river surface discharge at Ng'iriama, using discharges at Msembe and Haussman's Bridge gauging stations. The volumetric daily outflow is computed from Equation 4.

*Evapotranspiration from wetlands*: A portion of total inflows into the wetlands is lost by evaporation from open pools within the wetlands, and by transpiration from vegetation. The total volumetric evaporation loss from the pools ($V_{evap}$) is estimated using Equation 7:

$$V_{evap} = PE_{pools} \times A_{pools}$$

**Equation 7**

where $PE_{pools}$ is potential evaporation from a total area of open water pools ($A_{pools}$).

Total volumetric evapotranspirational loss from the vegetated wetland ($V_{ET,veg}$) is estimated from Equation 8:

$$V_{ET,veg} = ET_{vegetation} \times A_{vegetation}$$

**Equation 8**

where $ET_{vegetation}$ is evapotranspiration from vegetated wetlands of surface area ($A_{vegetation}$).

ET is estimated from wetlands plants' transpirational rates. The total evapotranspiration volume ($V_{ET}$) is the sum of the two sub-components, as shown in Equation 9:

$$V_{ET} = V_{evap} + V_{ET,veg}$$

**Equation 9**

However, simplified methods are normally and practically used in the determination of evapotranspiration. They include the methods of Thornthwaite, Penman-Monteith, Turc, etc.

Subsurface outflows: Subsurface outflows are hard to measure, and consequently the subsurface outflow volumes are estimated from water balance Equation 2.

***Data availability***

The analysis requires a thorough investigation of water availability for the Ihefu swamp during the dry season, when frequent drying up of the GRR downstream of the wetlands has recently been observed. For such a requirement, the dry season is characterised predominantly by dry days, which are defined as those days receiving less than 1 mm of rainfall. Consequently, the water balance inflow components involving rainfall ($V_{runoff}$, $R_{wetlands}$) become zero, leaving Equation 2 as:

$$\Delta S_{t,t-1} = (Q_{nyaluhanga} + Q_{ndembera} + Q_{kioga} + Q_{kimbi} + Q_{sub,in}) - (Q_{Ng'iriama} + ET + Q_{sub,out})$$

**Equation 10**

Therefore, Equation 10 is used in water balance components estimations. The availability of relevant data for each component of Equation 10 is presented in subsequent sections. It should be noted that data were obtained from various sources, which are indicated in the full hydrology report (Available from WWF TCO and RBWO.)

*Wetlands information relevant for storage and area determination*

*Water levels:* The measurement of water levels in the Ihefu wetlands has mainly been carried out at random intervals at specific locations, using gauges. However, continuous water level records are available at several open water areas of the wetlands for 1999 (Table 52). The source of the SMUWC data in Table 52 to Table 61 is SMUWC Interim Report Technical Annex 1: Hydrometric Monitoring Data.

**Table 52: Continuous wetlands water level data availability in Ihefu wetlands**

| Gauging identification information | | | | Data Availability | |
|---|---|---|---|---|---|
| Place | N (m) | E (m) | Established | Period | Source |
| Nyangokolo Swamp | 9076924 | 0667431 | 14/06/1999 | 14/06/1999 – 31/12/1999 | SMUWC |
| Ruaha Swamp | 9069720 | 0658619 | 14/06/1999 | 14/06/1999 – 31/12/1999 | SMUWC |

Wetland water levels were also spot measured using sounding methods mainly in 1999, as well as during the February 2010 field survey as part of this project, at several open water and vegetated wetlands areas (Table 53).

**Table 53: Spot wetlands water level data availability in Ihefu wetlands**

| Place | Data Availability | | Comments |
|---|---|---|---|
| | Period | Source | |
| Nyangokolo Minor Swamp | 14/06/1999 | SMUWC | Coordinates and depth at 48 points are available |
| Nyangokolo Main Swamp | 10/02/2010 | Field survey | Coordinates and depth at 102 points are available |
| Ruaha Swamp | 14/06/1999 | SMUWC | Coordinates and depth at 45 points are available |
| Nyamwono Swamp | 14/06/1999 | SMUWC | Coordinates and depth at 20 points are available |
| Lyangulaje Swamp | 14/06/1999 | SMUWC | Coordinates and depth at 50 points are available |

*Wetlands boundaries (Permanent wetlands):* The boundaries of the permanent Ihefu swamp have been delineated using two main methods: Physical establishment of boundary points at various locations around the wetlands, and delineation of the wetlands from areas photos and satellite images. The establishment of wetlands boundaries by GPS coordinate measurements was carried out in January and May 1999, when a number of waterline points were located (Table 54).

**Table 54: Spot wetlands edge data availability for permanent Ihefu wetlands**

| Data Availability | | | Comments |
|---|---|---|---|
| Place | Period | Source | |
| Ihefu Seasonal Swamp | 21/01/1999 | SMUWC | 170 boundary coords available from GPS measurements |
| Ihefu Seasonal Swamp | 05/05/1999 | SMUWC | 151 boundary coords available from GPS measurements |

*Wetlands boundaries (Open water areas):* The boundaries of the open water areas within the permanent Ihefu swamp were established in June 1999 using GPS (Table 55). The field survey carried out as part of this project in February 2010 also relocated the boundaries of three open areas of the Nyangokolo Main, Ruaha and Lyangulaje swamps using GPS.

**Table 55: Spot wetlands boundary data for open water areas in the permanent Ihefu wetlands**

| Place | Data Availability | | Comments |
|---|---|---|---|
| | Period | Source | |
| Nyamwono Swamp | 14/06/1999 | SMUWC | 57 boundary coordinates are available |
| Nyangokolo Main Swamp | 14/06/1999<br>10/02/2010 | SMUWC<br>Field Survey | 74 boundary coordinates are available<br>44 boundary coordinates are available |
| Nyangokolo Minor Swamp | 14/06/1999 | SMUWC | 40 boundary coordinates are available |
| Lyangulaje Swamp | 14/06/1999 | SMUWC | 122 boundary coordinates are available |
| Ruaha Swamp | 14/06/1999 | SMUWC | 139 boundary coordinates are available |
| Semkuya Swamp | 14/06/1999 | SMUWC | 123 boundary coordinates are available |

*Wetlands inflows*

*River flows:* The two perennial rivers (GRR and Ndembera) are gauged, while the two seasonal rivers (Kioga and Kimbi) are not gauged, although some spot discharge measurements have been carried out. The GRR inflow into Ihefu is considered to be at the point where it is gauged at Nyaluhanga.

The data inventory from SMUWC and Kashaigili indicate that this station has a continuous time series of observed daily discharges for the period 25th October 1998-31st March 2004, as shown in Table 56. RBWO re-established the station and consequently it has been observing it since 2001. Data for the period between 1st April 2001 and 31st December 2008 were obtained from RBWO (Table 56).

**Table 56: Inflow river discharge data at inflow gauging stations for Ihefu wetlands**

| St No. | Location | | | Established | Data Availability | |
|---|---|---|---|---|---|---|
| | Name | River | Location | | Period | Source |
| | 1KA71 | GRR | Nyaluhanga | | 25/10/1998 – 27/10/1999<br>01/01/1999 – 31/03/2004<br>01/04/2001 – 31/12/2008 | SMUWC<br>Kashaigili<br>RBWO |
| 51 | 1KA33 | Ndembera | Madibira | 03/12/1956 | 01/01/1957 – 30/04/1990<br>19/01/1999 – 31/12/1999 | WRED<br>SMUWC |
| 41 | 1KA15 | Ndembera | Ilongo | 12/02/1956 | 13/02/1956 – 31/01/1990<br>04/01/2000 – 31/01/2010 | WRED<br>RBWO |

Spot measurements have been carried out at Nyaluhanga between October 1998 and December 1999 (Table 57).

**Table 57: Inflow discharge spot data for Ihefu wetlands**

| Location | | | | Data Availability | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| River | Location | N (m) | E (m) | Date | WL (m) | Area ($m^2$) | Vel (m/s) | Discharge ($m^3$/s) | Source |
| GRR | Nyaluhanga (1KA71) | 9067437 | 0635479 | 12/10/1998 | | 19.100 | | 1.873 | SMUWC |
| | | | | 25/10/1998 | 6.50 | 14.637 | 0.09 | 1.341 | |
| | | | | 10/11/1998 | 6.38 | 12.334 | 0.08 | 0.921 | |
| | | | | 26/11/1998 | 6.14 | 1.271 | 0.40 | 0.512 | |
| | | | | 12/01/1999 | 6.05 | 0.401 | 0.34 | 0.137 | |
| | | | | 15/05/1999 | 7.18 | 46.520 | 0.29 | 13.522 | |
| | | | | 18/06/1999 | 6.62 | 15.448 | 0.25 | 3.798 | |
| | | | | 3/08/1999 | 6.55 | 13.381 | 0.19 | 2.572 | |
| | | | | 24/08/1999 | 6.72 | 19.439 | 0.23 | 4.446 | |
| | | | | 23/09/1999 | 6.34 | 6.516 | 0.19 | 1.231 | |
| | | | | 5/12/1999 | | | | 0 | |
| Ndembera | Ifunda | 9110821 | 0772268 | 24/01/1999 | | | | 0.800 | SMUWC |
| | | | | 19/05/1999 | | 3.557 | 0.09 | 0.327 | |

| Location | | | | Data Availability | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| River | Location | N (m) | E (m) | Date | WL (m) | Area ($m^2$) | Vel (m/s) | Discharge ($m^3$/s) | Source |
| | | | | 12/06/1999 | | 2.640 | 0.07 | 0.171 | |
| | | | | 6/09/1999 | | 2.708 | 0.05 | 0.140 | |
| | | | | 30/09/1999 | | 2.570 | 0.05 | 0.115 | |
| | | | | 13/12/1999 | | 2.567 | 0.06 | 0.144 | |
| | | | | 19/05/1999 | 1.205 | 6.331 | 0.33 | 2.058 | |
| | | | | 11/06/1999 | 1.130 | | | | |
| | | | | 9/08/1999 | 1.040 | 3.362 | 0.15 | 0.504 | |
| Ndembera | Ilongo (1KA15A) | 9085940 | 0738418 | 2/09/1999 | 1.010 | 3.241 | 0.11 | 0.358 | SMUWC |
| | | | | 30/09/1999 | 0.950 | 2.967 | 0.106 | 0.313 | |
| | | | | 13/12/1999 | | 2.187 | 0.083 | 0.181 | |
| | | | | 9/02/1999 | | 2.038 | 0.62 | 1.256 | |
| | | | | 1/04/1999 | | 7.731 | 0.69 | 5.343 | |
| Kioga | Mawindi | 9041079 | 0659400 | 15/06/1999 | | 0.344 | 0.46 | 0.159 | SMUWC |
| | | | | 5/08/1999 | | 0 | 0 | 0 | |
| | | | | 29/08/1999 | | 0 | 0 | 0 | |
| | | | | 28/8/1999 | | 0.225 | 0.369 | 0.083 | |
| Kimbi | Idunda | | | 8/12/1999 | | 0.016 | 0.034 | 0.00064 | |

Of 11 discharge measurements carried in 1998 and 1999, only four were done in 1998, and seven in 1999. Comparison of low flow discharge from SMUWC/Kashaigili data and RBWO indicated relatively very low discharges, e.g. close to and sometimes zero in the SMUWC/Kashaigili dataset, while RBWO low flow discharges were reasonable. This could result from the fact that the SMUWC rating curve was established using only a few measurements taken in 1998 and 2000.

However, a reported measured discharge of 0.180 $m^3$/s on 4th December 2003 (Msuya, 2003) was closer to the SMUWC/Kashaigili discharge estimate of 0.010 $m^3$/s than to the RBWO discharge estimate of 0.791 $m^3$/s. Similarly, the reported dry GRR at Nyaluhanga between 22$^{nd}$ and 30$^{th}$ November 2003 was closer to SMUWC/Kashaigili discharge estimates (0.192 $m^3$/s) than to RBWO discharge estimates (0.491-0.536 $m^3$/s).

These observations pose a question concerning the definition of a “dry” GRR at Nyaluhanga: Is it a completely dry river bed, or a very low flow that could be estimated by the rating curves? Despite such small differences, the two records were merged to provide a continuous inflow discharge of the GRR at Nyaluhanga spanning the period 1st January 1999 – 31st December 2008.

The longest inflow discharge series is available for the Ndembera River at Madibira. The data series spans two periods: 1 Jan 1957-30 Apr 1990 and 19 Jan 1999-31 Dec 1999 (Table 56). A time series of daily discharges was also available at an upstream gauging station (Ndembera at Ilongo) for the period 13 Feb 1956-31 Jan 2010.

Six spot discharge measurements have been taken at different times in 1999 at two locations (Ifunda and Ilongo) along the Ndembera River (Table 57), whilst five spot discharge measurements were taken in 1999 for the ungauged Kiogo River at Mawindi, and two on the Kimbi River at Idunda (Table 57).

The discharges for the total catchment area of the partly-gauged Ndembera River were estimated in three steps Daily discharges of Ndembera at Ilongo were first used to extend the daily discharge record of the Ndembera at Madibira. The extension procedure added the average long-term differences of daily flows between the two stations ($\Delta Q$) to Ilongo daily discharges. Flow routing was irrelevant, since within the same periods low river flows were recorded at Madibira, while no flows were recorded at Ilongo, so that routing of zero flows at Ilongo could not provide the recorded non-zero flows at Madibera. The area coefficient method was used to estimate daily discharge series at the outlet of the Ndembera River catchment, which was further increased by 20% to cater for ungauged daily flows of a tributary entering the Ndembera downstream of Madibira gauging station.

The low flow discharges in ungauged Kioga and Kimbi Rivers for the 1999-2010 period were estimated from low flow daily discharges of The GRR and Nyaluhanga. A few available low flow measurements in June-early December (Table 57) indicate that the flow in the Kimbi is about 1-2% that of the GRR at Nyaluhanga in the same day, whilst the daily low flow discharge of the Kioga is slightly higher, with a maximum of 4%. The maximum fractions (2% for Kimbi and 4% for Kioga) were used to estimate low flow discharges in the Kimbi and Kioga rivers from available low flow discharges of the GRR at Nyaluhanga.

Daily discharges of the Kioga River for the period 1961-1983 were estimated from the measured daily discharges of the upstream tributaries of Hukuni and Ruaha. The area ratio method was used to rescale observed daily discharges at 1KA23A and 1KA56 to obtain daily discharge at Mawindi. The low flow statistics (average, maximum and minimum) discharges were comparable to those estimated for the recent period from Nyaluhanga discharges. They were therefore considered to be of satisfactory quality.

It is noted that irrigation agriculture is widely practiced in the Usangu plains, using water from nearby rivers. Irrigation agriculture is abstracting significant amounts of water from the Ndembera and Kioga rivers, and small amounts from the Kimbi River (Table 58) (SMUWC, 2001c).

**Table 58: Estimated maximum irrigation abstractions in rivers draining into Ihefu wetlands**

| Catchment | Number of abstraction points | Total maximum abstraction ($m^3/s$) | 2004 abstraction level (%) | Evaporation loss from fan ($m^3/s$) |
|---|---|---|---|---|
| Kioga | 11 | 7.0 | 100 | 4.0 |
| Kimbi | 3 | 0.2 | 70 | 4.0 |
| Ndembera | 6 | 4.3 | 65 | 0 |

*(Source: SMUWC, 2001c)*

The estimated total maximum abstraction from six off-take points located downstream of the Madibira gauging station (1KA33), was about 4.30 $m^3/s$ (Table 58). Total maximum irrigation abstraction from eleven off-take points along the ungauged River Kioga was 7.0 $m^3/s$ by 2004, while that from three off-take points along the ungauged Kimbi River was only 0.2 $m^3/s$.

Inflow losses occur in the fans into which the Kioga and Kimbi rivers drain before they discharge into the Ihefu wetlands. The estimated water loss from each 14 $km^2$ fan was 4.0 $m^3/s$ (Table 58). The inflows from the three rivers (Ndembera, Kioga and Kimbi) into the Ihefu wetlands are therefore corrected by subtracting the corresponding irrigation abstractions and fan losses from the estimated discharges at the catchment outlets.

*Wetlands outflows*

*Outflow surface volumes:* Whilst the outlet of the Ihefu wetlands is at Ng'iriama, the river flow is gauged at two downstream locations: Msembe and Haussman's Bridge. Since their establishment in 1963 and 1956 respectively, the two stations have operational for much of the 1950s/1960s-2000s despite a few spells of malfunctioning. Consequently, long time series of daily discharge data are available at these two gauging stations (Table 59).

**Table 59: Inflow river discharge data availability at inflow gauging stations for Ihefu wetlands**

| St No. | Location | | | Established | Data Availability | |
|---|---|---|---|---|---|---|
| | Name | River | Location | | Period | Source |
| 42 | 1KA59 | GRR | Msembe | 23/10/1963 | 23/10/1963 – 28/02/1995<br>17/01/1999 – 19/09/1999<br>01/01/1957 – 31/10/2004<br>01/01/2001 – 28/02/2010 | WRED<br>SMUWC<br>Kashaigili<br>RBWO |
| 105 | 1KA27 | GRR | Haussman's Bridge | 26/05/1956 | 01/11/1956 – 31/12/1988 | WRED |

*(Source: SMUWC, 2001c)*

Different rating curves have been established at Msembe. Kashaigili (personal communication) reviewed the previously existing rating curves (Table 60), which did not adequately provide the best rating relationship.

**Table 60: Rating curves of the Great Ruaha River at Msembe (1KA59)**

| Rated Period | Source | Stage Range (m) | Equation | | |
|---|---|---|---|---|---|
| | | | k | Ho | x |
| Dec 1963-May 1985 | | $0 \leq H < 1.65$<br>$1.65 \leq H < 10$ | 0.095<br>8.930 | 0.50<br>1.65 | 9.098<br>3.163 |
| Dec 1963-May 1985 | WRED | Dec 1963-8 May 1979<br>0.39 – 10<br>9 May 1979-May 1985<br>0.71 – 10 | 20.50186<br><br><br>87.73802 | 0.39<br><br><br>0.71 | 3.2995<br><br><br>2.0606 |
| Dec 1963-Sep 2004 | Kashaigili | $0 \leq H < 0.91$<br>$0.91 \leq H < 10$ | 16.598<br>68.296 | 0.36<br>0.59 | 2.8000<br>2.724 |
| Dec 1963-Sep 2001 | SMUWC | $0.39 \leq H < 10$ | 20.502 | 0.39 | 3.299 |

Kashaigili finally proposed new rating curve equations, making use of the new set of rating data available up to September 2004. The proposed rating curve utilised mostly the post-1979 information (Figure 29) during its establishment.

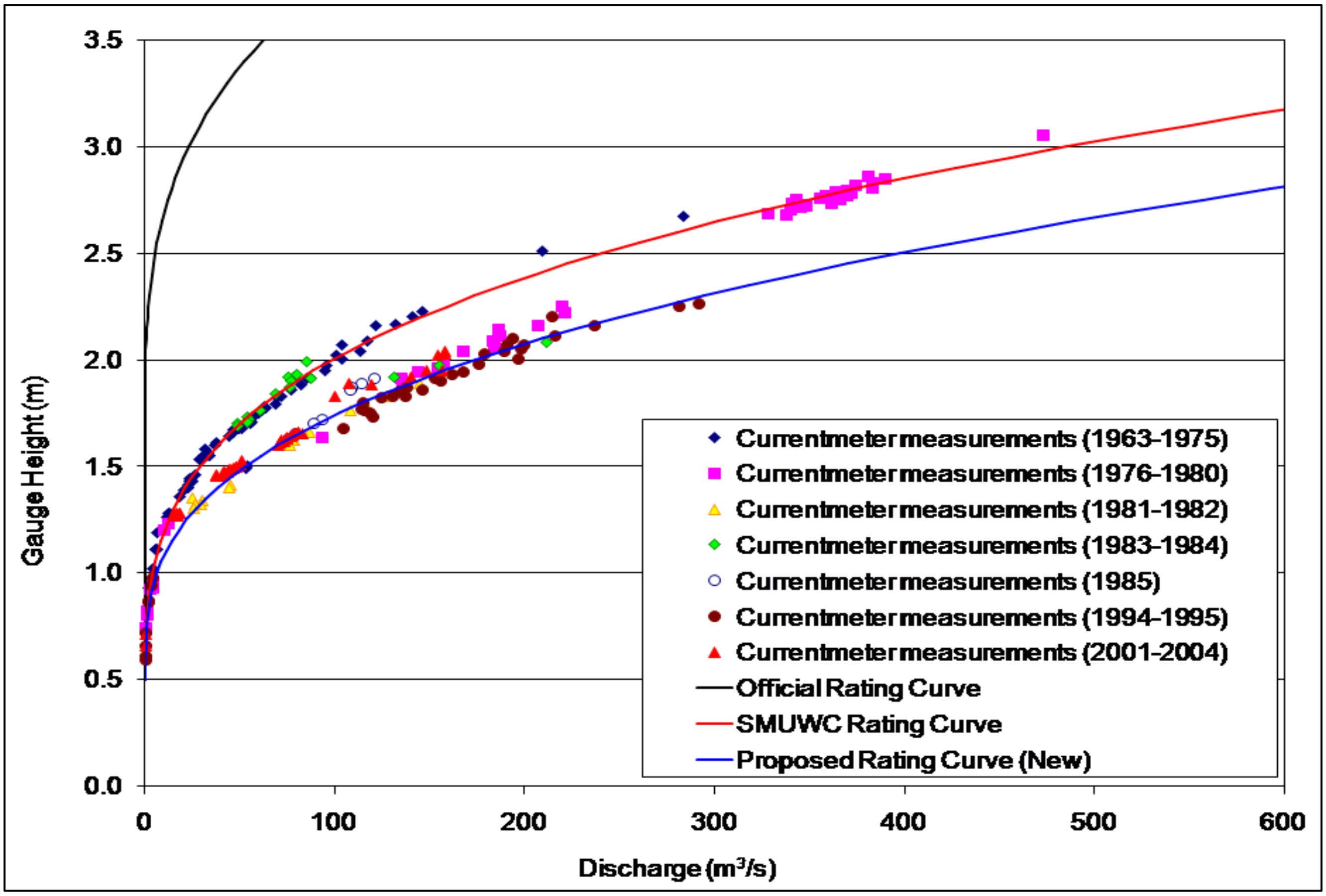



**Figure 29: Plot of rating information for the period 1963-2004 (Kashaigili, 2008)**

Although established from the rating data available between December 1963 and May 1985, the rating curve equations developed by Water Resources Engineering Department (WRED) of the University of Dar es Salaam and implemented by the Ministry of Water and Irrigation (MoWI) adequately identified the pre-May 1979 and post-May 1979 periods. (Table 60).

A comparison of daily discharge estimated by the two rating curves indicated almost comparable discharges during the low flows period (July-January). The comparison of moderate and higher daily discharge estimates at Msembe and Haussman's Bridge indicates that the WRED rating curve provides discharges at Msembe which are almost half those at Haussman's Bridge, while rating curves developed by Kashaigili provide daily discharges at Msembe comparable to those at Haussman's Bridge.

Daily discharges from the rating curves developed by Rufiji Basin Water Office (RBWO), however, gave slightly lower low flows that were factored to scale them up to compare with those estimated by the other two rating curves. This enabled the extension of the Msembe discharge series to 28th February 2010.

The estimated distance along the river between Ng'iriama outflow (1KA70) and the Haussman's Bridge gauging station (1KA27) is about 33 km, while that between Haussman's Bridge and Msembe (1KA59) is about 53.86 km. Kashaigili (2008) indicated a slight loss (~ 7.8%) of flow between Haussman's bridge and Msembe during the dry season and a slight flow gain (~ 0.5%) during the wet season. As a result, daily discharges at Haussman's Bridge were used to fill missing and extend daily discharges at Msembe to 1st November 1956 (Equation 11) for the period 1st June – 31st January:

$$Q_{1KA59} = 0.9217Q_{1KA27}$$

**Equation 11**

This filling and extension resulted in the Msembe daily discharge record spanning the period between 1st November 1956 and 28th February 2010. Simultaneous measurements of discharges at Ng'iriama (e.g. Table 61) and Haussman's Bridge for short periods in 1998 and 1999 indicated comparable discharges corresponding to a slight (~ 7%) discharge increase between Ng'iriama and Haussman's Bridge. Consequently, daily discharges at the Ng'iriama outflow (1KA70) were estimated from discharges at Haussman's Bridge (1KA27) using the relationship in Equation 12:

$$Q_{1KA70} = 0.93Q_{1KA27}$$

**Equation 12**

A few available measurements of Ng'iriama discharges and wetlands water surface elevations (Table 61) were used to establish the rating curve at Ng'iriama. The rating curves are given by the following relationships:

For March 1999:

$$Q_{1KA70} = \begin{cases} 7.960(h - 4.42)^{2.354} & \{0 - 5.99\ m\} \\ 0.740(h - 4.47)^{8.202} & \{6.00 - 6.08\ m\} \\ 8.160(h - 4.47)^{3.162} & \{6.09 - 10.0\ m\} \end{cases}$$

**Equation 13**

For February 2000:

$$Q_{1KA70} = 7.159(h - 4.48)^{2.204} \qquad \{4.48 - 5.95\}$$

**Equation 14**

**Table 61: Spot outflow discharge data availability for Ihefu wetlands**

| Location | | | | Data Availability | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| River | Location | N (m) | E (m) | Date | WL (m) | Area ($m^2$) | Vel (m/s) | Discharge ($m^3$/s) | Source |
| | | | | 25/11/1998 | | 0 | 0 | 0 | |
| | | | | 20/03/1999 | 4.74 | 0.781 | 0.34 | 0.269 | |
| | | | | 12/05/1999 | 6.28 | | | | |
| | | | | 10/07/1999 | 5.05 | 61.840 | 0.04 | 2.195 | |
| | | | | 15/07/1999 | 4.97 | 58.332 | 0.04 | 2.223 | |
| GRR | Ng'iriama | 9091232 | 0666815 | 19/07/1999 | 4.92 | 56.151 | 0.03 | 1.776 | |
| | | | | 23/07/1999 | 4.86 | 3.246 | 0.39 | 1.255 | SMUWC |
| | | | | 8/08/1999 | 4.69 | 1.338 | 0.40 | 0.528 | |
| | | | | 1/09/1999 | 4.53 | 0.498 | 0.27 | 0.133 | |
| | | | | 28/09/1999 | 4.32 | 0.250 | 0.06 | 0.014 | |
| | | | | 9/10/1999 | | | | 0 | |

The outflow discharge at Ng'iriama is the function of water elevation in the wetlands. The Ihefu wetlands overflow at Ng'iriama at a water depth of 4.40 m, which is equivalent to a sill elevation of 1009.525 masl (SMUWC, 2001c). This suggests that the bottom elevation of the Ihefu wetlands at Ng'iriama ($Elev_{Ihefu,Ng'iriama}$) is 1005.125 masl. Ndomba (2010) indicated a sill elevation of 1009.109924 masl and from his established wetlands elevation, area and storage information, the rating at Ng'iriama was developed as shown in Equation 15:

$$Q_{Ng'iriama} = 4.737(Elev - 1009.109924)^{2.99}$$

**Equation 15**

where *Elev* is the wetlands surface water elevation.

Equation 15 was therefore used to reconstruct a time series of daily water surface elevations for the Ihefu wetlands for the period 1st January 1957 – 28th February 2010. The estimated water levels were then used to establish daily wetlands surface area and storage volumes.

*Evapotranspiration from wetlands:* Evaporation data were estimated from available climatic information at the Dodoma Airport Station. Available climatic data at Dodoma Airport were used to compute the monthly evaporation using Penman-Monteith and Thornthwaite methods (SMUWC, 2001c). The value of the coefficient for the modified Thornthwaite model (SMUWC, 2001c) for temperatures exceeding 23$^{o}$C was modified from 16 to 24 (equation 3.15) to provide appropriate monthly potential evapotranspiration (PET) monthly estimate. The adopted modified Thornthwaite model for Dodoma Airport for PET was therefore as shown in Equation 16:

$$PET_i = \begin{cases} 0.126 \times T_i + 2.274 & T_i \leq 23℃ \\ 24 \times a \times \left(\frac{10 \times T_i}{I}\right)^b & T_i > 23℃ \end{cases}$$

**Equation 16**

where $T_i$ is the monthly mean temperature (°C), $PET_i$ is the monthly potential evaporation (mm/day) month *i* and *a* is a correction factor to account for the day length. The parameter *a* is computed from Equation 17:

$$a = \left(\frac{L_i}{12}\right) \times \left(\frac{N_i}{30}\right)$$

**Equation 17**

where $L_i$ is the mean actual day length (hours) and $N_i$ is the number of days in month *i*.

The parameter *b* is given in Equation 18:

$b = 6.75I^3 \times 10^{-7} - 7.71I^2 \times 10^{-5} + 1.792I \times 10^{-2} + 0.4924$

**Equation 18**

where *I* is given by Equation 19:

$$I = \sum_{1}^{12} \left(\frac{T_i}{5}\right)^{1.514}$$

**Equation 19**

Daily minimum and maximum temperature data were available at Dodoma Airport station for the period 1st January 1958 – 31st December 1993 (Table 62). Mean daily temperatures were computed as the average of daily maximum and minimum temperatures, while mean monthly temperatures were calculated simply as average of mean daily temperatures.

**Table 62: Availability of climatic data at Dodoma Airport station**

| Variable | Period of data availability |
|---|---|
| Temperature (min) | 1 Jan 1958 – 31 Dec 1993 |
| Temperature (max) | 1 Jan 1958 – 31 Dec 1993 |
| Relative humidity | 1 Jan 1973 – 31 Dec 1994 |
| Wind speed | 1 Oct 1973 – 31 Dec 1994 |
| Sunshine hours | 1 Oct 1973 – 31 Dec 1990 |

Data for other climatic variables including relative humidity, wind speed and sunshine hours were available for 1973 to 1994. Mean daily temperature, relative humidity, wind speed, net radiation and air pressure were obtained from RBWO for the Madibira and Ilangali Meteorological Stations for respective periods of 1st November 1998-31st January 2001 and 1st November 1998-31st October 2000.

Monthly PET values were estimated at Madibira from Penman-Monteith method. Estimated monthly PET at Dodoma Airport correlated well with monthly PET at Madibira (SMUWC, 2001c) and therefore a time series of monthly evaporation at Dodoma Met was used.

A disaggregation method was used to disaggregate monthly PET to daily evaporation. PET disaggregation simply distributed monthly PET to days of that particular month according the temperature of that day. The PET in day *j* of month *i* ($PET_{i,j}$) was disaggregated from PET of month *i* ($PET_i$) and day Temperature ($T_{i,j}$) using Equation 20:

$$PET_{i,j} = \left(\frac{T_{i,j}}{\Sigma T_{i,j}}\right) \times PET_i$$

**Equation 20**

Equation 20 was used to calculate daily evaporation values for the period 1st January 1958 – 31st December 1993 and 1st November 1998 – 31st January 2001. Daily evaporation data for the Ihefu wetlands were also obtained from Kashaigili (personal communication) for the period 1st January 1958 – 31st October 2003.

***Modelling procedure***

The focus of this hydrological study of Ihefu wetlands lies on the estimation of water cycle components relevant for the wetlands during the dry season. However, it is the low flow period of the dry season that has been particularly associated with the loss of river flows along the GRR downstream of the Ihefu wetlands. Despite many factors contributing to this situation of zero downstream flows, climate induced occurrence of (consecutive) dry years could aggravate the problem of a dry GRR. Therefore, the water balance modeling approach is based on estimating the water quantities of each active component of the water balance during the low flow period. Consequently, the overall procedure involves:

i) Identification of the low flow period

ii) Identification of historical dry years

iii) Carrying out low flow water balance modelling

*Identification of low flow period*

To appropriately establish a threshold that adequately isolates the four seasons, it was important to account for the spatial variation of flow magnitudes across the rivers that drain into the Ihefu wetlands. The experience of spatial hydrological analysis in various basins in the country indicated that the use of thresholds derived from average daily flow (ADF) was appropriate to provide comparable results, as ADF describes hydrophysiographic differences between the catchments.

Several thresholds, expressed as a percentage of ADF (ranging from 50% to 125% of ADF), are applied to average annual flow hydrographs to separate high, medium and low flows. These were applied to the long discharge record of the Ndembera River at Madibira. The selected thresholds are thereafter used to identify historical durations of low flow period in each year between 1957 and 2010.

*Identification of historical normal, wet and dry years*

The identification of dry years is based on the separate identification of dry early *Vuli* (November-January) and *Masika* (February-April) flow seasons, due to the occurrence of rainfall in the Ihefu, Usangu, and Rufiji basins. In most parts of Tanzania these are the two main rainy seasons, although the southern highlands in certain years may receive a single combined rainy season between November/December and April/May.

Drier (wet) days making the drought season were simply defined as those recording average daily discharge ($Q$) less (more) than one standard deviation ($\sigma$) from the long-term daily average discharge (μ). (i.e. $Q_{dry} < \mu - \sigma$; $Q_{wet} > \mu + \sigma$). The normal day discharge is that falling within the two bounds defining a dry and wet day discharge. Normal, wet and dry year years are therefore identified and documented.

*Water balance modelling*

Estimation of water balance components is carried for the low flow period in each year. Low flow water balance modelling is carried out separately for normal, wet and dry years, assisted by the above analysis. The procedure includes the determination of net groundwater flow ($Q_{sub,in} – Q_{sub,out}$) as the residual of the balance between wetlands inflow, outflow and storage change. Equation 10 is thus rearranged as shown in Equation 21:

$$(Q_{sub,in} - Q_{sub,out}) = (Q_{nyaluhanga} + Q_{ndembera} + Q_{kioga} + Q_{kimbin}) - (Q_{Ng'iriama} + ET) - \Delta S_{t,t-1}$$

**Equation 21**

Equation 21 indicates that the difference between the net storage change (estimated as the difference between total surface inflows and outflows) and observed storage change (estimated from daily storages computed from wetlands' water surface elevation) could be contributed to by flow beneath the ground surface. This unaccounted-for water is considered to be the net change of groundwater inflow and outflow. If negative, the groundwater is contributing to drying of wetlands, and vice versa.

***Analysis of lugoda reservoir releases option***

The releases from the planned Lugoda reservoir are expected to increase inflow into Ihefu wetlands so as to sustain a continuous flow of the GRR downstream of the wetlands through the Ng'iriama natural weir. To identify the level of required reservoir releases, the Ihefu wetlands water levels required to sustain different downstream discharges was maintained as a constant during the analysis. The analysis procedure involved:

i) Setting out of required magnitude of outflow discharge at Ng'iriama

ii) Addition of a constant reservoir release to balance out the net outflows

The discharge that balanced the inflows and outflows with zero wetlands storage change was considered as the required release. This discharge was estimated as described in subsequent sections.

***Effects of dry years on ihefu wetlands***

The analysis of the impact of dry years on the size and outflow of the Ihefu wetlands was carried out considering mainly three options:

i) Absence of early *Vuli* rains

ii) Deficit *Masika* rains

iii) Deficit *Vuli* and *Masika*

The analysis was based on historical flow hydrographs in drought years. Consideration was given to years when:

i) Only *Vuli* failed while *Masika* rains occurred in one year

ii) Only *Masika* failed while Vuli *were* received in one year

iii) Both *Vuli* and *Masika* failed in one year

iv) Consecutive *Vuli, Masika* and *Vuli* of consecutive years failed

v) *Vuli* and *Masika* failed in two consecutive years

## Water balance modelling

### *Identification of low flow period*

The recession from high flows through medium flows to low flows and vice versa is a lengthy process. 30 - 40% ADF thresholds were appropriate for the separatation of the low flows from the medium flows. The results indicated that the average low flow season in different parts of the GRR sub-basin extends between mid/late June, and mid December (Figure 30). The average low flow period lasts for about 174 days between 18th June and 8th December in the Ndembera River, while extending between 30th June and 26th December (~ 181 days) in the GRR at Msembe (Table 63). This low flow period around the Ihefu wetlands is a characteristic in rivers in the GRR Sub-basin as indicated by similar low flow period of GRR at Salimwani, which extends for about 164 days between 24th June and 4th December.

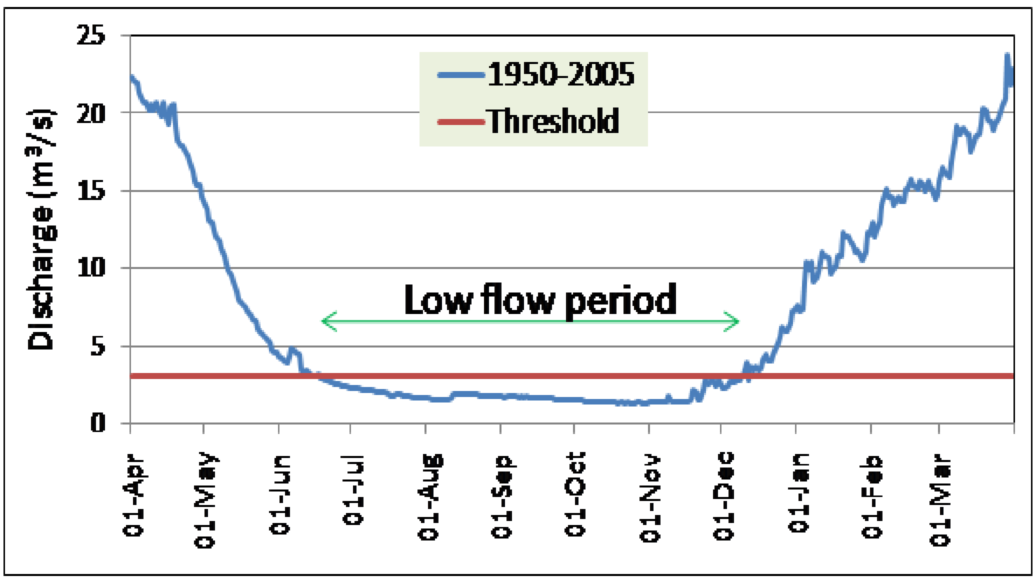
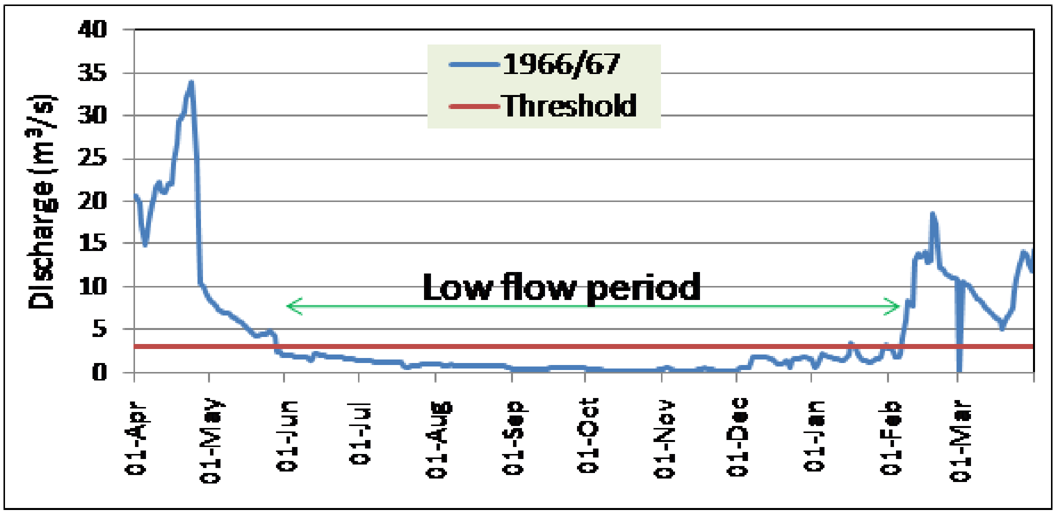



**Figure 30: Low flow season identification of Ndembera at Madibira in the Ihefu wetlands catchment**

**Table 63: Average date and duration of low period in Usangu plains**

| Gauge name | River | Location | Low flow period | |
|---|---|---|---|---|
| | | | Dates | Length (days) |
| 1KA33B | Ndembera | Madibira | 18$^{th}$ Jun – 8$^{th}$ Dec | 174 |
| 1KA59 | GRR | Msembe | 30$^{th}$ Jun – 26$^{th}$ Dec | 181 |
| 1KA8A | GRR | Salimwani | 24$^{th}$ Jun – 4$^{th}$ Dec | 164 |

The average dates and durations of low flow periods are dynamic, i.e. varying from one year to another depending on the rainfall situation in particular years. The low flow period is prolonged for several days due to delays or failure of the early rains in November/December. The low flow period in Ndembera, for example, which was estimated to start on 29th May 1966 was significantly prolonged to 5th February 1967 (Figure 31a), spanning a total of 253 days. A short low flow period of 130 days in Ndembera was observed between 9th August and 21st December 1969 (Figure 31b). As a result, low flow periods were established each year while keeping the low flow threshold discharge constant.



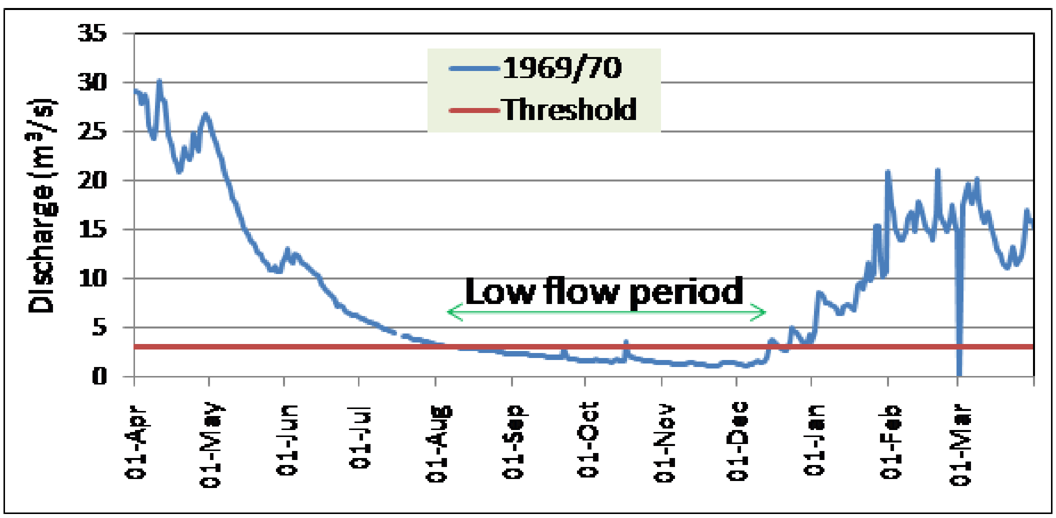




**Figure 31: Flow seasons in Ihefu wetlands catchment in different years**

***Identification of historical wet years***

Separation of discharges exceeding one standard deviation above the long-term average discharge ($\mu + \sigma$) for each day of the year (e.g. Figure 32a) indicated higher discharges in several years. The longest period experiencing discharges higher than the μ + σ discharge was observed between April and September 1968 (177 days), followed by that which occurred between April and August 1974 (120 days) and March-September 1987 (109 days). Other long periods (> 70 days) where daily discharges exceeded μ + σ discharges all occured between April and September in 1964 (83 days), 1979 (87 days), and 1980 (73 days).

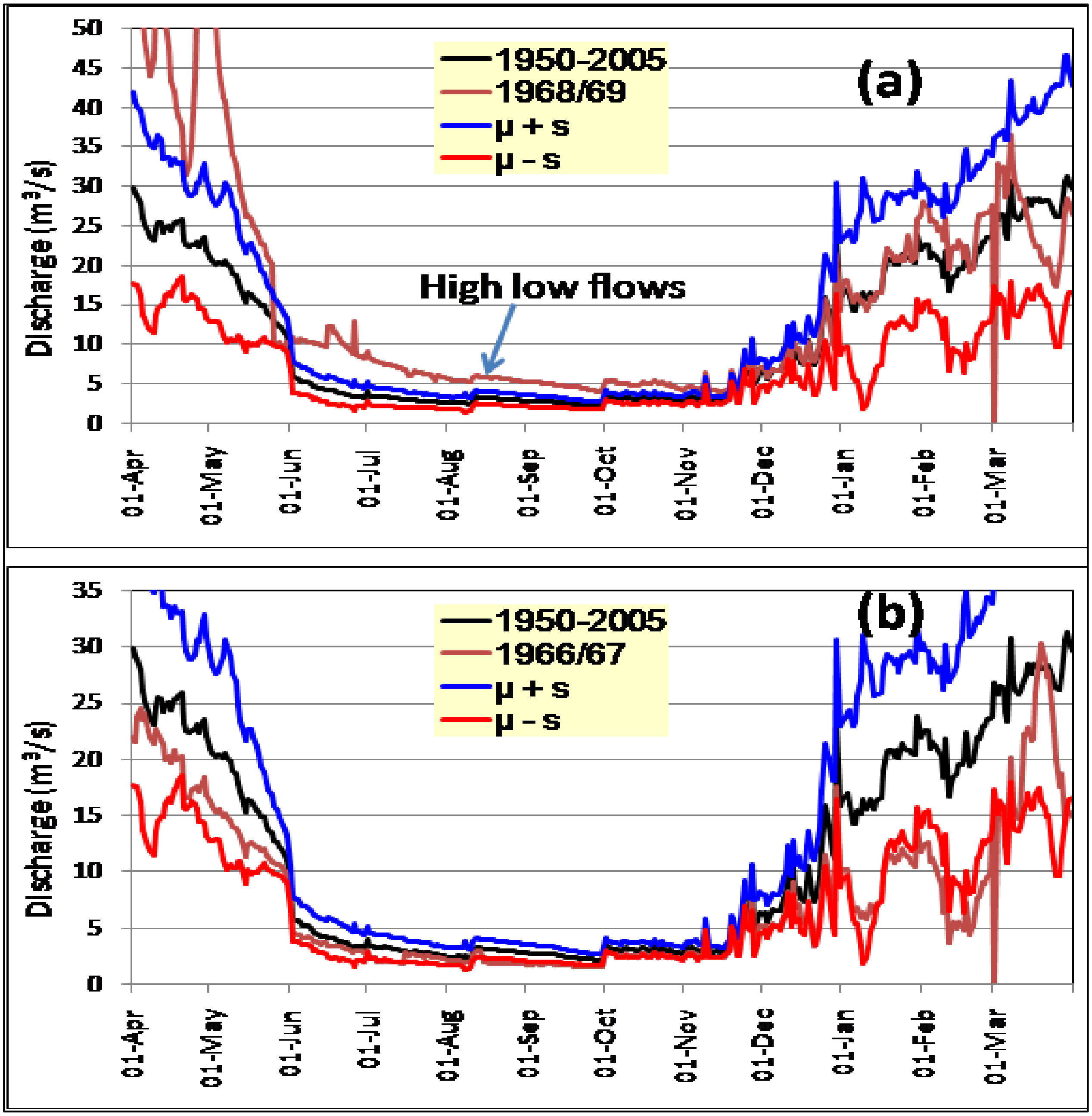



**Figure 32: Annual flow hydrographs for long-term average, thresholds and a) wet year and b) dry year in Ndembera at Madibira**

***Identification of historical dry years***

The identification of drought periods making up drought seasons in different years was indicated by different lengths and locations of drought periods within the annual hydrographs. The annual hydrographs of the Ndembera at Madibira, for example, indicated preference of drought conditions that extend within the year.

With the year defined between 1st April and 31st March of the following year, several multi-year drought conditions have occurred in the catchment. The longest in the 1960s occurred between July 1966 and October 1967 (Figure 32b) while September 1976-November 1976 and June-September 1977 were the longest drought condition periods in the 1970s (Table 64). The 2000s have seen several recurring drought conditions including the historical longest, which extended for about 188 days between November 2003 and August 2004.

**Table 64: Characteristics of historical drought conditions in Ndembera River at Madibira**

| Period | Length (days) | Pause |
|---|---|---|
| November 2003 – August 2004 | 188 | March, April 2004 |
| July 1966 – October 1967 | 159 | May, July, August 1967 |
| January – August 2000 | 146 | April |
| February – August 2003 | 113 | |
| June – September 1977 | 81 | |
| November 2005 – March 2006 | 63 | |
| September – November 1976 | 63 | |

***Water balance results***

Water balance modelling was carried out for low flow periods throughout the entire record (1956-2010), as well as for low flows in selected normal, wet and dry years, to assess the magnitude of the contributions of different water balance components. The years and the low flow analysis periods selected were

i) Normal year: 1st April 1972 – 31st March 1973 {15th Jun – 15th December}

ii) Wet year: 1st April 1968 – 31st March 1969 {1st Jul – 30th Nov}

iii) Dry year: 1st April 2003 – 31st March 2004 {1st Aug – 15th Dec}

The estimation of discharges of the GRR at Nyaluhanga from the upstream gauging stations for the period between 1955 and 1984 gave very high discharges values even for the low flow period. At some points, particularly during the high flows, the estimated higher discharges closely corresponded to floods recorded downstream at the Haussman's Bridge and Msembe gauging stations. This was observed, for example, for the estimated Nyaluhanga discharge of 362.7 $m^3/s$ on 12 April 1979 while the corresponding flow at Haussman's Bridge was 516.1 $m^3/s$ and the Ndembera at Madibira recorded only 37.3 $m^3/s$.

Owing to the need for further checks and refinement of discharge estimation at Nyaluhanga, the present analysis used observations at Nyaluhanga and therefore the 1999-2010 period was analysed. The water balance of Ihefu wetlands for the normal (1972/73) and wet (1968/69) years are waiting further refinement of discharge estimations at Nyaluhanga.

*Ihefu wetlands size and volume during low flow periods*

The historical analysis indicated that the Ihefu wetlands has extended between 17.3 and 68.2 $km^2$ during different low flow periods between 1999 and 2009, which corresponded to wetlands volumes of 14.8 and 97.3 $Mm^3$.

The estimated lowest area of the Ihefu wetlands in 1999 was about 18.714 $km^2$ corresponding to a wetlands volume of 16.5 $Mm^3$. The estimated lowest area of the Ihefu wetlands from this study for 1999 was about 18.714 $km^2$ corresponding to wetlands volume of 16.5 $Mm^3$. The estimated minimum area of the wetlands in 1999 was respectively 50 $km^2$ (SMUWC, 2001c), which was substantially higher than the estimated in this study. Similarly, SMUWC (2001c) indicated a very high estimated area of the wetlands of 1767 $km^2$ corresponding to an outflow discharge of 1565 $m^3/s$ while corresponding wetlands area for this discharges were 659.9 $km^2$ (Kashaigili, 2008) and 399.1 $km^2$ from relationships developed by Ndomba (2010) for this study.

*Water balance for 1999/2000-2009/10 low flow periods*

An estimation of the water balance components (as shown in Table 65) for the Ihefu wetlands during the low flow periods (1st August – 25th December) between 1999/2000 and 2009/10 indicated the dominance of the inflow from the GRR and losses from evapotranspiration on the wetlands water balance. Inflows from the GRR at Nyaluhanga contributed an average of 144,840 $m^3$ (~ 68% of the total surface water inflows) to the wetlands, while evapotranspiration contributed about 138,060 $m^3$ 63% of water losses from the wetlands.

Despite such a dominance of inflow from the GRR at Nyaluhanga, the actual daily contributions ranged between 0 and 897,200 $m^3$, the zero contribution is a result of periodic flow cessation occurring during the low flow period particularly between late October and early December as has been frequently occurring since the early 1990s (e.g. November, 2003). Evapotranspiration has withdrawn a daily average of 138,060 $m^3$ although it actually withdrew between 89,000 and 283,300 $m^3$ daily from the Ihefu wetlands. The estimated evapotranspiration losses from Ihefu are equivalent to daily outflow discharges of 1.03 – 3.28 $m^3/s$ (average: 1.60 $m^3/s$).

The volumetric contributions of the inflows of the Kioga and Kimbi rivers to the average low flow water balance of the wetlands (Table 65) were relatively small, ranging from 0 – 2.8% (Kioga) and 0 – 1.4 % (Kimbi) of the total inflows into the wetlands.

**Table 65: Summary of average of low flow water balance components ($m^3$) for Ihefu wetlands for the Jan 1999-Jan 2010 period**

| Index | Surface Inflows | | | | | Surface Outflows | | | Net GW flow ($m^3/s$) | |
|---|---|---|---|---|---|---|---|---|---|---|
| | $V_{Nyaluhanga}$ | $V_{Ndembera}$ | $V_{Kioga}$ | $V_{Kimbi}$ | Total | $V_{Ng'iriama}$ | $V_{PET}$ | Total | Outflow | Inflow |
| Average | 144,840 | 59,460 | 6,068 | 3,034 | 213,400 | 80,620 | 138,060 | 218,670 | 0.754 | 1.815 |
| High | 897,200 | 247,500 | 63,860 | 31,930 | 1,075,930 | 693,600 | 283,300 | 1,356,600 | 2.559 | 4.421 |
| Low | 0 | 0 | 0 | 0 | 0 | 0 | 89,200 | 89,200 | 0.002 | 0.002 |

The estimation of unknown groundwater contribution to the water balance of the Ihefu wetlands gave a general subsurface outflow of 0.02 – 2.60 $m^3/s$ (average: 0.75 $m^3/s$) and a net inflow of 0.002 – 3.18 $m^3/s$ (average: 1.19 $m^3/s$).

The variation of net subsurface flows indicates predominant outflows during the early part of the low flow period (August-September) followed by a general subsurface inflow into the wetlands from October through to November (Figure 33). This could suggest the effects of high inflow during the wet season that needs a general net subsurface outflow to balance the high surface inflows. The low surface inflows during the late part of the low flow period require net subsurface inflows to balance total outflows contributed highly by evapotranspiration losses plus Ng'iriama outflows.

The estimated net outflow from the Ihefu wetlands that can be attributed to evapotranspiration and groundwater components is equivalent to outflow discharges of 0.16 – 4.60 $m^3/s$, with an average of 1.77 $m^3/s$. However, the sum of minimum, maximum and average quantities of evapotranspiration and groundwater flows are respectively 1.05, 5.88 and 2.35 $m^3/s$, exceeding the computed values from the daily wetlands water balance model. This indicates that the highest values of evapotranspiration and groundwater do not occur concurrently.

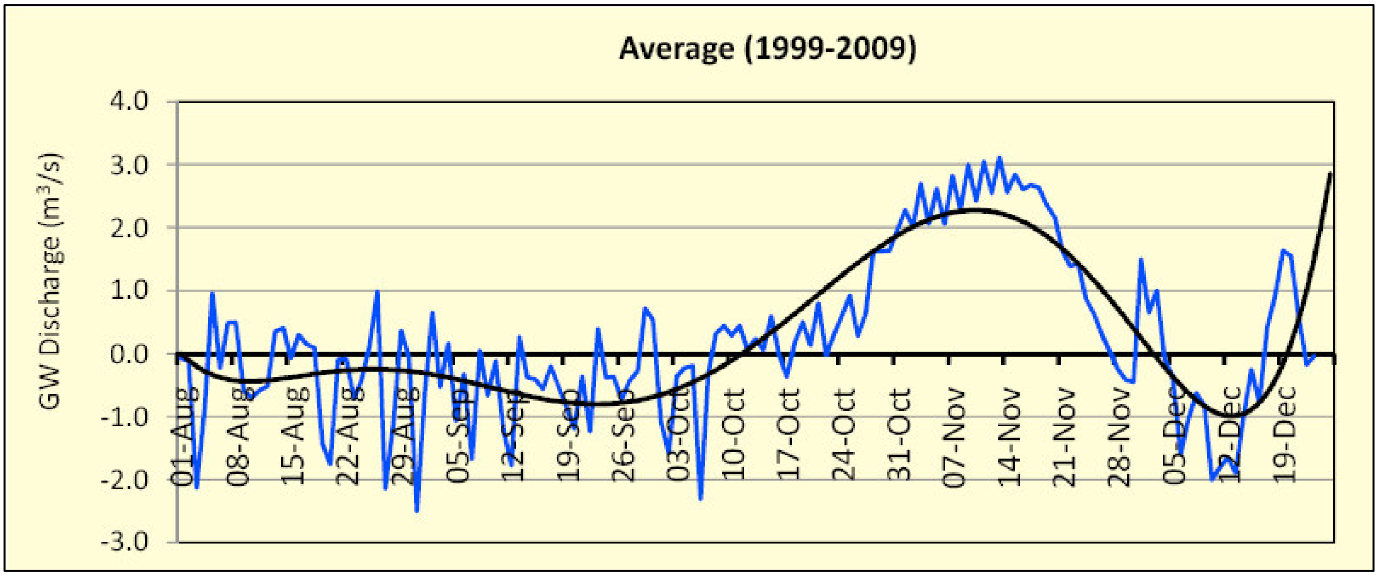



**Figure 33: Estimated average pattern of subsurface flow contribution to Ihefu wetlands water balance during the low flow period**

*Water balance for drought low flow periods*

The estimation of water balance components for the Ihefu wetlands for the low flow period of 2003 indicated still the predominance of inflows of the GRR and evapotranspiration losses on the wetland water balance. Inflow from the GRR at Nyaluhanga contributed an average of 68,830 $m^3$ to the wetlands while evaporation caused approximately 110,610 $m^3$ of water to be lost from the wetlands (Table 66).

**Table 66: Summary of average of low flow water balance components ($m^3$) for Ihefu wetlands for Aug – Dec 2003**

| Index | Surface Inflows | | | | | Surface Outflows | | | Net GW flow ($m^3$/s) | |
|---|---|---|---|---|---|---|---|---|---|---|
| | $V_{Nyaluhanga}$ | $V_{Ndembera}$ | $V_{Kioga}$ | $V_{Kimbi}$ | Total | $V_{Ng'iriama}$ | $V_{PET}$ | Total | Outflow | Inflow |
| Average | 68,830 | 0 | 0 | 0 | 68,830 | 11,720 | 110,610 | 122,640 | 1.364 | 1.722 |
| High | 198,200 | 0 | 0 | 0 | 198,200 | 93,430 | 151,010 | 464,620 | 5.461 | 3.602 |
| Low | 0 | 0 | 0 | 0 | 0 | 0 | 97,130 | 97,130 | 0.068 | 0.013 |

The GRR inflow at Nyaluhanga contributed between 198,200 $m^3$ in the early part of the low flow period and 0 $m^3$ towards the late part of the low flow period when the river dried out completely in late November-early December. Evapotranspiration withdrew between 97,130 and 151,000 $m^3$ daily from the Ihefu wetlands during the same period, which was equivalent to daily discharges of 1.12 – 1.75 $m^3$/s (average: 1.28 $m^3$/s). Other rivers (Ndembera, Kioga and Kimbi) made almost no volumetric contribution to surface inflow.

The estimation of unknown groundwater contribution to water balance of the Ihefu wetlands indicated estimates of a general subsurface outflow of 0.07 – 5.46 $m^3/s$ (average: 1.36 $m^3/s$) and a net inflow of 0.013 – 3.60 $m^3/s$ (average: 1.72 $m^3/s$). The variation of net subsurface flows indicates earlier subsurface inflow into the wetlands since early September (Figure 34). The subsurface inflows continued to supply the wetlands until the early December, when the surface inflows started to contribute to wetlands water storage.

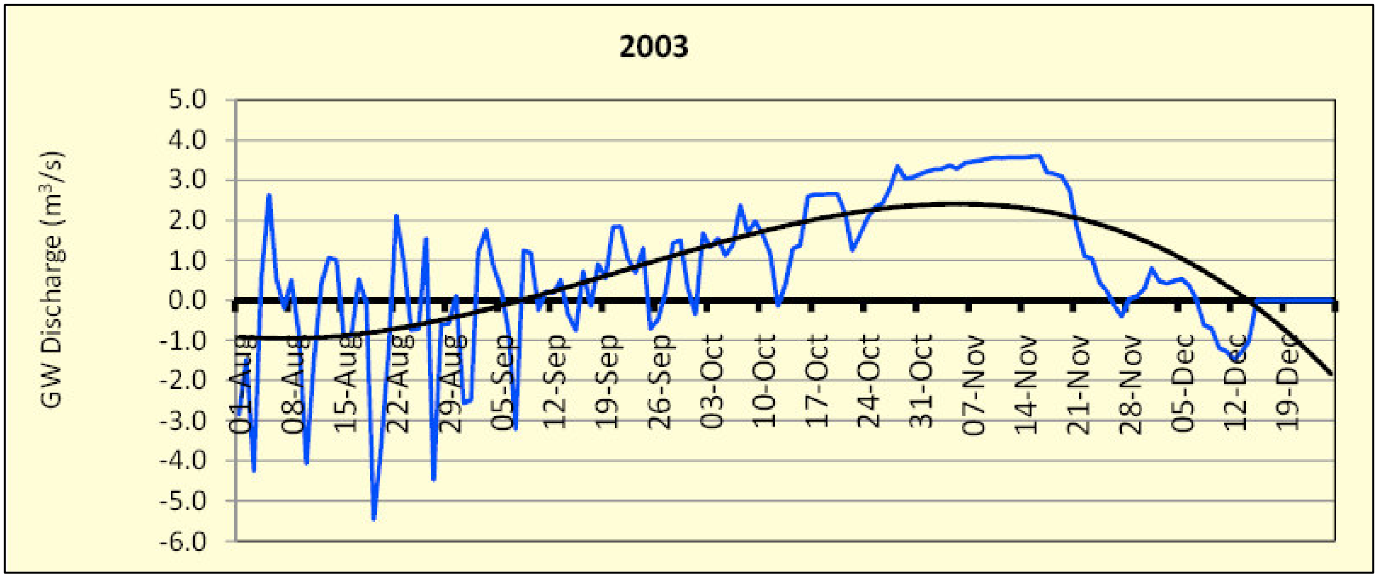



**Figure 34: Estimated pattern of subsurface flow contribution to Ihefu wetlands water balance during the low flow period of 2003**

The estimated net outflow from the Ihefu wetlands due to the evapotranspiration and groundwater components is equivalent to outflow discharges of 0.04 – 5.97 $m^3/s$,with an average of at 1.61 $m^3/s$. The sum of the 2003 lowest equivalent PET and subsurface discharges is 1.19 $m^3/s$ and that of the highest is 7.21 $m^3/s$, which exceed the above model computed range of 0.04 – 5.97 $m^3/s$.

This indicates that the lowest and highest values of evapotranspiration and groundwater do not occur concurrently. Similarly, the net of subsurface inflows and evapotranspiration losses in 2003 ranged between 0.11 and 2.40 $m^3/s$ equivalent discharge averaging at 1.34 $m^3/s$.

***Analysis of inflow increase from Lugoda reservoir releases***

The impacts of changing inflow and climatic conditions on the Ihefu wetlands are most apparent during the drought low flow periods. The option of supplying the wetland with flows from the proposed Lugoda reservoir (to be located on the Ndembera River) is explored for the drought low flow conditions, as achieving a satisfactory flow during drought low flow conditions will guarantee excess flows during low flow periods in normal and wet years.

From the historical record for the period January 1999- January 2010, the target of ~ 1 $m^3/s$ outflow discharge at Ng'iriama that is required for the restoration of GRR dry season flows (Franks *et al.*, 2004) was observed on different dates during the hydrograph recession towards low flows (Table 67).

This outflow discharge occurred early in July and August in the early 2000s (2000, 2001, 2003) but predominantly in mid to late September towards the end of 2000s (2006, 2008, 2009) (Table 67). The total inflows at these times vary mainly between 2.25 $m^3/s$ and 4.60 $m^3/s$ ($Q_{inflow,\ 1d}$) while the 10 day (to date of 1 $m^3/s$ outflow) average inflows ($Q_{inflow,\ 10d}$) ranged mainly between 2.27 and 5.22 $m^3/s$ (Table 67). However, the outflow decreased progressively to very low flows and zero outflows on some days of October and November.

**Table 67: Summary of inflow discharges at the date of 1 $m^3/s$ Ng'iriama outflow**

| Year | Date | $Q_{Ng'iriama}$ | Inflows ($m^3/s$) | | | | | |
|---|---|---|---|---|---|---|---|---|
| | | | $Q_{Nyaluhanga}$ | $Q_{ndembera}$ | $Q_{Kioga}$ | $Q_{Kimbi}$ | **$Q_{inflow,\ 1d}$** | **$Q_{inflow,10d}$** |
| 1999 | | | | | | | | |
| 2000 | 25 Jul | 1.007 | 2.818 | 0.332 | 0.113 | 0.056 | 3.319 | 3.621 |
| 2001 | 29 Aug | 1.023 | 5.534 | 0.693 | 0.221 | 0.111 | **6.559** | **7.857** |
| 2002 | 09 Sep | 1.015 | 3.973 | 0.390 | 0.159 | 0.079 | 4.602 | 4.568 |
| 2003 | 02 Aug | 1.023 | 1.754 | 0.390 | 0.070 | 0.035 | 2.249 | 2.273 |
| 2004 | 12 Sep | 1.050 | 1.789 | 0.423 | 0.072 | 0.036 | 2.319 | 2.305 |
| 2005 | 24 Sep | 1.025 | 1.262 | 0.195 | 0.050 | 0.025 | **1.533** | 1.735 |
| 2006 | 30 Sep | 1.004 | 1.178 | 0.073 | 0.047 | 0.024 | **1.322** | **1.339** |
| 2007 | 21 Aug | 1.007 | 2.706 | 0.747 | 0.108 | 0.054 | 3.615 | 3.737 |
| 2008 | 12 Sep | 1.033 | 2.974 | 0.353 | 0.119 | 0.059 | 3.505 | 5.217 |
| 2009 | 20 Sep | 1.021 | | 0.263 | | | | |
| **Average (μ)** | | **1.021** | **2.665** | **0.400** | **0.107** | **0.053** | **3.225** | **3.628** |
| **Standard deviation (σ)** | | **0.015** | **1.407** | **0.213** | **0.056** | **0.028** | **1.640** | **2.053** |
| **μ + σ** | | **1.035** | **4.072** | **0.613** | **0.163** | **0.081** | **4.864** | **5.681** |
| **μ - σ** | | **1.006** | **1.258** | **0.187** | **0.050** | **0.025** | **1.585** | **1.575** |

Note: Values in red and blue are respectively below and above one standard deviation (σ) from the mean (μ).

The requirement to maintain a minimum outflow discharge of 1 $m^3/s$ at Ng'iriama was investigated by computing the total daily outflows from the Ihefu wetlands that must be balanced by the total inflow into the wetlands. For the fixed wetlands water surface elevation at 1009.704 masl that produce a Ng'iriama outflow discharge of 1 $m^3/s$, the total outflows from the wetlands between 1st July and 31st December

2003 varied between 5.08 and 5.52 $m^3$/s. For an outflow of 2 $m^3$/s that would reliably ensure availability of at least 1 $m^3$/s at RNP EF site, the total inflows into the wetlands for the 2003 conditions would be between 6.31 and 6.81 $m^3$/s.

Therefore, for maintenance of an outflow at Ng'iriama of at least 1 $m^3$/s, a total surface water inflow of at least 5.52 $m^3$/s is required. However, for a 1 $m^3$/s at the RNP, an inflow of at least 6.81 $m^3$/s should enter the wetlands. It is therefore recommended to provide at least 6.81 $m^3$/s to the wetlands in order to sustain the EF requirement at RNP. At the presumed existing flow regime of the GRR at Nyaluhanga, all the 6.81 $m^3$/s should be supplied from the reservoir during the zero inflows of the GRR at Nyaluhanga.

***The Ndembera transfer option***

The water transfer can be considered to take place either on-channel through the Eastern wetland or off-channel (or canal transfer) using the shortest aerial distance before the wetlands.

Given the existing situation of zero GRR inflows into Ihefu, the entire 6.81 $m^3$/s would need to come from the Ndembera River, which could not be assured without the reservoir.

The first option of on-channel transfer of water would require a minimum of 0.93 $m^3$/s and a maximum of 6.81 $m^3$/s from the Lugoda reservoir, under the situation of 5.81 and 0.0 $m^3$/s inflows of Great Ruaha at Nyaluhanga respectively, to ensure a minimum discharge of 1.0 $m^3$/s across BBM sites.

Any required high flow (> 1 $m^3$/s) across the BBM sites would require a much higher discharge (> 0.93 – 6.81 $m^3$/s) from the Ndembera River.

The second option, i.e. a canal transfer of water before the wetlands, would require 0.93 – 6.81 $m^3$/s to be left into the river to flow into the wetlands to cater for instream flow requirements, resulting in a discharge of 1 $m^3$/s flowing through the BBM sites downstream of the Eastern wetland. For the canal to fully supply this 1 $m^3$/s, the required inflow into the Eastern wetlands from the Ndembera River would vary between 0.93 and 4.65 $m^3$/s depending on the amount of inflows of the GRR.

***Effects of consecutive dry years on ihefu wetlands***

Historical records have indicated the least chance of occurrence of multi-year drought conditions in the catchment areas of the Ihefu wetland. This lack of connectivity of drier early and late rains is reflected in an annual replenishment of the wetlands as its total volume of 121.6 $Mm^3$ at at area of 80 $km^2$ requires a constant inflow of 47 $m^3$/s for a period of 30 days or 31 $m^3$/s for 45 days, which has always been available during the rainy season. Therefore, the effect of isolated dry years is represented by the effects during 2003 drought conditions.

### 6.4.3. Hydraulics

### Study methodology

The hydraulics component in this study contributed to the assessment of environmental flows of the Ihefu perennial wetland by developing rating relationships. Therefore, the product of the hydraulics component of this study was a series of relationships between stage and other flow parameters that were used by the team of specialists to arrive at water management scenarios in the Ihefu wetland system. These relationships included flow discharge, inundated surface area, and volume/storage.

The hydraulic modeling study for Ihefu wetland comprised the following components:

- Literature review or desktop study to identify gaps and additional data needs;
- Reconnaissance survey;
- Topographic/geometric and hydraulics data survey;
- Geometric and hydraulic data analysis;
- Setting up of a hydraulic model for the study reach.
- Reviewing sediment and water quality data

The specific tasks of the Hydraulic team were to:-

(i) Review existing information and data from the previous studies (i.e., SMUWC and RIPARWIN) on Usangu wetlands, identify gaps and additional data needs.

(ii) Participate in a pre-wetland survey meeting between specialists to discuss and document criteria for selecting transect location and other fieldwork related issues (i.e. agreeing on transect location/s and wetland trip schedules) considering that the same logistical/survey boat will be used by all experts.

(iii) Lay transects and conduct hydraulic (bathymetry) and cross-sectional surveys in different wetland zones.

(iv) Conduct sediment and water quality sampling and analysis (establish sedimentation and water quality status).

(v) Conduct hydraulic modeling of the Usangu wetlands and characterize inflows in relation to storage, inundated area and depth/elevation.

(vi) Describe the impact of flow reduction to the wetlands.

(vii) Prepare a starter document, to be circulated amongst the specialist team in advance of the EFA workshop

(viii) Attend the EFA workshop and participate in discussions to

a. recommend water requirements (flow recommendations) for the wetlands,
b. present findings to stakeholders and
c. incorporated comments/additional inputs on your starter report before submitting the starter report for incorporation into the final EFA report.

### Reconnaissance survey

Reconnaissance surveys were conducted in both December 2009 and February-March 2010. The first visit took place in the low flows season, where hydraulic features such as

- material forming the river channel bed,
- roughness conditions,
- cross section geometry and
- hydraulic controls,

could be observed/studied. Additionally, the visit allowed the hydraulic specialist to ascertain river patterns, schematise problems, and select an appropriate modelling framework.

The second field visit took place during the wet season when the wetland extended beyond banks of the main channel and ponds. The reconnaissance survey entailed relocating SMUWC bathymetry survey control points (i.e. beacons corresponding to wetland border, highest water marks) and flow gauging stations, and establishing the location of the Ng'iriama natural rock outcrop sill, and open water ponds. Additionally, people with familiarity with the study reach (e.g. villagers, fishermen, elders, Rufiji Basin Water Office; Rujewa sub-office, and TANAPA staff) were interviewed during the survey, in order to collect other relevant information such as historical flood levels and recent river geomorphologic changes.

### Topographic and hydraulic data survey

The study area was surveyed to collect topographic and hydraulic data pertaining to ponds and channels. The main focus of the geometric data survey was on ponds and the micro channels. The geometric data collected included transverse (cross section) and longitudinal profiles for selected representative river reaches, and sounding depths for the bed topography of the open water ponds.

The hydraulic data/information collected included stage readings and rating curves for the following gauging stations:

- GRR at Nyaluhanga-1KA71, (WBBM1)
- Nyankokolo and Ruaha ponds; Historical flood levels/highest water marks, (WBBM2) and
- Ndembera at Madibira-1KA33B, GRR at Ng’iriama-1KA70 (WBBM3)

Roughness conditions were assessed by analysing hand-picked grab samples of the material forming the channel banks and flood plains. A guideline by Chow (1959) was used when estimating the roughness number.

Supplementary data on longitudinal water surface profile levels from Nyaluhanga to Ng’iriama was recorded by hand held GPS. The readings were used to estimate relative elevation differences between consecutive measurements. (The hydraulic specialist is however aware of the inaccuracy of this technology with respect to elevation measurements)

Sounding depths were measured in open water ponds and strategic wetland locations such as the outfall at Ng’iriama sill, and reduced to mean sea level by tying them to SMUWC beacons. Most of the sounding depth measurements were tied to SMUWC No. 4 beacon which was the nearest intact and reliable elevation reference point.

Additionally, it should be noted that the geometric and hydraulic data surveys were conducted during medium flow season. Whilst the channel geometry is more accessible during low flows, using an airboat when the wetland is inundated during the wet season alloeds the hydrographic survey to be undertaken more efficiently.

### Geometric data analysis

The study area is extensive and the geometric data requirement is immense. Existing sources of data such as previous reports, the SMUWC database and internet resources were therefore accessed, allowing relevant data and information from previous reports pertaining to the study area to be reviewed. Data and information gaps, overlaps and inconsistencies were identified and described, and the need for the collection of additional relevant data was motivated where necessary. Data from previous SMUWC projects, in addition to freely downloadable Digital Elevation Model (DEM), were both considered as potential sources of topographic data. (Figure 35).

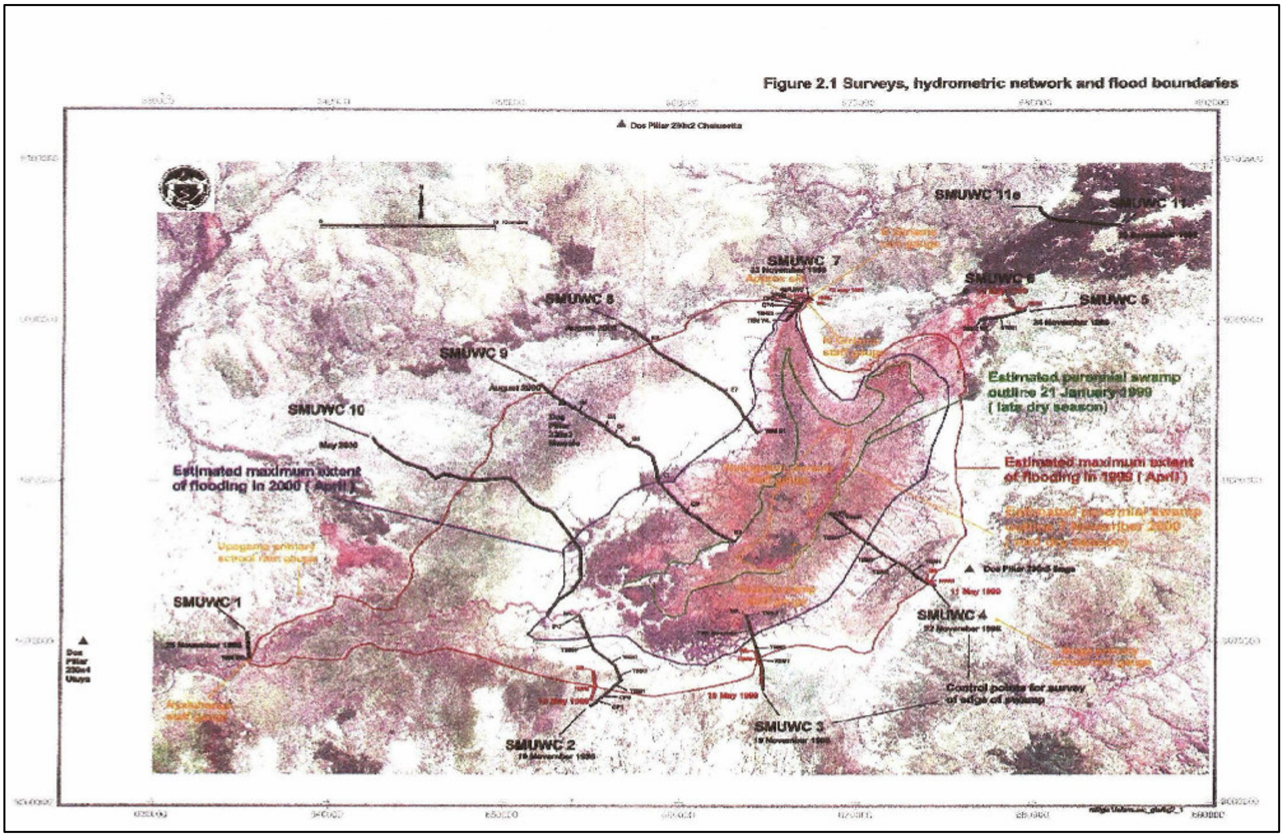



**Figure 35: Topographic data from previous SMUWC survey**

Geometric data such as cross-section geometry, longitudinal profile, bed slopes, reach lengths, bank stations, river patterns and flow paths were extracted from Global Advanced Spaceborne Thermal Emission and Reflection Radiometer (ASTER) DEM, using HEC-GEORAS, an Arc View Environment based software/Extension/Subroutine. The DEM was available at a resolution of 30 metres, formatted in 1 x 1 degree tiles as GeoTIFF files. For the purpose of analysing uncertainties of various data inputs, an additional DEM was developed using available sounding data from both the SMUWC and the current project.

The topographic data points surveyed by SMUWC and this study) were also used to construct a contour map of the wetland bed, using Surfer Software Version 8.0 (Golden Software, 2002). Data interpolation was carried out using a Kriging algorithm for gridding. The raw data points were filtered for noise, and the contours were automatically generated using software. These contours were then checked and edited to conform with reality (as reported in literature and as observed during the field visits). A Triangular Irregular Network (TIN) was constructed from the contour map using Arc View software Version 3.2 Environment.

It was decided to use the DEM derived from sounding data and supplemented by topographic data in the hydraulic study, as further analysis (as presented in Appendix G2 of hydraulics report, available from WWF TCO) suggested that the 30m DEM downloaded from the internet did not satisfactorily capture the main hydraulic features of the wetlands. There was a lot of “noise” in the elevation data, and it did not accurately depict the general terrain of the Usangu plains. It should be noted that current ASTER DEMs are generated without using Ground Control Points (GCPs).

The seasonal extent of wetland was mapped from Satellite images as presented in SMUWC reports under ArcView Environment.

### Hydraulic data analysis

The water levels of an almost 50 km reach of the Ihefu wetlands (measured by hand held GPS) were checked against the logical precept that water must flow downhill.

In the absence of a pronounced backwater curve, the water levels of the upstream cross sections (Nyaluhanga reach) must be higher than the downstream ones (Ng’iriama reach).

It was assumed that there is no exchange of energy across the boundaries. In this context both the water surface elevation measured along the accessible right bank locations and the total energy head are considered constant along the entire cross section.

Initial values for channel Manning’s roughness coefficient (“n”) for input to the HEC-RAS Version 4.0, hydraulic Model, were determined using values reported in literature (Chow, 1959) which corresponded to the roughness condition of the Ihefu study reach.

The Manning values were estimated based on the characteristics of the material forming the channel banks and floodplains (i.e. fine-grained particles compromised mainly of clay and silts) and the vegetation cover (i.e. open bush to dense grass). The estimated initial “n” values ranged from 0.075 to 0.15, as the surface condition of the river reach could be characterised as very weedy reaches, deep pools, or floodways with heavy stands of timber and underbrush (Webb, 1971).

The stream flow data for modelling the upstream boundary condition was estimated using data from the nearest upstream gauging stations, Nyaluhanga-1KA71 and Ndembera-1KA33B, using the flow rating curve presented in Appendix F of the hydraulics report, available from WWF TCO.

A water stage reading of 4.315 m, taken around noon on March 4 2010, gave a discharge of 93.504 $m^3/s$ for Nyaluhanga river reach. Similarly, a stage of 2.4 m for Ndembera gave a discharge of 16.467 $m^3/s$. Assuming a steady state flow condition, a total flow of 109.970 $m^3/s$ was therefore estimated to pass through Ng'iriama outfall. However, since the rock outcrop (sill), at the Ng'iriama outlet does not resemble a typical weir/dam, it was not possible to validate the stream flow estimate with a weir discharge equation result for the measured flow depth.

### Setting up the hydraulic model for the study reach

A hydraulic model, HEC-RAS Version 4.0 was set up in order to rate the wetland, and interpolate/extrapolate or estimate hydraulic parameters other than the measured/observed ones.

The computational procedure of HEC-RAS is based on the solution of a one-dimensional energy equation with energy loss caused by friction, evaluated with Manning's equation, and form loss.

This model requires characterisation of the terrain through a series of cross-sections perpendicular to the direction of flow for which the average water depth and flow velocity are calculated. These values are interpolated for the area between the cross-sections and the spatial extent of the flooded surface.

This type of modelling is often applied to hydraulic analysis, and the underlying assumption is that the river flow is in the direction of a predefined flow path (the river). This assumption is true in areas with well-defined valleys where the direction of the flow is clearly one-directional downstream. Any flow perpendicular to the main flow-direction is neglected, and lateral spread happens instantaneously as the water level in the river rises.The equations are solved by an iterative procedure in order to calculate an unknown water surface elevation at a cross section. This procedure is known as the "Standard Step" method.

The hydraulic model was linked to GIS based software, HEC-GeoRAS in order to access available spatial data (i.e. satellite images, DEM and landuse maps) to output the hydraulics (inundated surface area, depth, etc.) spatially. The modelled reach extends approximately 50.0 km, and was set up using 36 cross sections (Figure 36 ) spaced at 1.4 km average intervals

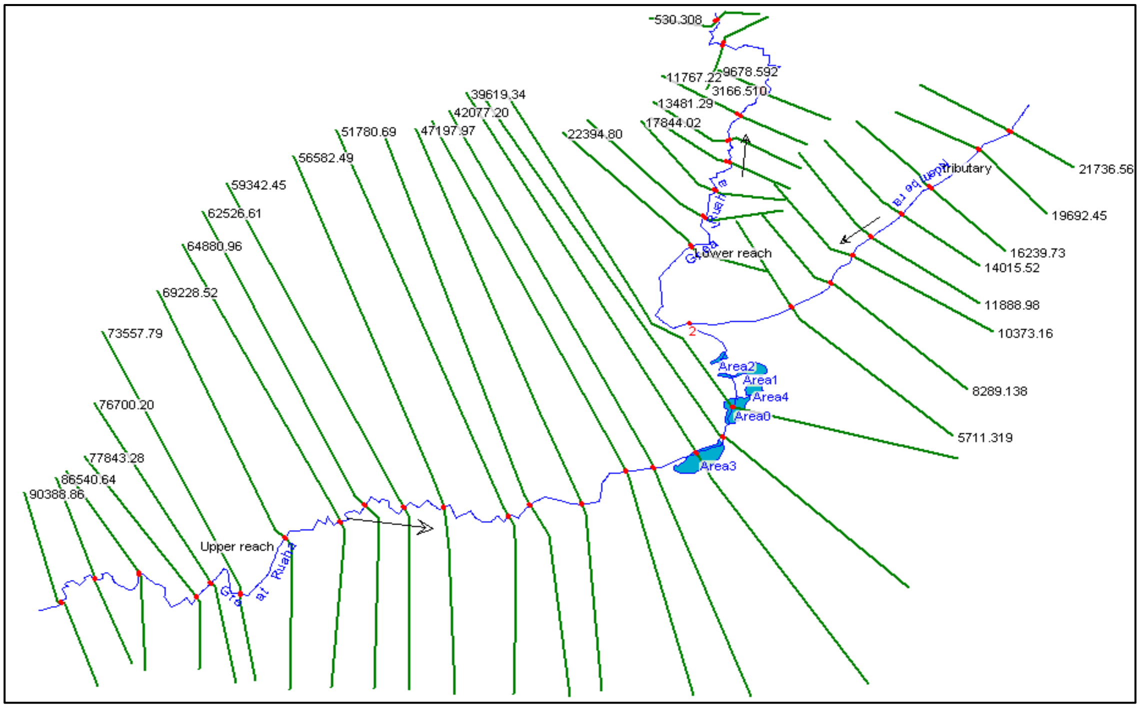



**Figure 36: Strategically-placed cross sections for hydraulic model input**

Cross sections were placed strategically at locations as per model requirements, and as agreed with other EFA specialists, to represent features such as freeboard, floodplains, pond areas, and main channels.

The downstream boundary condition for the study reach is assumed to be uniform flow. Uniform flow condition in the river reach is manifested when gravity and friction forces are equal. The flow in the reach downstream of Ng'iriama sill is concentrated, as riverine conditions prevail, and supercritical, with the water surface profile nearly parallel to the bed profile. Therefore, the normal depth (i.e. normal slope) is used as known information for the Standard Step computation method as required in HEC-RAS model. Additionally, the flow in the reach was classified as steady, since the water level measurements taken at the water line near SMUWC No. 4 beacon did not show significant variations within a day.

It should be noted that computations in the model began downstream, and proceeded upstream, as the state of flow in the reach was characterised as subcritical. The hydraulic grade line slope (i.e. approximate to normal slope) of 0.01% was estimated as a ratio of the difference in water surface elevation at the (upstream) Nyaluhanga gauging station and at Ng'iriama outfall (downstream), to the distance between these two points.

The upstream boundary conditions were taken to be the stream flow data of 93.504 $m^3/s$ and 16.467 $m^3/s$ as observed at Nyaluhanga-1KA71 and Ndemebera-1KA33B, respectively. The total discharge for the GRR reach after Ndembera and Nyaluhanga confluence is estimated as 109.970 $m^3/s$.

A fully-fledged river (i.e. dendritic) model was set up. The hydraulic specialist understood that the sill at Ng'iriama is effective only during floods, as the thalweg of the site follows the general river bed profile of the study reach. The flows upstream behind the sill are swift to the extent that the survey boat drifted downstream. Professional judgment suggested that such flow conditions would have maximum flow velocities greater than 0.8 m/s at the deepest portion of the main channel, although no stream flow measurements were conducted at the site. With such flow conditions during low to medium flow season the sill was not considered to play a role as an impounding dam or weir.

It is also imperative to note that, despite the presence of various river patterns and features such as braided, straight and meandering and multi-channels, the model implemented a single main river channel (GRR upstream, GRR downstream and Ndembera rivers) with meandering patterns incorporated.

Water level/depth is the most reliable hydraulic data for calibrating hydraulic models. The model was calibrated by qualitatively matching the simulated and observed water depths and wetland inundation area, mainly by adjusting Manning's values, "n", in specific cross sections.

The model performance was evaluated qualitatively based on plots of water surface profiles and inundated surface areas. Additionally, model performance for other unmeasured hydraulics such as velocities was evaluated based on professional experience/judgment. For example, Froude numbers of less than 1 and low velocities are typical characteristics of water bodies such as ponds, wetlands and lakes reaches such as Ihefu wetland. Further, the hydraulic specialist observed stagnant waters in most parts of the wetland during fieldwork of February-March 2010, evidences of a river with low hydraulic energy.

The model simulated the hydraulics of a range of flow discharges in order to guide the EFA team.

### Reviewing sediment and water quality data

As the time and funding resources were not adequate to carry out a sediment and water quality sampling programme, this study reviewed the secondary data collected by various initiatives and organisations as outlined below:

(i) Three successive years of monthly sediment data from the FAO (1960) Rufiji Basin project

(ii) General hydrological and hydrometric results produced within the SMUWC project.

(iii) 18 months of routine SMUWC water quality monitoring data.

(iv) Data from the intensive sampling campaign conducted under the Environmental Functions Study of the Eastern Wetland.

Most of the data collected by SMUWC dates back to 2001. Further, it should be noted that in order to update and validate the secondary data, reconnaissance field observations, as well as detailed field surveys were used to complement the existing data from the literature survey.

## Hydraulics results and discussions

The main results presented include spatially and longitudinally mapped wetland inundation as per river flow condition of February-March 2010 (Figure 37 and Figure 38) and rating relationships with reference to the Ng'iriama site Water Elevations (Figure 39 and Figure 40).

The rating at Ng'iriama, (WBBM3) particularly the water elevation versus streamflow was used by hydrologist during the EFA workshop to simulate seasonal wetland water contents dynamics. As mentioned earlier, the mapping of wetland inundation was used to qualitatively calibrate and verify the performance of the hydraulic model.

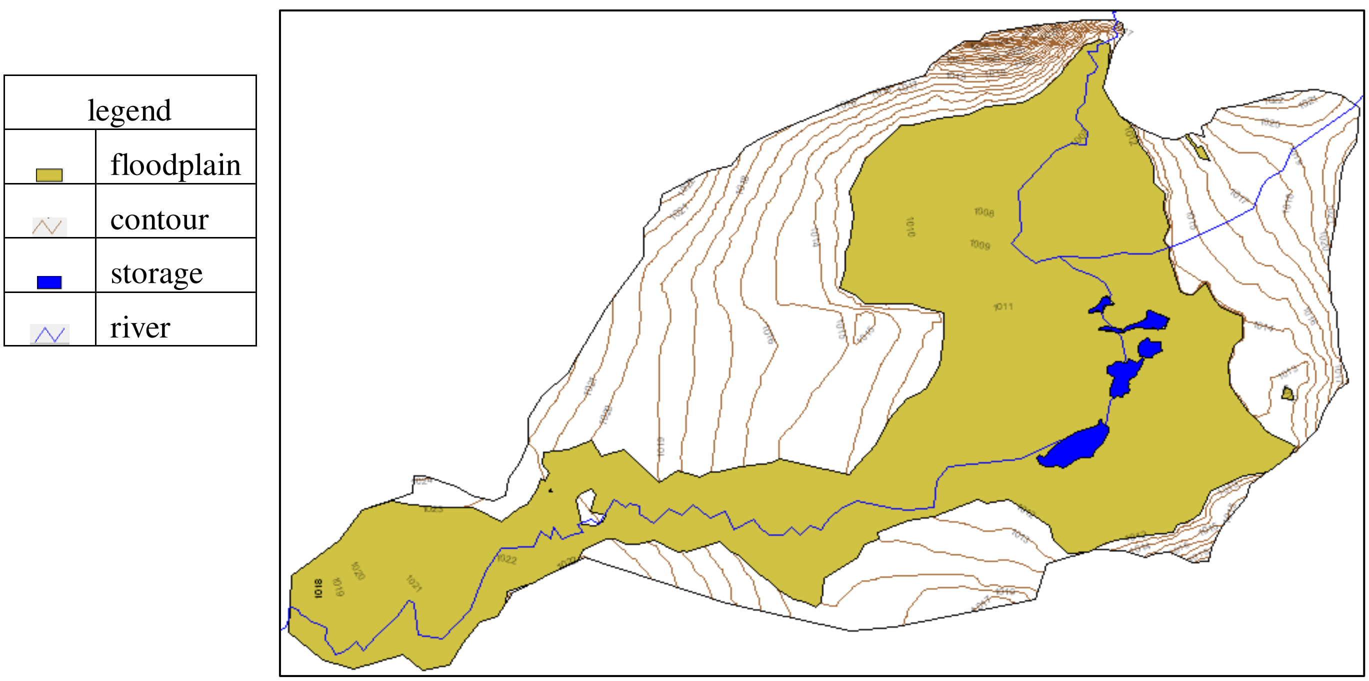



**Figure 37: Simulated wetland inundated surface area for March 4, 2010 for a total streamflow of 109.970 $m^3/s$ as contributed by Ndembera River (i.e. 16.467 $m^3/s$) and GRR –Nyaluhanga (i.e. 93.504 $m^3/s$)**

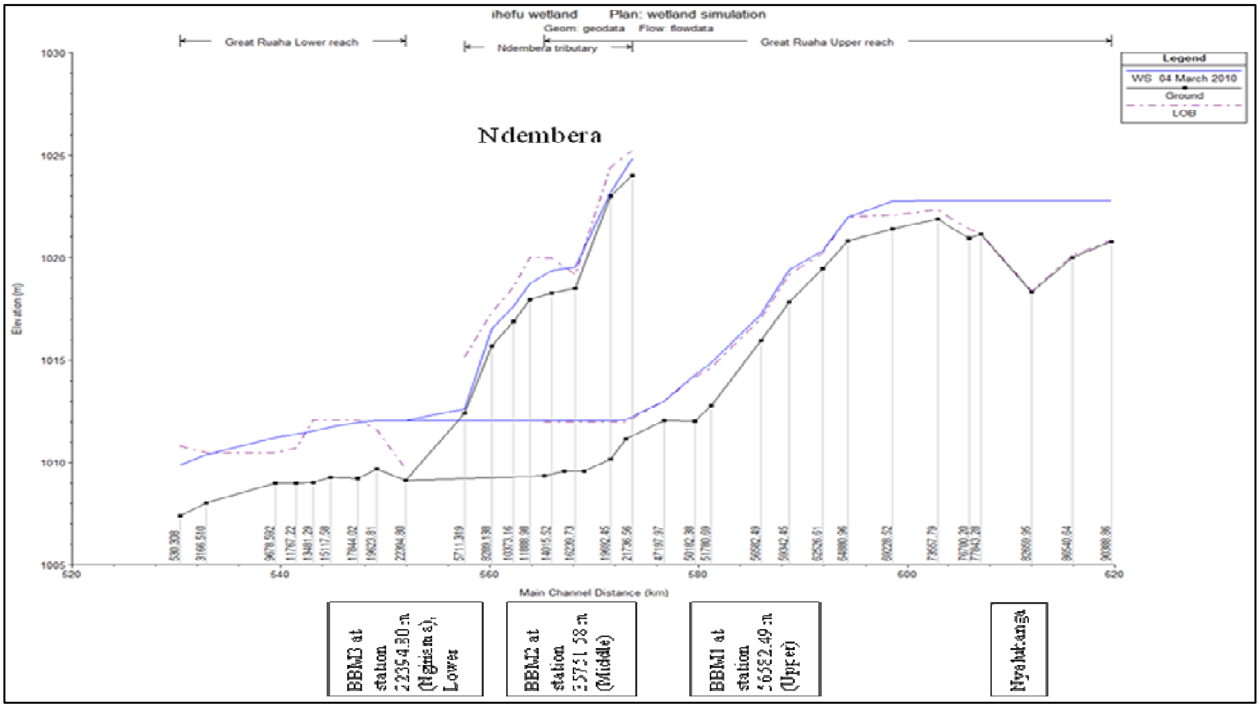



**Figure 38: Simulated Water surface Profiles (WSL) for the study reach for flow condition of March 4, 2010 with a total stream flow of 109.970 $m^3/s$ as contributed by Nyaluhanga (93.504 $m^3/s$) and Ndembera (16.467 $m^3/s$)**

Based on the longitudinal profiles of the wetland (Figure 38) three EFA study reaches could be proposed – WBBM1, WBBM2, and WBBM3 at river stations (chainages) 56 582.49 m, 35 751.58 m, and 22 394.80 m, respectively, located on the main GRR. WBBM1 represents upper reaches near Nyaluhanga gauging station with steeper bed slopes and shallow flow depth. WBBM2 represents middle reach, open water ponds, characterised with stagnant waters and higher depths. Further analysis indicates that the state of flow is subcritical. The lower reach, Ng'iriama sill reach, is represented by WBBM3. At this point there is significant change of bed slope as compared to the pools site. It is therefore a hydraulic control of the reach in this context. It is worth noting that Ng'iriama sill is not behaving like an impounding dam, but rather its thalweg follows smoothly with the general terrain of the reach. One may also note that generally within the wetland boundary Ndembera river reach bed slope is much higher than the main GRR. The state of flow in this reach could be characterised as supercritical with high flow velocity and low flow depth. The two rivers meet and join in the wetland just before Ng'iriama sill.

The data used to fit the rating relationships in Figure 39 and Figure 40 come from calibrated/validated hydraulic model simulations. In all cases the hydraulics are presented in respect to water surface elevation/discharge at Ng'iriama sill site.  For detailed outputs of model results one may refer to Appendix H of the Hydraulics report., (available from WWF TCO.)

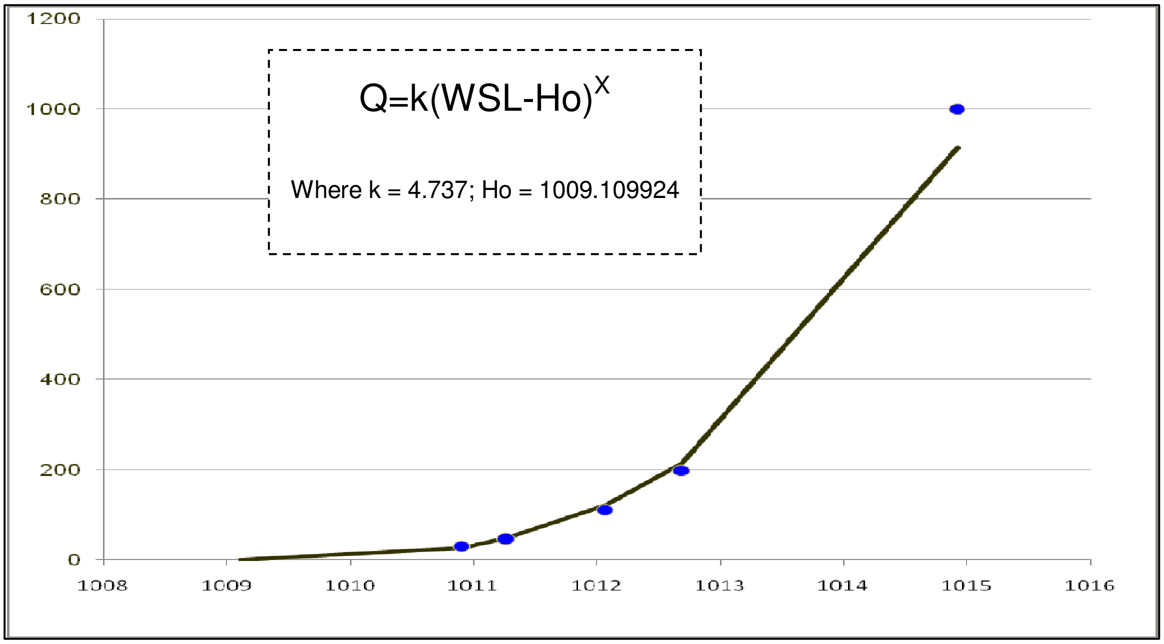



**Figure 39:  Simulated flow rating curve at Ng'iriama outfall, model river station No. 22394.8**

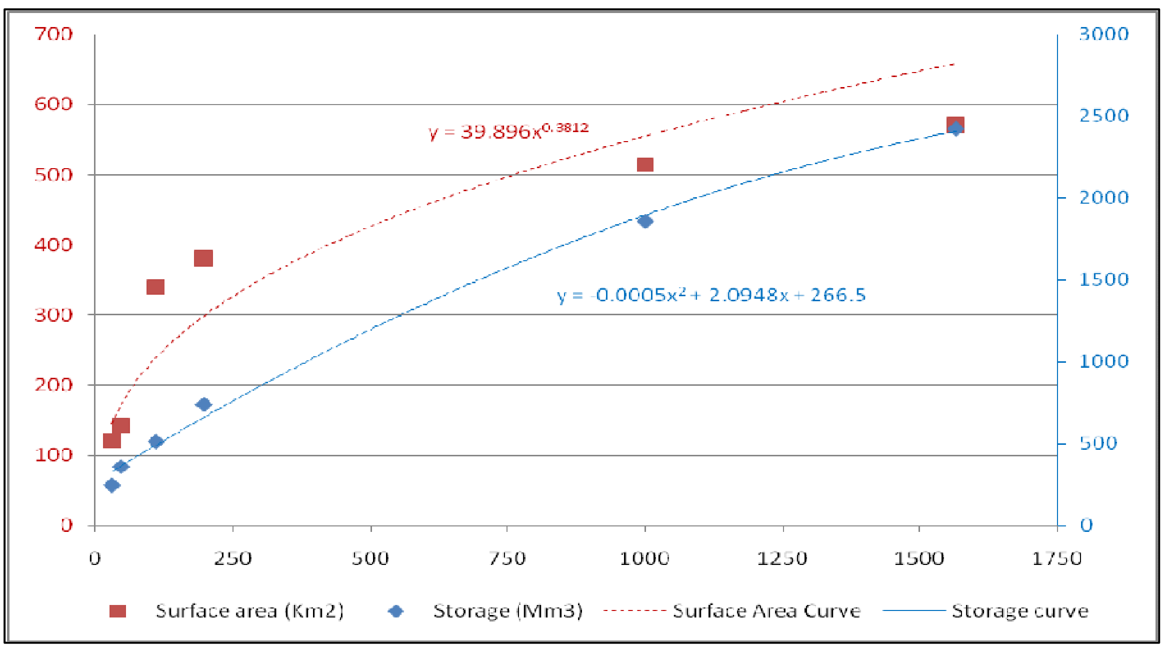



**Figure 40:  Elevation versus surface area-Storage curves**

Based on literature review and field observations it is understood that the rivers draining the high catchment have a relatively low suspended sediment content. Whilst flowing over the alluvial fans and the plains, the rivers pick up fine sediment in the rice farms and other irrigation systems. This material remains in suspension until flow velocities drop between Nyaluhanga and the beginning of the middle reach of the Ihefu wetland. The sediment is then deposited, causing a gradual infilling of the open water ponds, particularly at the western end of the Ruaha pond, building up a soft layer of mud on the floor of the swamps.

Progressing eastwards through the Ruaha and Nyangokolo ponds, the quantity of mud decreases and the water becomes clearer. As estimated by SMUWC (2001), the small amount of data available suggests that some 30 000 tonnes of suspended sediment enter the Ihefu Wetland in an 'average' year. An average depth of around 20 mm/year of soft, gelatinous, sediment is deposited across the Ruaha pond. Although some small catchments such as the Kioga contribute sediment-laden waters, the observed maximum suspended sediment concentration is below 1000 mg/l.

Considering the wetland maximum coverage area and storage of ca. 570 $km^2$ and 2400 $Mm^3$ respectively, this suggests that sedimentation is not a serious problem in the Ihefu wetland.

The quality of inflows and outflows to the wetland differ, reflecting the intense biochemical activity occurring within the Ihefu. The inflowing water is fully oxygenated, slightly alkaline, has low mineralisation and is highly turbid. It has a low Dissolved Organic Carbon (DOC) content, and a low permanganate value. The outflowing water, by contrast, has a low oxygen content, is slightly acidic to neutral, and is relatively clear (although a pale brown colour). It has a high DOC content and a high permanganate value.

### Hydraulics conclusions and recommendations

It was found that the Ihefu wetland system could be rated using a one dimensional hydrodynamic model, HEC-RAS Version 4.0, using readily-available secondary spatial data complemented by recent field-based data on pond geometry and derived flow data from neighbouring gauging stations.

The data from the SMUWC project and those extracted from base maps served as secondary data. The model was qualitatively calibrated and validated. The model was found satisfactory, based on experience and professional judgement. As a result various inputs for the EFA workshop were simulated, including wetland outfall, Ng'iriama sill site, stage versus discharge rating curves, and storage and inundation maps at various streamflows.

### 6.4.4. Riparian vegetation

*Introduction*

This section presents the wetland vegetation ecology of Usangu wetland between Nyaluhanga where the GRR enters and Ng'iriama where the GRR leaves the wetland

The objective of the Usangu wetland vegetation study was to assess the ecological importance of the wetland vegetation ecology in relation to its accrued functions. The assessment was based on minimum water requirements in aquatic ecosystems, and the sensitivity of the biotic components.

It included collecting information such as species diversity, abundance, and the presence of plant species that would assist in determining minimum water needs for aquatic and terrestrial biota. The assessment of water requirements in the Usangu wetland was expected to provide the critical baseline data regarding the :

- maintenance of wetland vegetation communities,
- species distribution patterns, and
- the quality and quantity of water required to maintain the individual functions and processes in the ecosystem

in the context of human development needs and biodiversity conservation needs.

The Usangu wetland vegetation is an important component in the biodiversity conservation of the RNP. It consists of high percentage cover of wide-spread grasses as the major source of energy for herbivores in the park, fish of the wetland and the GRR, birds and other biota in the system.

The vegetation provides the most important elements of the existing major food chains in the Usangu wetland, playing great role in maintaining the biodiversity integrity of the lower catchments of the GRR downstream as it provides organic matter to support other life forms.

The major wetland system functions are primarily performed by vegetation. However, it has been tremendously degraded, to the extent that the wetland is failing to perform its major functions in the ecosystem.

Changes in plant communities provide an easy criterion for identifying changes in the wider biodiversity integrity of the Usangu wetland. Vegetation is the easiest visual and hydrologically-recognised indicator of changes in the amount of water in the Usangu wetland, and of the overall ecological health of the wetland system.

*Methodology*

The vegetation study involved in the following activities:

- To assess the current ecological integrity in the wetland, in terms of species composition, diversity and distribution.
- To define the vegetation zones in the wetland (Open water floating vegetation, seasonally inundated, submerged, emerged and transition zones) including communities and species present.
- To characterise sensitive ecosystems, the size and degree of degradation and relate this to the life history of the characteristic key plant species.
- To examine the effects of the timing and magnitude of freshwater flow in the system, and the effect of past and future alterations of inflow on the abundance and distribution of communities and key plant species in the wetland.

*Field sampling and assessment*

A reconnaissance survey was conducted on 16th Dec. 2009 that provided an overview of the tasks and logistics involved the hydraulic, vegetation, fish, invertebrate, geomorphologic and hydrological assessments to be carried out in the Usangu wetland. The wetland vegetation assessment methodology was planned on the understanding that resources (especially the air-boat) would be shared among study groups during the field work.

Field sampling and assessments were carried out between 28th February and 5th March 2010. Due to the relatively homogeneity of vegetation, and the pattern in the wetland as the result of dominance by almost the same community, and uniformity in habitats that might have been caused by the spreading of water from the channel, both qualitative and quantitative approaches were employed so as to obtain the basic information for management of the system. Photographic records of the different vegetation communities occurring in the wetland were taken.

Sampling was done from the edge, across the wetland through the seasonally flooded region to the permanent swamps. Intensive sampling was carried out around the edge of each perennial swamp and across the swamp to obtain prerequisite data representing the vegetation communities.

Since the wetland is essentially dominated by the grass family in the seasonally inundated region, and water lilies in open waters, a plot size measuring 1$m^2$ was used to sample vegetation at the grass layer in the wetland.

On the other hand, a qualitative approach was used in addition to the quantitative approach in some parts of the wetland, due the complexity of vegetation pattern.

### Vegetation community types in the Usangu wetland

The vegetation communities in the Usangu wetland are composed of different species than the terrestrial communities, and are homogeneous over a large area in the seasonally flooded zones, recurring with a clearly defined zonation of communities in most part of the wetland.

The homogeneous vegetation distribution pattern might be due to uniformity in habitat conditions that might have been caused by spreading of environmental resources (i. e. water and nutrients) due changed main channel geomorphology of the GRR. Some of the permanent water depended plant species such as *Ipomoea aquatica, Schoenoplectus nodiflorum, Nymphaea lotus* and *Nymphaea capensis, Aeschynomene pfundi* perform well in the seasonally flooded areas with luxuriant co-existence among them.

However, *Lagarosiphon ilicifolius, Ceratophyllum demersum, Nymphaea nouchali, Urtica masaica, Aeschynomene elaphroxylon, Utriculais foliosa, Aeschynomene schimperi* and *Aeschynomene indica* were completely localised in the perennial swamps. During vegetation analysis, the wetland ecosystem was dominated by *Vosia cuspidata, Echnocloa spp, Nymphaea spp, Cyperus mundtii. Leersia hexandra, Oryza longistaminata, Phragmites mauritianum, Ipomoea aquatica, Cyperus mundtii, Typha capensis, Seabanis greenwayi , Achyranthes aquatica, Ceretophyllum demersum and Aeschynomene spp*, are either floating, floating but rooted or submerged plant species which require permanent flows, and hence were the important plant species that indicated the quality and health of the system.

These species were classified into vegetation communities, based on the dominant plant species in the specific habitat described.

### Vegetation zones in eastern Usangu wetland

*Open water submerged communities*

The open water vegetation community is located in perennial swamps, and consists of floating vegetation, and some floating species which are rooted. Open water floating vegetation was composed of *Azolla nilotica, Azolla filliculoides, Lagarosiphon ilicifolius, Ceratophyllum demersum, Pistia stratiotes, Polyginum senegalensis, Urtica masaica, Utricularis foliosa, Nymphaea nouchali, Trapa natans var.africana, Utricularia stellaris, Utricularia gibba,* and *Lagarosiphon ilicifolius*.

These species are hydrophilic in nature and their survival, performance and productivity is totally dependent on the high water level. These species however are sunloving plant species and perform in light free zones and extract dissolve nutrients in aquatic environments.

From the channel and deeper zones to the edge of the swamp, a clear zonation was identified and the above group of species was classified into the following communities:

(i) *Lagarosiphon-Ceratophyllum* community

This community was dominated by *Lagarosiphon ilicifolius* and *Ceratophyllum demersum*. These plant species are in-stream macrophytes and submerged aquatic plants. They provide shelter and food for many freshwater fish and insects, and the organisms which they feed upon. The open water channels in the wetland have an extensive area covered by partially submerged reeds as the main source of organic detritus which shelter a variety of animal life forms. They may thus be critical to the recruitment and success of some fish and invertebrate species resident to the river.

*Ceratophyllum demersum* (coontail) has leaves coated with lime (making it feel crunchy) and stiff whorls. It forms the most important feeding and breeding habitat for young fish, small aquatic animals and insects. This community performs best at depths between 2.5m to 3.0m in wet season and 1.5 - 2.0m in the dry season. This plant species prefers constantly-flowing streams, and is found just below the water surface, prefering areas with low light intensity and deeper waters (see the frontal side of Figure 42). The species can extend beyond 3m in length, and has no roots. It attaches onto sediments and debris, and requires high flows, therefore acting as potential indicator of stream flow.

(ii) *Trapa-Lagarosiphon* community

This is community is dominated by *Trapa natans, Lagarosiphon ilicifolius and Ceratophyllum demersum* (Figure 41). *Trapa natans* provides leafy cover that could potentially prevent light penetration required for the performance of other members in the community, but generally allows sufficient light to reach the submerged *L. ilicifolius* and *C. demersum*. However, in the open water zones of the perennial swamps, this leafy property of *Trapa natans* could affect *L. ilicifolius* and *C. demersum*. This community also dominated the deeper zones in the perennial swamps, and performed best at high flows, between depths of 2.0 to 2.5m.

**Figure 41: *Lagarosiphon-Ceratophyllum* community in deep zones of the swamps**

(iii) *Nymphaea - Trapa* community

This community was dominated by *Nymphaea nouchali, Trapa natans var.africana, Utricularia stellaris, Utricularia gibba* and *Fuirena stricta*. These species are dependent on permanent flow. However, they prefer slow flows or stagnant water just away from the channel.

All the species are rooted in the substrate with elongated stalks which form a single green leaf on the surface. The leafy cover of *Nymphaea nouchali* and *Trapa natans* provides green material for macro-invertebrates, and also provide good habitats and feeding areas for wetland birds and fish that feed upon these invertebrates (see the foreground of Figure 42.) The broader exposed leaves of *Nymphaea nouchali,* and *Trapa natans* are also useful in the open waters of the swamps as they help to attenuate light from directly striking the water body, providing shade and a cool environment in the swamp during hot sunny days.

*Floating but rooted communities*

These communities are dominated by *Acyranthes aquatica, Ipomoea aquatica, Ludwigia stolonifera, Polygonum senegalensis, Cyperus mundtii, Sesbania greenwayi* and *Aeschynomene elaphroxylon, cyperus denudatus, Cyperus articulatus, Vosia cuspidata, Cyperus alopecuroides*.

These communities are typically found next to the *Nymphaea - Trapa* community, and adjoining seasonally-inundated vegetation communities. It then includes plant species surrounding the edge of the perennial swap and covers some of the areas in seasonally flooded zones in the wetland.

(i) *Aeschynomene –Nymphaea* community

This community is dominated by *Aeschynomene elaphroxylon, Aeschynomene elaphroxylon, Nymphaea nouchali, Polygonum senegalensis, Ploygonum salicifolia.* This community is located along the former channel of the GRR, forming the characteristic vegetation of the river bank and the flood plains.

However, after the lost defined flow channel, water spreads over the flood plain forming the existing perennial swamps. While *Nymphaea nouchali* covered most of the perennial swamps, a small population of *Aeschynomene elaphroxylon* still persists in some parts along the former GRR channel. Flooding is important for the vegetative regeneration of *A. schimperi* and its population expansion has been arrested significantly. The small patches of *Aeschynomene elaphroxylon* function as resting areas for a variety of bird species (Figure 42).

**Figure 42: *Aeschynomene –Nymphaea* community rooted on the banks of the former channels of the GRR**

(ii) *Cyperus-Leersia* community.

This community is dominated by *Cyperus mundtii, Fuirena ciliaris, Ludwigia stolonifera, Polygonum senegalensis, Cyperus denudatus, Cyperus dives Cyperus craspes, Cyperus latifolius, Leersia hexandra, Striga forbesi, Scoparia dulcis, Marslea minuta* and *Imperata cylindrica*.

Although several segments of floating mats exist in the open perennial swamps with relatively different species composition, *Cyperus mundtii* sometimes occurs as a monodominant mat community, covering a larger area of the perennial swamps with only a few clusters of *Pteridium aquilium* individuals. The plants form dense mats with trapped sediments that make it freely float on the water surface. Rafts may be blown around the wetland by wind, or shifted by hippo or crocodile.

The contribution of the roots of *Cyperus mundtii* is very substantial, since it helps to absorb nutrients for the plant and also helps to form the mats, keeping them afloat and exposed to sunlight for photosynthesis without being buried in the deeper zones at high floods. The dense mats may block the channels and alter the water flow pattern in the channels that connect the swamps in Ihefu.

However, the floating mats prevent direct evaporation of water, and delay the downstream flows through the existing channels along the swamp, hence contributing to the persistence of the potential reservoir of water in the system during the dry season.

(iii) *Vosia- Cyperus* community

This community is typically found next to the *Nymphaea-Trapa* community, and adjoining seasonally inundated vegetation communities (Figure 43), and includes plant species surrounding the edge of the perennial swap. This community is dominated by *Vosia cuspidata, Cyperus mundtii, Fimbristylis sp, Cyperus articulatus, Fuirena stricta* and *Cyperus denudatus*,

**Figure 43: *Cyperus mundtii* mat floats over the Ihefu swamps**

*Seasonally inundated vegetation*

The seasonally inundated zone covers the largest area of the Usangu wetland, with more extensive vegetation communities than those of perennial swamps. Plant species in this area are adapted to seasonal flooding, thus the reproductive cycle can be completed within one annual flooding season.

The most common plant species include, *Cyperus grandis, Echnocloa scabra, Echnocloa stagnina, Vosia cuspidata, Urena lobata, Plygonum salicifolia, Aeschynomene indica, Aeschynomene pfundi, Oryza longistaminate, Sorghum arundinaceum* and *Leersia hexandra, Polygonum senegalensis, Ludwigia stolonifer, Vernonia glabra and Senecio abyssinica.*

(i) *Achyranthes- Ipomoea -Nymphaeae* community

This community occurs in the seasonally flooded zones, and co-existing with *Sesbania-Echnocloa* community. The community is dominated by *Achyranthes aquatica, Nymphaea lotus* and *Ipomoea aquatica* (Figure 44). Other well-represented plant species in this community include *Cyperus articulata, Echnocloa spp. and Oryza longistaminata*.

This community is found in the flood plains and downstream closer to Ng'iriama where the water is clear with less suspended particulate matter, as the distribution of plant species in this community is affected by turbidity in the channel itself. The distribution of *Achyranthes aquatica, Nympaheae capensis, Aeschynomene indica, Nymphaea lotus* and *Ipomoea aquatica* in the wetland shows that such species are sensitive to turbidity caused by suspended sediments in the channel from upstream and from agricultural lands. Therefore, increased siltation and sedimentation in the wetland affects the microhabitats of *Achyranthes aquatica, Nympahea lotus, Ipomoea aquatica* and *Nymphaea capensis,* consequently decreasing their abundance and changing community composition.

**Figure 44: *Achyranthes-Ipomoea* community in the seasonally flooded zones in Ihefu wetland**

(ii) *Voscia- Echnocloa* community

This community is dominated by *Vosia cuspidate, Echnocloa stagnina, Echnocloa scabra and Echnocloa colonum.* In this community, there are also other well represented species such as *Leerdia hexandra* forming the greenish cover with reddish inflorescence, and *Leerdia denudatus* with white inflorescence with a substantial cover whenever they occur. Also, *Oryza longistaminata, Cyperus articulata* and *Sorghum arundinaceum* are well represented in many parts in the seasonally inundated regions. *Aeschynomene schimperi* and *Sesbania greenwayi* occur randomly and scattered throughout the community forming conspicuous *Sesbania* patches protruding in the uniform distributed *Voscia-Echnocloa* community (Figure 45).

**Figure 45: *Echnocloa-Vosia* community in the seasonally flooded zones**

(iii) *Sesbania –Echnocloa* community

This community is dominated by *Sesbania sesban, Sesbania greenwayi* and *Echnocloa scabra*. Although the two populations do not mix intimately, they co-exist adjacent to each other. Underneath *Sesbania* spp. however are the populations of *Nymphaea capensis* which prefer shaded habitats with diffuse or attenuated light. This community occupies a significant area of the seasonally inundated or seasonally flooded zones, and is estimated to be the second largest after the *Vosia-Echnocloa* community. (Figure 46)This is a favourable habitat and feeding area for python - a very large Python was observed catching birds in this community.

**Figure 46: *Sesbania-Echnocloa* community in the seasonally flooded areas of the wetlands**

(iv). *Cyperus-Typha* community

This community is essentially dominated by *Cyperus articulatus, Hibiscus diversifolius, Cuperus pfundii* and *Polygonum senegalensis*, and is found in ditches in the seasonally flooded area where water is remains as a swamp. (Figure 47) Some of these communities were also located in the seasonal streams found scattered throughout the wetland (SMUWC, 2000). There are, however, very few of these communities, probably due to the rapid drying of the wetland due to disturbance from livestock grazing, or due to abstraction of water from the system, resulting in the lack of flows for an extended period of the year. This community provides feeding habitats for bird species, insects, amphibians and fish.

**Figure 47: *Cyperus-Typha* community in seasonally flooded zones of the Usangu wetland**

## Depth variation and vegetation distribution in perennial swamps

Variation in water depth in the perennial swamps and other wetland zones results in different vegetation communities (Figure 48). The deeper sides with an average of 2.5m - 3.0m depth were occupied by the *Lagarosiphon-Ceratophylum* community in which *Lagarosiphon ilicifolius, Ceratophyllum demersum, Urtica massaica* and *Utriculaaris foliosa* were the most dominant species.

This was then followed by the *Nymphaea-Trapa* community in which *Nymphaea nouchali, Urena lobata, Trapa natans* and *Urtica massaica* were the most dominant species.

The community found at the edge of the open swamp is the *Vosia – Echnocloa - Cyperus* community, with a dominance of *Vosia cuspidate, Echnocloa scabra* and *Cyperus mundtii* which performed well between water depths of 1.5m - 2.0m at high flows.

**Figure 48: The effect of depth on vegetation community distribution at the perennial swamp**

### Plant species diversity and distribution in the wetlands

The eastern Usangu wetland has generally very low plant species diversity that ranges from H' = 1.5 to H' =2.1. This might be due to previous disturbances, for example where the wetland species composition might have changed due to the effects of grazing pressure, or lack of water due to abstraction for irrigated rice cultivation.

Diversity and evenness was high at Lyang'ulage (H' = 2.1 ± 0.038 and E = 0.49 ± 0.009) whilst Ng'iriama recorded the lowest diversity and evenness (H' = 1.5 ± 0.06 and E = 0.35 ± 0.014) compared with other sampling locations in the wetland (Figure 49).

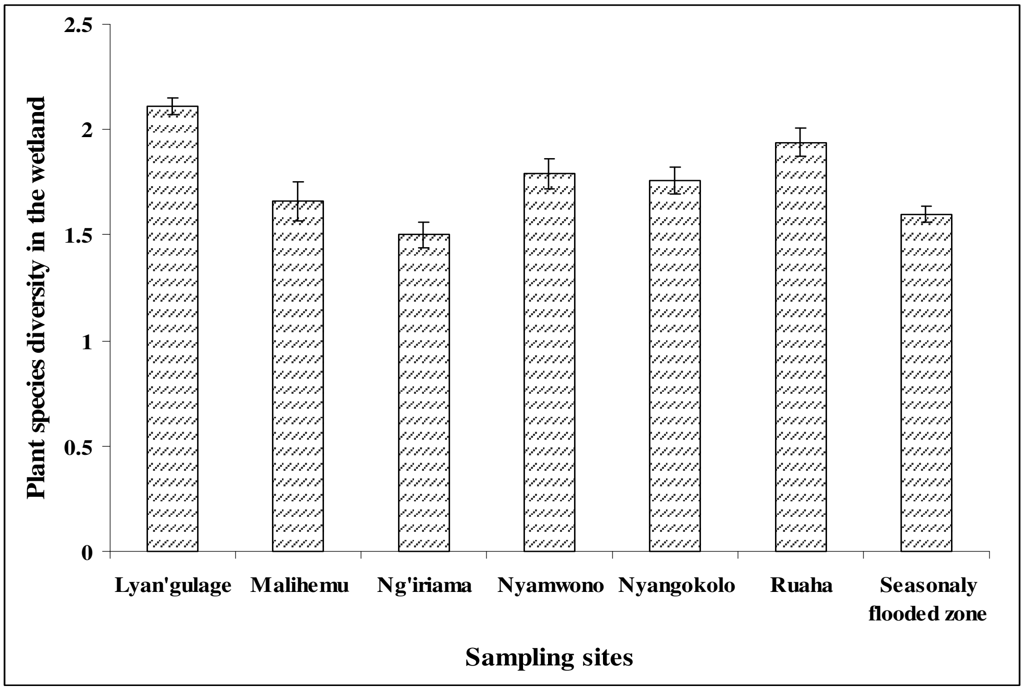



**Figure 49: Variation in species diversity among sampling locations in the wetland**

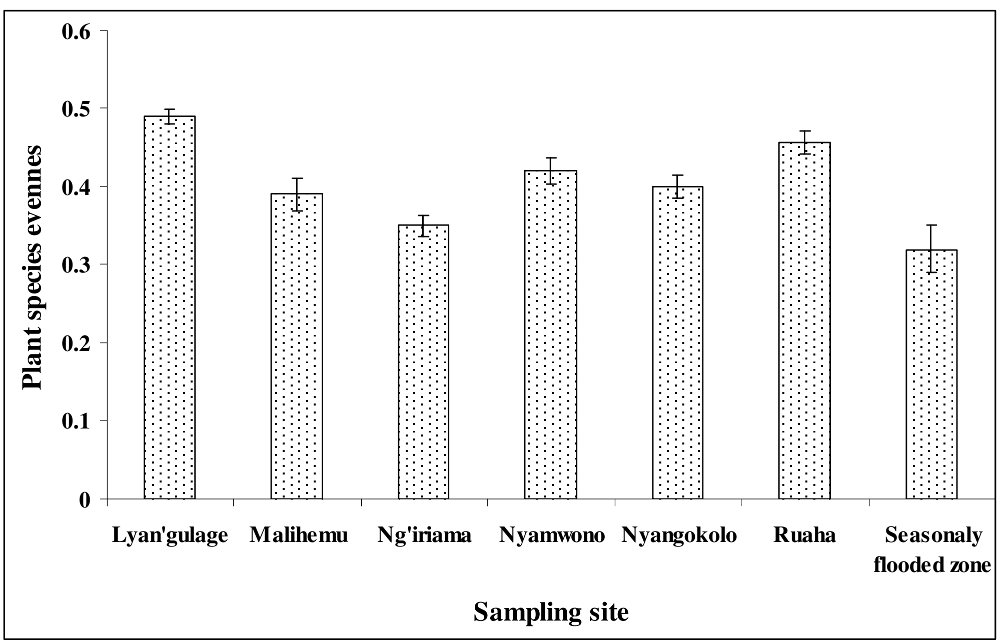



**Figure 50: Variation in species evenness among sampling locations in the wetland**

The high diversity at Lyang'ulage swamp might be encouraged by the favourable moist habitats resulting from long term persistent high volumes of water, that might be flowing backward from Ndembera channel to fill the swamp even in the dry season. The decreased surface area in other swamps during the dry season, due to lack of inflow from their upper catchments, might have affected the microhabitats of many flow-dependent plant species. Adaptation to intermittent change of moisture levels is likely to be poor for many of the wetland plant species. The decrease in water level in the systems might have narrowed the surface area of the swamp, which limits the diversity of plant species and their partners.

Detrended Correspondence Analysis (DCA) (Figure 51) showed that species composition among sampling points in the swamps did not vary considerably during this period of field sampling.

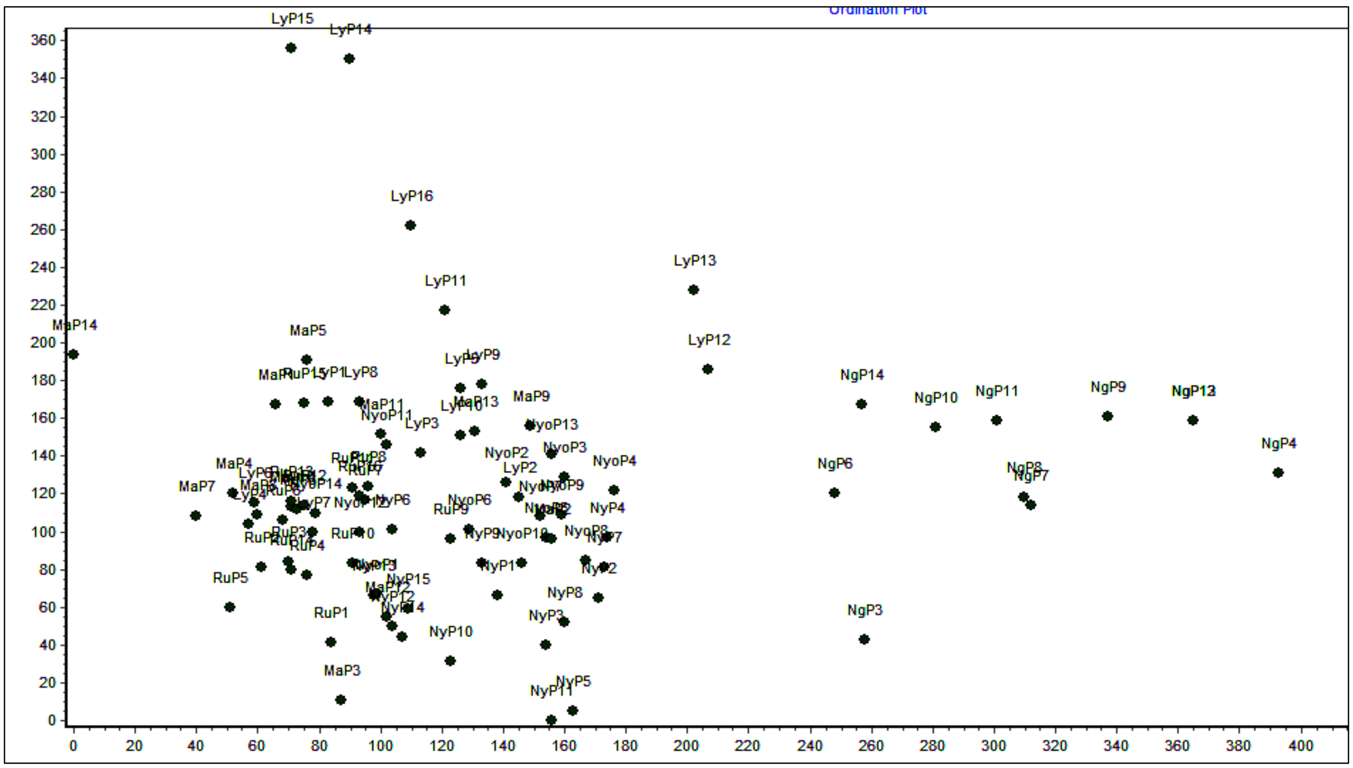



**Figure 51: DCA ordination of vegetation samples from Usangu wetland**

*(LyP1= Lyang'ulage, Ma= Malihemu, Ng= Ng'iriama, Ru= Ruaha, Ny = Nyamwono, Nyo= Nyangokoro)*

However, data from samples from Ng'iriama are grouped to the right of the ordination diagram. The reason for this is unclear, however it can be anticipated that composition was lower than at other sampling sites. This site is less or the same as the seasonally flooded zone and suffers from lack of flow for an extended period in the dry season. This might be the reason that habitats are not favourable for the performance of high diversity of plant species. Only a few flow dependent (wetland) plant species were represented at this location, which was dominated by *Vossia cuspidata, Aeschynomene indica, Cyperus nodiflorum, Nymphaea capensis, Phragmites mauritianum* and *Miscanthidiurn violaceum*. On the other hand, vegetation community composition varied considerably between the swamps and the seasonally inundated zones.

The seasonally flooded area had low diversity since it was widely dominated by only a few species, such as *Echnocloa* sp. in one zone, *Leersia hexandra* as an isolated cover, as well as the *Sesbania* community.

## Invasive Species

Some invasive plant species were recorded in some parts of the channels in the perennial swamps and many parts of the riparian areas in the GRR upstream of the wetland. These include *Pistia stratoites, Azolla nilotica, Azolla filiculoides* and *Typha capensis.* However, *Pistia stratiotes* was observed in the perennial swamp and *Typha capensis* in seasonally flooded areas.

Of these species, *Pistia stratoites* is a threat to the communities in the perennial swamps as it is a fast-colonising species which has caused widespread blockage of waterways in Africa. It also covers the surface of water body, preventing sunlight from reaching other plants. It also causes drying of water bodies during the dry season when the flow into the wetland decreases, making habitats anoxic. The plant species has a very high rate of transpiration and hence its abundance causes a decrease in the quantity of water. *Pistia stratoites* also causes a decrease in oxygen available to aquatic fauna and hence causes suffocation of fish and amphibians, and destroys the breeding places of these organisms.

*Pistia stratiotes* cover (Figure 52) greatly reduces biological diversity through eliminating native submerged plants which are sensitive to invasion. such as *Ceratophyllum demersum, Trapa natans, Lagarosiphon sp*. and *Nymphaea nouchali* by blocking sunlight in the deeper waters of the perennial swamps, thus altering aquatic plant and animal communities. The colonisation of the wetland by *Pistia stratiotes* affects the abundance of the above species. Figure 52 shows the effect of colonisation on *Trapa natans* and *Lagarosiphon ilicifolius.*

**Figure 52: *Pistia stratiotes* suppressing *Trapa natans* in the swamp**

The speed of invasion is very high, due to the rapid vegetative reproduction of this species in open waters. This species is reducing the surface area of the open waters and is likely to affect *Trapa natans* and *Lagarosiphon ilicifolius* communities currently co-existing in the swamps. *Pistia stratiotes* need to be monitored or eradicated to minimise its negative effects in the wetland, as part of a wetland management strategy to curb invasive species. The area cover of this species needs to be monitored regular so that the integrity of the wetland can be affect.

*Typha capensis* results in the replacement of wetland plant species. Its expansion also needs to be monitored so that its effects can be checked regularly.

### The effects of degradation of sensitive plant species

Plant species in the Usangu wetland differ in their level of sensitivity to change in flows caused by a change in the volume of water. The fluvial plains are dominated by a reasonable number of plant species co-existing in their prescribed communities. However, degradation caused by activities upstream, as well as disturbance in the wetland has resulted in significant changes in patterns of many plant species.

The increased turbidity in the channels and the flood plain has negatively affected the performance of *Nymphaeae lotus* and *Nymphaea capensis*, particularly in open waters. Such species prefer clear water for survival, growth and reproduction. Water quality data shows that at the inflow (Nyaluhanga) turbidity was 265 Jackson Turbidity Units (JTU) whilst the outflow and at Ng'iriama was 22 JTU. (SMWUC, 2001).

Areas where turbidity was low had high representation of *Nymphaeae lotus* and *Nymphaea capensis*. In the Usangu wetland these plant species were found well away from the channel after water has been filter through dense grasses. *Nymphaeae* lotus was well distributed in the north and the south of the wetland, co-existing with *Sesbania greenwayi* and *Aeschynomene pfundi* whilst *Nymphaea capensis* performed well down stream at Ng'iriama. It is anticipated that it will be very difficult to restore this pattern, since agricultural activities upstream are expanding, and runoff from farmlands will continue filling the wetland during the rain seasons. Confronting these problems may create new conflicts between stakeholders in the region.

Continued decreased flow or lack of flow in the channels has decreased the population of *Phragmites mauritianum* in the banks such that only small patches, that are poorly supported by favourable habitats, remain in the wetland. However, if perennial flow can be restored through the swamps to Ng'iriama, the *Phragmites mauritianum* population can be restored through natural vegetative propagation. The increase frequency of no flow into the wetland over an extended period will decrease the size of the swamps, since *Vossia cuspidata, Aeschynomene pfundi* and *Echnocloa scabra* will significantly colonise the degraded parts of the swamps. This will decrease the habitat size for the open water floating plant species such as *Nymphaea nouchali, Trapa natans var.africana*, *Utricularia stellaris, Utricularia gibba* and *Lagarosiphon illicifolius*.

## Pattern of vegetation in Usangu wetland

A specific and directional flow channel is present at the inflow to the eastern wetland The flow then spreads across the plains, including the perennial swamps, narrowing to a neck at Ng'iriama.

From interviews with local fishermen, SMUWC (2001) reported that the GRR in the wetland comprised a single channel extending from Nyaluhanga to Ng'iriama, with flow available through the existing perennial swamps even during the dry seasons.

Today, the visible channel does not exist. The flow of water is from the west to the east (SMUWC, 2001), with most of the suspended sediments from runoff, agricultural land, and the upper catchments being deposited in the GRR channel. This is due to the decreased velocity of the water, caused by flattening of the Usangu landscape, and the filtering effects of significantly dense vegetation and organic deposits, resulting in shallowing and decreased capacity of the channel. Subsequently, water spreads across the flood plains.

The spreading of the water in the Usangu wetlands, in addition to the presence of vegetation and organic debris has lowered the velocity of inflows from various channels, runoff and seasonal streams. However, the velocity is restored at Ng'iriama due to the increased slope, with cascades over rock outcrops, and clean water.

On the bank of the GRR, various conspicuous and well organised communities of riparian vegetation patterns, follow the direction of the channel up to the entry of the wetland (Figure 53)

**Figure 53: Riparian vegetation community including woody species in the riverbank in the GRR**

This organised pattern from upstream stabilises the banks and perform all the necessary functions in the riparian zones. These woody species communities, (including *Acacia tortilis, Acacia xanthophloea, Tamarindus indica, Commiphora africana, Garcinia livingstonia, Kigelia africana, Mimosa pygra, Acacia brevispica, Acacia albida, Combretum paniculata* and *Acacia polyacantha*,) diminish downstream as waterlogging begins in the eastern wetland.

However, permanent flow dependent species such as *Phragmites mauritianum, Polygonum senegalensis, Ceratophyllum demersum, Pistia stratiotes, Ipomoea aqautica, Oryza longistaminata* and *Vosia cuspidata* (Figure 54) extended further with the channel.

**Figure 54: *Phragmites mauritianum* on the bank of the GRR**

Towards the middle of the eastern wetland *Aeschenomene elaphroxylon* covers large parts of the banks, continuing through the currently existing perennial swamps to the junction at Lyang'ulage and Nyamwono, where all the channels merge and take their course to Ng'iriama.

*Vosia cuspidata, Phragmites mauritianum, Aeschynomene elaphroxylon, Polygonum senegalensis, Leersia hexandra, Ceratophyllum demersum* were characteristically found in the channel (Figure 55)

**Figure 55: *Vosia cuspidata* the basic composition on the upstream of the GRR bank**

*Ipomoea aqautica, Echnocloa spp., Nymphaea nouchali, Oryza longistaminata, Sesbania greenwayi* and *Typha capensis* were typically found on the flood plains. The vegetation communities along the riverbank were habitats for wetland birds and large mammals, including primates, that were using *Aeschynomene elaphroxylon* shrubs as their habitats. However, the riverbanks are not well defined in the wetland, and the well defined riparian community (*Vosia cuspidata, Phragmites mauritianum, Aeschynomene elaphroxylon)* is gone. A few small patches of *Aeschynomene elaphroxylon* were present at Lyang'ulage and Nyamwono swamp, with the few populations of *Phragmites mauritianum* protruding into the wetland indicating the direction of the previous channel.

According to fishermen in the wetland, changes in the population of riparian communities, particularly *Aeschynomene elaphroxylon* might have been caused by fire that occurred due to drought in the early 1980's. It appears that the extended drought period in those years killed many plant species in the wetland, creating large piles of dried litter. These piles of dead plants provided fuel leading to severe burning of parts of the wetland, destroying a large part of the *Aeschynomene elaphroxylon* community

(Vihefu) and inhabitants such as the monkeys that were living in this community when they failed to escape the fierce fires which were accelerated by wind in the wetland.

On the other hand, inundation of the floodplains has created microhabitat conditions for permanently flow dependent plant species (that were formerly found only along the channel and habitats closer to the channels) to spread over larger parts of the wetland. *Vosia cuspidata* (the hippo grass) which prefers the high flows of the GRR channels (Figure 55) is now mixed with other species such as *Sesbania* spp and *Echnocloa scabra*. *Oryza longistaminata* and *Leersia hexandra* which were the flow dependant species in the channel are now found all over the seasonally flooded region, due to the presence of favourable habitats that support them.

Due to a significant microhabitat shift in the wetland, water lilies such as *Nymphaea lotus* and *Nymphaea capensis* are now spread under the shade of *Aeschynomene indica* and *Sesbania greenwayi*, co-existing with *Ipomoea aquatica* and *Achyranthes aquatica* in the seasonally inundated regions of the wetland.

Based on the observation from this assessment, it can be predicted that continued improvement in the system and the upper zones of the eastern Usangu wetland will result in the long term existence of pools in seasonally flooded areas of the wetland. At present there has been already favourable microhabitat conditions supporting the permanently flow depended species in the seasonally flooded region of the wetland. Habitat for fish and macro-invertebrate is likely to increase in the wetland.

Historically, vegetation in the GRR banks was composed of *Vosia cuspidata, Phragmites mauritianum, Aeschynomene elaphroxylon, Aeschynomene indica, Aeschynomene pfundi, Polygonum senegalensis, Leersia hexandra,* and *Ceratophyllum demersum* as characteristic channel species, whilst *Ipomoea aqautica, Echnocloa spp. Nymphaea nouchali, Oryza longistaminate, Sesbania greenwayi and Typha capensis* were found on the flood plains. Today these communities have significantly changed, and new vegetation communities have emerged in the wetland.

The new wetland vegetation communities which enjoy the wide range of newly evolved favourable microhabitats feature a "hydroperiod pulse"; i.e. a seasonal spreading and expanding the community cover due to laterally spreading water from the channel in all directions in the wetlands. The new wetland vegetation communities contain diverse mixes of plant species in large parts in the wetland and perennial swamps.

Due to runoff from agricultural land and catchments, the wetland vegetation communities are well fed with high level of nutrients, and subsequently have overgrown. This overgrown condition provides a large quantity of food to fish, and invertebrates, provides shade to migratory fish and wildlife, as well as habitats for birds and other organisms in this wetland. The Usangu wetland supports unique and large numbers of species, raising the wetland's conservation status.

### Factors for the recent ecological change in Usangu wetlands

The recent changes in wetland vegetation have occurred as a result of normal wetland dynamism, flow irregularity and contaminants from agrochemical and general anthropogenic activities.

Wetland vegetation develops on different geomorphic surfaces that are characterised by a range of disturbance types, frequencies, and intensities (Villarin *et al*., 2009). It is well known that disturbance plays a major role in structuring wetland vegetation (Agee, 1988; Harris, 1999; Hupp, 1986).

The assessment of ecological health of the Usangu wetland is a problematic process, since it is anthropogenically stressed and is a dynamic ecosystem. Indicators of anthropogenic stress, such as declines in diversity and abundance, changes in biomass and primary production, and retrogressive succession may be difficult to apply in the wetland. However, the present assessment is a cautionary lesson in the power of unchallenged paradigms in shaping scientific and popular opinion about the current change of vegetation communities in Usangu wetland.

The existing paradigm of thinking about the ecosystem views Usangu wetland change as predominantly due to:

- Large-scale grazing activities and the establishment of new human settlements in the Usangu wetland that has been taking place for several decades,
- Complex water abstraction systems and climatic dynamism,and
- Eutrophication caused by agrochemicals.

Illegal fishing practices, overgrazing and changing from small to large scale irrigated cultivation (i.e. over-cultivation) are seen as the major factors for vegetation community change.

Mbarali and Kapunga farms are the main user of fertilisers such as urea, which is a potential contributor to eutrophication, and which may have caused the overgrowth of *Sesbania greenwayi, Echnocloa* spp. and *Vossia cuspidata* species over other species in the wetland. On the other hand, the recent change in vegetation communities, and the extended drying of the wetland might have been partly influenced by livestock grazing.

Overgrazing of grass species in the wetland during the dry season leaves the mbugu soil bare. This exposed land loses water faster than when it is lost through evapotransipiration. The moisture content available in these black cotton soils to support the aboveground vegetation cover is then lost, due to direct heating by sunlight. Further, wetland plants species productivity is low during the dry seasons, which causes high grazing pressure when the livestock population is high.

During the dry season, large populations of livestock are moved into the wetland when quality and quantity of the pasture in the surrounding terrestrial ecosystem decreases. As they move around in the wetland, they tramp vegetation with their hooves while grazing, leaving the ground bare. Livestock waste adds to fertilisers as causes of eutrophication. Livestock wastes are introduced to the wetland during dry season grazing, or through runoff from the newly established settlements and cattle enclosures that are constructed in nearby areas by pastoralists.

Nutrients from livestock wastes, in addition to those from fertilisers from rice irrigation farms may contribute to overgrowth of vegetation in the wetlands. The overgrown vegetation coils down in the wetland as the flows supporting the upright stalks decrease. This coiling and accumulating on the surface as the volume of water decreases covers the ground surface significantly and reduces the loss of water from the system through direct evaporation.

It is known that the effect on vegetation of overgrazing is the most important point of political interest ever to have been raised regarding the conservation of biodiversity in the of the Usangu wetland. It may be the most controversial subject raised in all the previous discussions about the Usangu low plain landscapes, with respect to livestock grazing and its effects on wetland vegetation communities, ecosystem integrity, functions and dynamics.

When the adjacent vegetation (grasslands and wooded grasslands) of the wetlands have been overgrazed leaving the land bare, the greener vegetation near the permanent waters of the swamps becomes the victim during the dry season. However, the ecosystem recovers from overgrazed conditions once livestock are removed, allowing moisture retention in the soils to remain high enough to support vegetation during the dry season.

Whilst this trend of recovery will allow the Usangu wetland to return to its natural state, the pronounced vegetation change has been compounded by the large scale use of water for irrigated cultivation in the wetland. Populations of permanently flow dependent plant species are affected during the dry season since there is no flow or flooding in the wetland, which causes such vegetation to retreat and die back, thus decreasing its abundance and diversity.

From professional point of view, the vegetation change in Usangu wetland is not a static event; rather it is a dynamic gradual process due to a combination of anthropogenic effects, natural hazards, or climatic changes, which have occurred at all times in the history of Usangu wetlands.

Our ideas on way forward should not be fixed in one direction, since the Usangu wetland is a dynamic system, where unpredictable significant changes are likely to emerge. Further, our current knowledge about the wetland is supported by limited data to strengthen our present direction of ideas. Long term studies are needed to accumulate more data for the proper management and planning for biodiversity conservation of this system.

## Conservation significance of Usangu wetland vegetation

The densely vegetated Usangu wetland may be regarded as the “kidney” of the Usangu landscape, because of the functions it performs in hydrological and chemical cycles as a down stream receiver of wastes from runoff from both catchment and agricultural sources.

It cleanses polluted waters by trapping sediments, prevent floods, and recharges ground water aquifers. The Usangu wetland is a valuable system component as a transformer of a multitude of agrochemicals, and storage of genetic resources. Figure 56 depicts the difference between inflow and outflow water in the wetland.

*Inflow of water into the system*

*Outflow from the system*

**Figure 56: The “kidney” functions of the Usangu wetland**

A wide variety of birds, reptiles, fish, amphibians and mammals, (both predators and prey), were observed throughout the wetland. The diversity of bird life in the Usangu wetland is greater than in any other East African park, due to its geographical location. It is visited by both northern and southern migrants (WWF, 2002).

The Usangu wetland (Ihefu) plays a major and valuable role in the Usangu landscape by providing unique habitats for a wide variety of flora and fauna whose presence enriches the global gene pool.. It supports the existence of various food chains that are rich in biodiversity, including a large number of species (plants and animals) with special physiological and biochemical adaptations to anaerobiosis, nutrient limitations, hydrological change, and other environmental stress.

The high density of overgrown vegetation in the Usangu wetland provides a potential carbon dioxide sink and climate stabiliser, particularly in the southern highlands.

The value of the wetland has now been recognised and translated into protection through the creation of national parks. Having come more recently to the attention of the global scientific community, it needs to remain the focus of interest to conservation minded people and organisations, as its degradation trend has been tremendous and is easily recognised through loss of species diversity and habitat.

### Future monitoring of in the using area cover and perimeter of perennial swamps

The Eastern Usangu vegetation has been tremendously degraded over the last three decades, and the magnitude of this degradation has not been accurately quantified, until recent studies (including this one) were carried out.

Data describing the perimeter and area cover of the perennial swamps provides the easiest method of identifying changes in the wetland vegetation communities. Table 68 shows the current area cover and perimeter of each perennial swamp. A decrease in area cover of open waters will indicate a decrease in inflow or volume of water in the system. This can also be evaluated by comparing the decrease in open water vegetation cover and vegetation community composition.

Lack of water in the system or wetland will be observed through decrease in area cover of water lilies or permanent water dependent plant species, and rapid colonisation of seasonally flooded vegetation communities.

**Table 68: The area cover and perimeter of perennial swamps in the Usangu wetland**

| Swamp Name | Shapes | Area cover ($M^2$) | Perimeter (m) |
|---|---|---|---|
| Ruaha | Polygon | 3299963.00 | 12047.35 |
| Nyangokolo | Polygon | 1274633.00 | 6801.63 |
| Lyang'ulage | Polygon | 1093769.00 | 8414.00 |
| Nyamwono | Polygon | 457683.12 | 3538.57 |
| Malihemu | Polygon | 25390.56 | 1249.87 |

### 6.4.5. Invertebrates and fish

#### Benthic macroinvertebrate sampling methods

Benthic macroinvertebrates (small aquatic insects, oligochaetes, molluscs and crustaceans and other organisms without backbones that inhabit the substrate surface for all or part of their lifecycles) were collected using a modified D-net with 500 µm mesh size attached to a metal frame (area 0.625 $m^2$) and handle (1.48 m long). At each sampling site the field crew randomly selected three subsampling locations within each aquatic habitat type present (i.e., open water, vegetation fringes, etc.). At each subsampling site 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. Each hand netting round took approximately one minute. The net contents were emptied into a white tray where large objects were removed, water 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 the University of Dar es Salaam for analysis.

Macroinvertebrate samples were sorted and identified using general invertebrate textbooks and manuals (Gerber and Gabriel, 2002; Ruppert and Barnes, 1994; and Day *et al.*, 2003) at the University of Dar es Salaam. 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. The abundances of each taxon in the subsamples were averaged and converted into average densities by dividing the average abundance by the area of the sampler. For sites containing only one habitat type (e.g., open water), the average densities were based on three randomly collected subsamples. For sites with two or three habitat types present, average densities were based on six and nine subsamples, respectively.

#### Fish sampling methods

Fish were sampled using gill nets and seine nets. Gill nets were used in deeper waters where human access by wading was not possible, while the seine net was set in shallow waters (< 1.2 m) and pulled towards the bank. Each of the two sampling gears was employed in each study sites and covered a variety of wetland habitat types. At each site two sets of 100 m by 2 m multimesh gillnet panels were set for the period of 3 hours. 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 stream or lake (< 1m) then pulled towards the banks.

Fish were then trapped and encircled. A single cast net sweep lasted for a period of 5 minutes. Two cast net sweeps were deployed at each sampling site. Captured fish were sacrificed for subsequent identification and life history analysis at the Project Camp Site.

The catches from each sampling method were sorted into major groups (taxa), before being counted and identified in the field using the taxonomic guides by Bernacsek (1980), Eccles (1992) and Skelton (1993). 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). Voucher specimens of fish species were photographed using a digital camera and similarly preserved with formalin for onward deposition in the University fish Museum.

## Data analysis

Fish and macroinvertebrate data were analysed using Shannon-Weaner diversity index (H') to provide an indication of relative abundance and distribution of resident fish and macroinvertebrate species among sampling sites (and habitats) in the Project Area in addition to presence-absence in the reaches assessed. In addition, this index allows for a more accurate measure of biodiversity than a simple account of number of species present in a given habitat.

## Assessment results

### Wetland habitats

The summary of river habitat characteristics at each sampling site in the Usangu Wetland is given in Table 69.

**Table 69: Summary river habitat description of the three sampling sites in the Usangu Wetland**

| **Site ID [Name at wetland reach]** | **GPS Location (ARC 1960)** | **Habitat description of fish and macroinvertebrate sampling sites** | **Dominant substrate type (%)** |
|---|---|---|---|
| NYALUHANGA<br><br>[The inlet area to the Usangu Wetland] | E 0646109<br>N 9070678 | • Elevation: 1023 masl<br>• Water depth: 2.5 m<br>Vegetation types:<br>• Submerged- *Ceratophyllum demersum, Lagaspho* sp<br>• Emergent- *Nymphaea notchilis* (water lilies)<br>• Floating- *Pistia* sp. Azolla sp. *Trapa natans* (Lilies like)<br>• Growing on floating matt - *Vosia sp*. Hippo grass, *Cyperus* sp., Sedges, *Typha* sp., *Aeschenomena* sp., *Polygonum senegalensis.* | Muddy clay (100) |

| Site ID [Name at wetland reach] | GPS Location (ARC 1960) | Habitat description of fish and macroinvertebrate sampling sites | Dominant substrate type (%) |
|---|---|---|---|
| | | Land use:<br>• Fishing (illegal) is the major pre-occupation | |
| RUAHA PONDS<br><br>[Central area of the Usangu Wetland] | E 0666555<br>N 9075242 | • Elevation: 1016 masl<br>• Water depth: 2.5 m<br>Vegetation types:<br>• Submerged- *Ceratophyllum demersum, Lagaspho* sp.<br>• Emergent – *Nymphaea notchilis* (water lilies),<br>• Floating- *Pistia* sp., *Azolla* sp., *Trapa natans* (Lilies like)<br>• Growing on floating matt- *Vosia sp.*Hippo grass, *Cyperus* sp., Sedges, *Typha* sp., *Aeschenomena* sp., *Polygonum senegalensis*<br>Land use:<br>• No visible human activities | Muddy clay (100) |
| NGIRIAMA<br><br>[The outlet area of the Usangu Wetland] | E 0666508<br>N 9091000 | • Elevation: 1024 masl<br>• Water depth: 3 m<br>Vegetation types:<br>• Submerged- *Ceratophyllum demersum, Lagaspho* sp<br>• Emergent- *Nymphaea notchilis* (water lilies)<br>• Floating- *Pistia* sp. Azolla sp. *Trapa natans* (Lilies like)<br>• Growing on floating matt- *Vosia sp.*Hippo grass, *Cyperus* sp., Sedges, *Typha* sp., *Aeschenomena* sp., *Polygonum senegalensis*<br>Land use:<br>Fishing (illegal) is the major pre-occupation | Muddy clay (100) |

**Macroinvertebrates**

Aquatic invertebrates are very sensitive indicators of the water quality and flow regime in rivers and of the overall ecological health of the system. Species used in the present survey included insects, worms, molluscs and crustaceans that occur on the riverbed or along the channel margins.

A total of 1275 macroinvertebrates belonging to 21 taxa were encountered in the samples collected from three sampling sites in the Usangu Wetland. These numbers are comparable to the other stream macroinvertebrate studies conducted in the tropics where macroinvertebrates have been identified only to lower taxonomic classes (e.g. subfamily, genus and, in few instances, to tribe). Due to a paucity of published literature and taxonomic keys of the Tanzanian stream fauna, most specimens were assigned only to the lowest taxon within which they could be placed with certainty. Subsequently, in the present study, all specimens were identified only to family level.

The larvae of midges Chironomidae (Diptera) were the most abundant taxon, accounting for 42% of the total, followed by Ampullaridae (Gastropoda) with 11% of the total microinvertebrate collected during the present study. Together with freshwater shrimp Actyidae (Crustacea) and backswimmers Notonectidae (Hemiptera) they composed the four most abundant taxa, accounting for 69% of collected invertebrates (Table 70). Descriptions of major groups of benthic macroinvertebrates collected in the present study are given in Appendix 1 of the fish and invertebrate report which is available from wWF TCO and RBWO.

The highest average macroinvetebrate density, exceeding 500 individuals per square metre per taxon, was observed at Ng'iriama for the larvae midge Chironomidae. For Nyaluhanga and Ruaha Ponds the highest taxon densities were 204 and 145 recorded for mystery snails (Ampullaridae) and backswimmers (Notonectidae) respectively. Although the cumulative number of macroinvertebrate taxa were relatively different, the analysis of variance (ANOVA) showed no significantly difference in macroinvertebrate density per taxon between the three sites ($p = 0.09$).

When the 21 macroinvertebrate taxa were further divided into three arbitrary groups based on their sensitivity or pollution tolerance (Gerber and Gabriel, 2002), 14 taxa were identified as being highly tolerant to pollution, six moderately tolerant and one with very low tolerance to pollution (Table 71). This is in contrast to results of a similar study conducted in the GRR whereby three out of 19 taxa (16%) comprised macroinvertebrates with a very low tolerance to pollution compared to only 5% for the present study.

In addition to macroinvertebrate abundance scores and computation of a species diversity index, a SASS macroinvertebrate index was used to assess the health of the river and the general quality of the water at the three WBBM sites. SASS uses the average macroinvertebrate scores computed from sensitivity of the various animals to water quality to measure the health of a river. Based on this index SASS Average Scores of 0-2 signifies a highly impacted stream, 2-4 as impacted stream, 4-6 as slightly impacted stream and >6 as good quality stream. The average scores computed for the three sites (Table 70) define all of them as slightly impacted sites.

The Shannon-Weaner diversity index (H′) was also computed for macroinvertebrate in each of the three sampling sites, in order to account for their species richness and evenness. This index allows for a more accurate measure of biodiversity than a simple account of number of species present in a given habitat. Table 72 gives the values of Shannon Weaner species diversity indices and evenness for the three sites.

**Table 70: Summary results of macroinvertebrate density (no./m²), sensitivity score, total score and average score per taxon for WBBM sites in the GRR**

| Taxonomic group / SITE | NYALUHANGA (INLET) | | | RUAHA PONDS | | | NGIRIAMA (OUTLET) | | | Total No. | Percent Contrib. |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | Number | Density (no/m²) | Sensitivity score | Number | Density (no/m²) | Sensitivity score | Number | Density (no/m²) | Sensitivity score | | |
| **Annelida** | | | | | | | | | | | |
| Oligochaeta | 0 | 0 | 0 | 0 | 0 | | 31 | 49.6 | 1 | 31 | 2.43 |
| **Crustacea** | | | | | | | | | | | |
| Actyidae | 113 | 180.8 | 8 | 0 | 0 | | 0 | 0 | | 113 | 8.86 |
| **Acarina** | | | | | | | | | | | |
| hydracarina | 0 | 0 | 0 | 0 | 0 | | 7 | 11.2 | 8 | 7 | 0.55 |
| **Ephemeroptera** | | | | | | | | | | | |
| Baetidae | 89 | 142.4 | 6 | 0 | 0 | | 16 | 25.6 | 6 | 105 | 8.24 |
| **Odonata** | | | | | | | | | | | |
| Coenagriidae | 23 | 36.8 | 4 | 49 | 78.4 | 4 | 0 | 0 | | 72 | 5.65 |
| **Hemiptera** | | | | | | | | | | | |
| Notonectidae | 0 | 0 | | 91 | 145.6 | 3 | 0 | 0 | | 91 | 7.14 |
| Pleidae | 0 | 0 | | 29 | 46.4 | 4 | 0 | 0 | | 29 | 2.27 |
| Naucoridae | 8 | 12.8 | 7 | 0 | 0 | | 0 | 0 | | 8 | 0.63 |
| Nepidae | 0 | 0 | | 0 | 0 | | 1 | 1.6 | 3 | 1 | 0.08 |
| Belostomatidae | 4 | 6.4 | 3 | 23 | 36.8 | 3 | 0 | 0 | | 27 | 2.12 |
| Corrixidae | 0 | 0 | | 0 | 0 | | 2 | 3.2 | 3 | 2 | 0.16 |
| **Trichoptera** | | | | | | | | | | | |
| Ecnomidae | 0 | 0 | | 0 | 9.6 | 8 | 3 | 0 | | 6 | 0.47 |
| **Coleoptera** | | | | | | | | | | | |
| Dytiscidae | 2 | 3.2 | 5 | 9 | 14.4 | 5 | 20 | 32 | 5 | 31 | 2.43 |
| Helodidae | 0 | 0 | | 2 | 3.2 | 12 | 0 | 0 | | 2 | 0.16 |
| Hydrophilidae | 5 | 8 | 5 | 4 | 6.4 | 5 | 0 | 0 | | 9 | 0.71 |

| Taxonomic group / SITE | NYALUHANGA (INLET) | | | RUAHA PONDS | | | NGIRIAMA (OUTLET) | | | Total No. | Percent Contrib. |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | Number | Density (no/m$^2$) | Sensitivity score | Number | Density (no/m$^2$) | Sensitivity score | Number | Density (no/m$^2$) | Sensitivity score | | |
| Elmidae | 0 | 0 | | 0 | 0 | | 3 | 4.8 | 8 | 3 | 0.24 |
| **Diptera** | | | | | | | | | | | |
| Chironomidae | 83 | 132.8 | 2 | 79 | 126.4 | 2 | 372 | 595.2 | 2 | 534 | 41.88 |
| Ceratopogonidae | 4 | 6.4 | 5 | 0 | 0 | | 3 | 4.8 | 5 | 7 | 0.55 |
| **Gastropoda** | | | | | | | | | | | |
| Succinaidae | 0 | 0 | | 5 | 8 | 3 | 0 | 0 | | 5 | 0.39 |
| Planorbidae | 6 | 9.6 | 3 | 49 | 78.4 | 3 | 0 | 0 | | 55 | 4.31 |
| Ampullaridae | 128 | 204.8 | 3 | 9 | 14.4 | 3 | 0 | 0 | | 137 | 10.75 |
| | | | | | | | | | | | |
| **Total number of individuals** | 465 | | | 355 | | | 455 | | | 1275 | 100 |
| **Total number of individuals / m$^2$** | | 744 | | | 568 | | | 728 | | | |
| **Number of taxa per site** | 11 | | | 12 | | | 9 | | | | |
| **Total sensitivity score** | | | 51 | | | 55 | | | 41 | | |
| **ASPT score** | | | 4.6 | | | 4.6 | | | 4.6 | | |

**Table 71: Three arbitrary groups of macroinvertebrates in Usangu Wetland based on their sensitivity or tolerance to pollution**

| Microinvertebrate group | Microinvertebrate taxa | Highly tolerant to pollution | Moderately tolerant to pollution | Very low tolerance to pollution |
|---|---|---|---|---|
| **Annelida** | Oligochaeta | ✓ | | |
| **Crustacea** | Atyidae | | ✓ | |
| **Acarina** | Hydracarina | | ✓ | |
| **Ephemeroptera** | Baetidae | | ✓ | |
| **Odonata** | Coenagriidae | ✓ | | |
| **Hemiptera** | Notonectidae | ✓ | | |
| | Pleidae | ✓ | | |
| | Naucoridae | | ✓ | |
| | Nepidae | ✓ | | |
| | Belostomatidae | ✓ | | |
| | Corrixidae | ✓ | | |
| **Trichoptera** | Ecnomidae | | ✓ | |
| **Coleoptera** | Dytiscidae | ✓ | | |
| | Helodidae | | | ✓ |
| | Hydrophilidae | ✓ | | |
| | Elmidae | | ✓ | |
| **Diptera** | Chironomidae | ✓ | | |
| | Ceratopogonidae | ✓ | | |
| **Gastropoda** | Succinaidae | ✓ | | |
| | Planorbidae | ✓ | | |
| | Ampullaridae | ✓ | | |
| **Total** | **19** | **14** | **6** | **1** |

*[Prepared from descriptions given in the Aquatic Invertebrates of South African Rivers Field Guide by Gerber and Gabriel (2002)]*

**Table 72: Shannon Weaner species diversity indices for macroinvertebrate at the three sampling sites in the Usangu Wetland**

| Sampling site | Species diversity index | Species evenness |
|---|---|---|
| Nyaluhanga | 1.75 | .73 |
| Ruaha Ponds | 2.01 | 0.81 |
| Ng'iriama | 0.77 | 0.35 |

### Fish

*Resident fish in the project area*

The fish fauna of Usangu Wetland is one of the well-studied biota in the Tanzanian river basins. Much of the description of fish species of Usangu Wetland is embodied in the works of SMUWC (2010).

A list of fish species reported in the Usangu Wetland is given in Table 73. Length-weight measurements were recorded as shown in Appendix 2 of the fish and invertebrate report, and photographs of voucher specimens of representative species are given in Appendix 3 of the fish and invertebrate report, which are available from WWF TCO and RBWO. In total, 17 fish species belonging to 12 genera (8 Families) have been reported to be resident in the Usangu Wetland. A significant number of fish species reported by SMUWC (2001) were also encountered in the present study of fish in the Usangu Wetland (Table 73). Additionally, more fish were caught during the 7 days of intensive sampling in March 2010, (17 of the 19 described fish species in the study area), than the 9 fish species caught in a two-year sampling extending up to 2001 (SMUWC, 2001). This indicates that conditions have improved, and possibly that the various interventions that have been taken to minimise anthropogenic perturbations in the Usangu Wetland are yielding the intended results.

*Catch composition*

During the present sampling expedition, 914 fish specimens belonging to 12 genera and representing 17 different species were collected from three sampling sites (WBBM1:the inlet wetland site at Nyaluhanga; WBBM2: the central wetland at Ruaha Ponds; and WBBM3: the outlet from the wetland at Ng'iriama) in the Usangu Wetland (Table 74). These results resemble those that were obtained during the fish sampling for EFA study conducted in the GRR in June 2008. In that study, 205 fish specimens belonging to 12 genera representing 17 different species were collected from two sampling sites (WBBM 1 and WBBM 2). In both studies fish samples were collected by gillnets and a seine net.

The catch data generated from a sample of 914 fish specimens caught at the three sites indicates that the catch was dominated by members of the family Characidae, which comprised 59% of the total number of fishes. One small species of *Brycinus* (*B. imberii*) was the most abundant, followed by *Brycinus affinis*. Schilbeidae were the second dominant group with *Schilbe mystus* and *S. moebiusi* jointly comprising about 19% of the total number of fish caught. The Cyprinidae represented by *Barbus macrolepis*, *B. paludinosus* and *B. jacksonii* made up 12% with each of the remaining families contributing about 10% of total number of fish collected (Figure 57). Unlike June 2008 fish sampling expedition in the GRR, highly flow sensitive species such as *Chiloglanis* sp were not found in the Usangu Wetland.

In comparison with catch composition data observed in the 2001 (SMUWC, 2001), *Clarias gariepinus* and *Oreochromis urolepis* were not the most dominant fish species in the present study, possibly indicating that there has been a change in the composition of resident fish species in the Usangu Wetland.

**Table 73: Fishes reported from the Usangu Wetland based on collections by SMUWC (2001) and present study conducted in March 2010**

| FAMILY | SPECIES | SMUWC 2001 | Present Survey (March 2010) |
|---|---|---|---|
| **CYPRINIDAE** (Minnows and Carps) | *Barbus paludinosus* | ✓ | ✓ |
| | *Barbus jacksonii* | | ✓ |
| | *Barbus macrolepis* | | ✓ |
| | *Labeo cylindricus* | ✓ | ✓ |
| **CICHLIDAE** | *Oreochromis urolepis* | ✓ | ✓ |
| | *Oreochromis rukwaensis* | | ✓ |
| | *Tilapia zillii* | | ✓ |
| **MORMYRIDAE** | *Marcusenius macrolepidotus* | ✓ | ✓ |
| | *Petrocephalus steindachneri* | ✓ | |
| | *Petrocephalus catostoma* | ✓ | ✓ |
| | *Gnathonemus livingstonii* | ✓ | |
| **CHARACIDAE** (African tetras) | *Brycinus affinis* | | ✓ |
| | *Brycinus imberi* | | ✓ |
| **MOCHOKIDAE** (Squeakers) | *Synodontis maculipina* | | ✓ |
| | *Synodontis matthesi* | | ✓ |
| **SCHILBEIDAE** (Schilbeid catfishes) | *Schilbe mystus* | | ✓ |
| | *Schilbe moebiusi* | ✓ | ✓ |
| **CLARIIDAE** (Airbreating catfish) | *Clarias gariepinus* | ✓ | ✓ |
| **BAGRIDAE** | *Bagrus orientalis* | | ✓ |

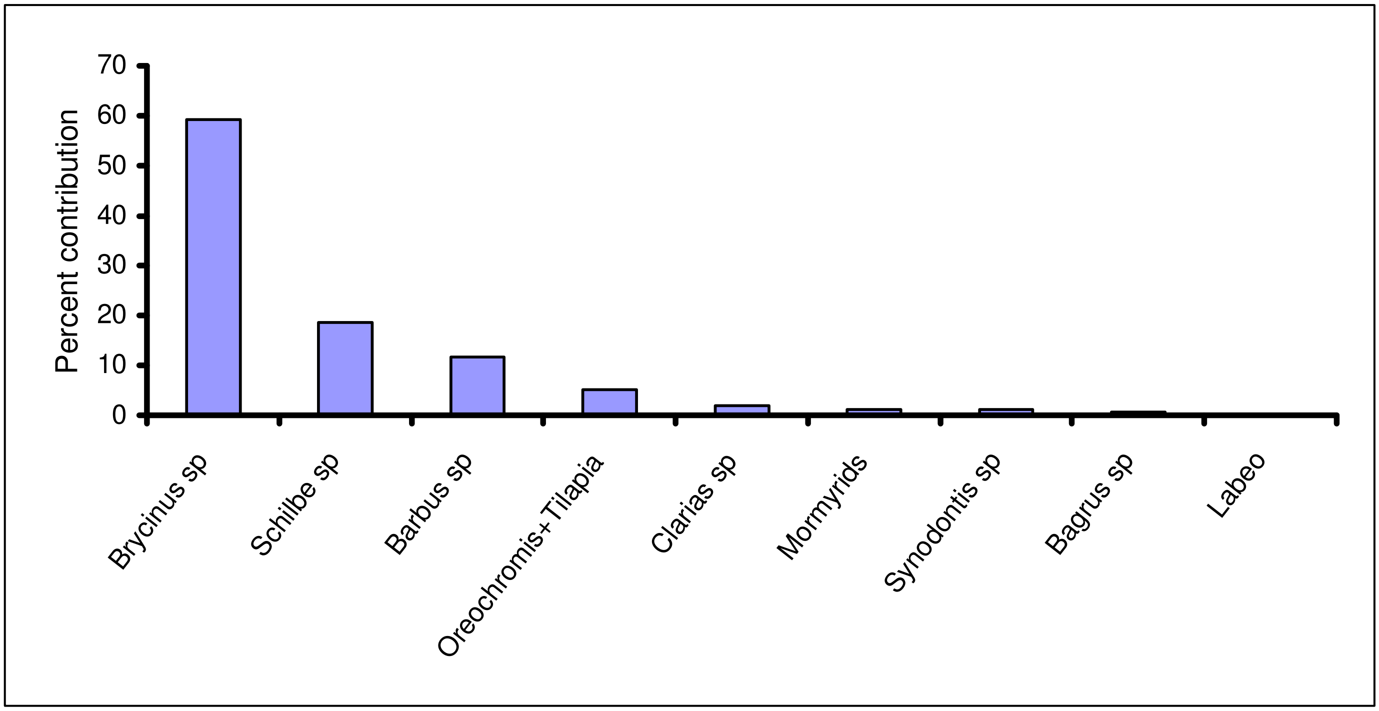



**Figure 57: Relative contribution (numbers) of fish species to the total catch in the Usangu wetland**

**Table 74: Fish species collected in the Usangu Wetland during present sampling**

| Family | Species Name | English Name | Local Name | Conservation Status | Sampling site | | |
|---|---|---|---|---|---|---|---|
| | | | | | Nyaluhanga | Ruaha Ponds | Ng'iriama |
| Cyprinidae | *Barbus paludinosus* | Straightfin barb | | Lc | ✓ | | |
| | *Barbus jacksonii* | | | Lc | ✓ | | |
| | *Barbus macrolepis* | | | Lc | ✓ | | |
| | *Labeo cylindricus* | Redeye labeo | Ningu | Lc | ✓ | | |
| Characidae | *Brycinus imberi* | | | Lc | ✓ | | |
| | *Brycinus affinis* | | | Lc | ✓ | | |
| Cichlidae | *Oreochromis urolepis* | | Sato | Endemic (GRR) | | | ✓ |
| | *Oreochromis rukwaensis* | | | | ✓ | ✓ | |
| | *Tilapia zillii* | Redbelly tilapia | Sato | Lc | ✓ | | |
| Clariidae | *Clarias gariepinus* | Airbreating catfish | Kambale | Lc | | ✓ | ✓ |
| Mochokidae | *Synodontis maculipina* | Squeaker | Gogogo | Lc | ✓ | | |

| Family | Species Name | English Name | Local Name | Conservation Status | Sampling site | | |
|---|---|---|---|---|---|---|---|
| | | | | | Nyaluhanga | Ruaha Ponds | Ng'iriama |
| | | catfish | | | | | |
| | *Synodontis matthesi* | | | LC | ✓ | | |
| Mormyridae | *Marcusenius macrolepidotus* | | | LC | ✓ | | |
| | *Petrocephalus catostoma* | | | LC | ✓ | | |
| Schilbeidae | *Schilbe mystus* | | | LC | ✓ | | |
| | *Schilbe moebiusi* | | | LC | ✓ | | |
| Bagridae | *Bagrus orientalis* | | | LC | ✓ | | |

*Fish distribution*

In order to account for possible site differences in fish species richness, the Shannon-Weaner diversity index (H′) was computed for fish data from each of the three fish sampling sites. This index allows for a more accurate measure of biodiversity than a simple account of number of species present in a given site or habitat. Table 75 presents the Shannon-Weaner fish species diversity indices for the three sampling sites in the Usangu Wetland.

The fish diversity indices ranged from the lowest value of 0.33 at Ruaha Ponds where only two species of fish were recorded, to the highest value of 1.51 at Nyaluhanga, where fifteen different species were caught. However, the computation of analysis of variance (ANOVA) showed that there were no significant differences in fish species diversity and evenness between the three sampling sites ($p = 0.160$). Although ANOVA did not show significant site differences in species diversity, it seems biologically significant that only two species of fish were caught in each of the Ruaha Ponds and Ng'iriama sites, despite the fact that the same types of fishing gear and effort were used across the three sites.

It is likely that Nyaluhanga, being the most upstream site in the wetland, enjoys the swift flows provided by inflowing highland streams feeding the Usangu Wetland. Many moderately flow sensitive species such as *Labeo*, *Schilbe* and *Synodontis* prefer swift flowing waters. The swampy habitats and minimal water flows characteristic of the remaining two sites (i.e. Ruaha Ponds and the outlet at Ng'iriama) make these sites only ideal to *Clarias* and *Oreochromis* which are well adapted to difficult ecological conditions in the Ihefu and surrounding wetland.

The low species-diversity is perhaps a reflection of the stressful environmental conditions of the wetlands and the faunal response of few species and high populations of those that are the better adapted to the ambient conditions.

**Table 75: Shannon-Weaner fish species diversity indices for the sampling sites in the Usangu Wetland**

| Sampling site | Species diversity index | Species evenness |
|---|---|---|
| Nyaluhanga | 1.51 | 0.56 |
| Ruaha Ponds | 0.33 | 0.48 |
| Ng'iriama | 0.67 | 0.97 |

When compared to a similar study conducted in the GRR near Msembe (Tamatamah, 2008), the diversity index of 2.10 computed in the GRR for BBM 2 is higher than those observed at the three sampling sites in the Usangu Wetland where the highest site fish diversity score is 1.51. This would possibly indicate that by comparison to fairly protected portion of the GRR flowing within the RNP, sampling sites in the Usangu Wetland are exposed to intense anthropogenic perturbations.

*Labeo cylindricus*, a fairly flow sensitive species, was only caught in the most upstream site in the Usangu Wetland. Although *Labeo* favours clear, running waters in rocky habitats of small and large mountainous streams, they also do well in sediment-rich rocky biotopes in middle and lower sections of large rivers. In the breeding season, *Labeo* migrates upstream in numbers to breed in clear running waters in rocky substrates. During migration, they use their mouths and broad pectoral fins to climb damp surfaces of barrier rocks and weirs, which helps to explain the presence of this species at Nyaluhanga, and its absence at the other two sites.

*Clarias gariepinus* and *Oreochromis urolepis* were restricted to the mid and lower sections of the wetland. The distribution of these two species along the wetland is consistent with the findings of SMUWC (2001). They observed that *C. gariepinus* occurs mainly in quiet waters and pools, and is widely tolerant of extreme environmental conditions. *C. gariepinus* possesses an accessory breathing organ which enables it to breath air under very dry conditions. These features make *C. gariepinus* of least usefulness as an indicator species when estimating Reserves for troubled river and wetland systems.

*Sexual maturity and breeding*

The present study was conducted in March at the peak of high water in the Usangu Wetland. The catch data was analysed for all fish species of which more than 25 specimens were caught, to obtain the proportion of adult males and females in the sexually active stages (Figure 58). Overall, the combined 17-species data showed that only 2.5% of the adult fishes carried ripe gonads. This finding, in conjunction with the occurrence of a relatively large number of immature/juvenile fishes and spent males and females in the populations indicated that possibly the main fish spawning activity in the Usangu Wetland takes place during short rain spells in December/January. The onset of breeding activity for the majority of tropical fish species is associated with rising water levels at the beginning of the rain seasons (Welcomme, 1985; Lowe-McConnell, 1975). This is also in congruence with the findings from previous studies conducted in the Usangu Wetland (e.g. SMUWC, 2001).

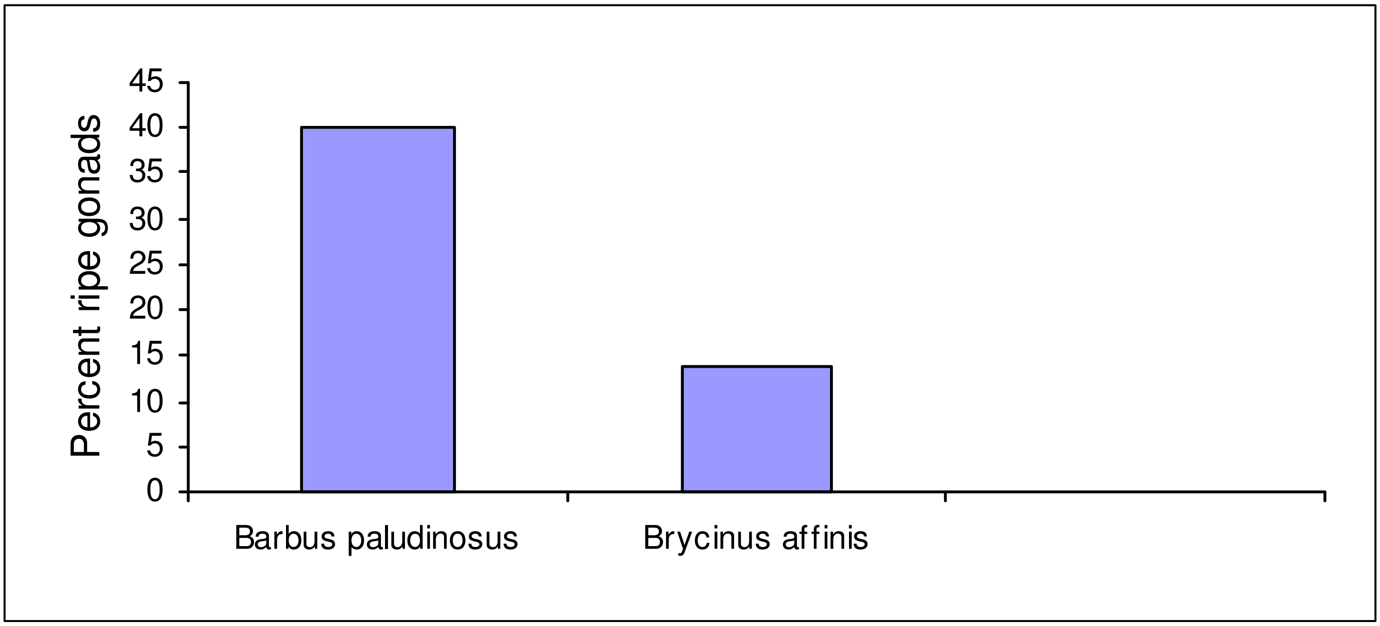



**Figure 58: Percent of adult fishes carrying ripe gonads**

*Fishing*

Before RNP was extended to include the Usangu Wetland, fish was important, both in the local diet as well as providing income for residents outside the former Usangu Game Reserve. SMUWC (2001), estimated that the Usangu Wetland fishery produced an average of some 700 tonnes of fish a year, giving fishermen the annual income of some 350 million shillings. The annual fish production ranged from about 400 to 1200 tonnes a year, depending upon rainfall patterns. Of this total catch, some 100 tonnes a year was thought to be taken for subsistence by local people. The most important species from the commercial fisheries perspective were the catfish or “kambale”, *Clarias gariepinus* with tilapia *Oreochromis urolepis* or “ngege” making up a very small proportion. Some other species such as Morymyrids or “somo” and Schilbeid and Synodontid catfish made a minor contribution of small-sized fish to the commercial catch and were also taken in the subsistence fishery.

The same study estimated that the Usangu Wetland fishery employed an estimated 300 fishermen full-time, with probably an equal number of part-time opportunistic fishermen who fished the flooded areas for a few months of the year. A small number of individuals were engaged in the processing, transporting and trading of fish. Fishing was carried out throughout the year, with its location following the pattern of the inundations. The fishing activity and yield began to increase at the beginning of the wet season in January, and declined after the rains stopped and the waters receded in April-May. Fishing was predominantly carried out by gillnets, seine nets and hooks and lines. As the water receded during the dry season, fish were increasingly taken by barrier traps, and directly from the shallow waters. All access to the deeper waters was by dugout canoe.

The need to use wood for the processing of fish was identified as the only significant environmental impact from the fishery. It was estimated that the average annual yield assessment of 700 tonnes required some 4,000$m^3$ of wood or approximately 4,000 mature trees.

The assumed National Park status (i.e. RNP) prohibits fishing activities taking place in the Usangu Wetland.

*Fish biodiversity and conservation status*

Currently, there are no endemic species of fish known from the Usangu study area. However, *Oreochromis urolepis* which was encountered in the Usangu Wetland during the present study together with three other species: *Labeo ulangensis*, *Alestes stuhlmanni* and the tiger fish *Hydrocynus tanzaniae*, all of which are found in the GRR downstream of the wetland, are endemic (i.e. confined) to the Ruaha / Rufiji system and have evolved in the basin. SMUWC (2001) described the Usangu Wetland as a system having a fish fauna with strong Zaire-basin affiliations.

This link between fish species in the Usangu Wetland system and the Zaire basin supports the geological evidence that in earlier times the GRR was a westward flowing river which drained into the Zaire basin. With the faulting which created the rift valley, including Lake Tanganyika and Lake Malawi, these headwaters were cut off from the main Zaire basin and forced to drain eastwards (Bannister and Clark, 1980). During this event the streams draining the Usangu Wetland took some of the species with them, some of which have remained unchanged, while others have evolved into new species through isolation. Since fish fauna of the Usangu Wetland bears the fingerprint of this geological and evolutionary shift, its conservation is of paramount importance.

The endemic tilapia of the GRR (*Oreochromis urolepis*), which also occur in the Usangu Wetland, have a peculiar genetic trait which is of major importance to modern aquaculture. As with female *O. hornorum*, hybridisation of female *O. urolepis* and male *O. mossambicus* yield all-male offspring. The use of monosex hybrids has become widespread in tilapia aquaculture as a method of choice to control overbreeding and stunted growth in ponds. This makes *O. urolepis* a most valuable national and international resource for selective breeding. It is important that the pure stock should be conserved in order to preserve the wild-type which possess this particular sex determination mechanism. Introduced tilapia species such as *O. niloticus* escaping and interbreeding with the wild population of *O. urolepis*, can cause breakdown of the wild genotype and loss of monosex trait.

Of the 17 fish species caught in the present sampling events, none appears on the IUCN Red List (IUCN, 2001). However, According to the Tanzanian fish conservation ranking system, *Barbus kerstenii* as well as *B. jacksonii*, *B. amphigramma*, *B. paludinosus*, *B. neumayeri* and *Haplochromis* sp are listed as threatened and declining in the Lake Victoria basin (Nhwani *et al*., 1996). Thus, a good number of fish species caught in the Project Area have some level of conservation priority, underlining the need to maintain their presence in the Usangu Wetland.

Specific management requirements have not been set for threatened fish species included in the national conservation ranking in Tanzania. However, the RNP forms a vital component of the conservation and management of freshwater fishes and biodiversity in these parts of the Tanzanian drainage network. Several fish taxa encountered in this study (e.g., *Labeo*, *Schilbe* and *Gnathonemus*) are known to undertake seasonal spawning migrations, with part of their distribution located within the upper reaches of the Usangu Plain and its wetland. Establishing management requirements for fish of conservation concern is the focus of ongoing work by National Environment Management Council (NEMC) of Tanzania.

### Present state of fish and flow-related information on fish species of the Usangu Wetland

Critical flow regime characteristics can be ascertained by studying the environmental guilds of fish present in the river, i.e. grouping fish species in the manner that they respond to changing hydrology and geomorphology of the river (Welcomme *et al*., 2006). This scheme is well adapted to holistic environmental flow assessment framework methodologies such as DRIFT and BBM (Arthington *et al*., 2003; King *et al*., 2003) that rely on limited knowledge and expert opinion rather than detailed local study. Understanding of fish guild responses has helped to guide river rehabilitation and restoration projects as well as releases of water for environmental maintenance.

Based on the scheme of Welcomme *et al*. (2006), fish fauna of the upper, middle and lower sections of the Usangu Wetland fall into two major environmental guilds: **rhithronic** or main channel communities (comprising guilds inhabiting riffles and pools) and the **potamonic** guild which includes *lotic* (longitudinal migrants), *lentic* (floodplain), and *eurytopic* (low dissolved oxygen tolerant) communities (Table 76).

There is no representative in the rhithronic communities of the true riffle guild in the Usangu Wetland. In tropical waters the true riffle guild would be represented by highly flow sensitive species such as *Chiloglanis*, which were not caught in the present study. Species in the pool guild of the rhithronic communities in the Usangu Wetland are represented by *Barbus*. They generally inhabit the slack regions of back eddies where emergent and floating vegetation may occur. They tend to be insectivorous, feeding on the drift dislodged from the riffles, or on insects falling into the river from riparian vegetation. They may be either breeding in the riffles (limnophilic) or by attaching their eggs to vegetation (phytophilic). They usually have well defined home ranges, and habitats delimited by depth, current strength and the distribution of vegetation. These species are also disturbed by changes to the flow regime that desiccate the pools or leave them for long periods without flow so they become anoxic. They also generally rely on the delicate balance between pool and riffle of the main channel and respond negatively to any influence that changes this balance.

*Labeo* are the true lotic guild of the potamonic communities in the Usangu Wetland. *Labeo* are generally longitudinal migrants that move within the main river channel, or up and down tributaries. Juveniles seek riffle/rapid habitats, and adults inhabit both riffles and pools. They require relatively high dissolved oxygen levels (second to riffle guilds) and as such they are sensitive to reductions in water quality, and may locally disappear under eutrophic conditions or when their river is dammed and prevents migration.

Lotic guild species have one breeding season a year that is closely linked to peak flows, and they rely on increased flow as a cue for migration and maturation. They are also vulnerable to changes in the timing of high flow events that are inappropriate to their breeding seasonality and for the needs of drifting larvae. During the present survey there were no true *lentic guild* species of the potamonic communities, i.e. non-migrant floodplain residents tolerant to low dissolved oxygen concentrations or even to complete anoxia.

The *Oreochromis*, *Tilapia*, *Clarias gariepinus* and Mormyrids are among the true representatives of the eurytopic (generalised and extremely adaptable) guild in the Usangu Wetland. This guild occupies the riparian zone and particularly the vegetation of the main channel and floodplain water bodies, and individuals may move onto the floodplain to occupy similar habitats during flooding. The species usually tolerate low dissolved oxygen. They are generally repeat breeders or may breed during both high and low flow phases of the hydrograph, as such breeding may be independent of flow cues. They are able to adapt behaviourally to altered hydrographs, are extremely flexible and may adopt other habitats (especially *Oreochromis* and *Tilapia*) as river conditions change. Thus, they generally increase in number as other species decline. Species in this guild are colonisers of regulated systems, and often increase to pest levels following control of flooding and stabilisation of river hydrographs, or declines in water quality through eutrophication. The habits of this guild make them suitable for rearing in ponds and they have been widely distributed for aquaculture (Welcomme, 1988). Species in this guild may be affected negatively by changes in riparian structure that suppress vegetation.

**Table 76: Representative fish species in major environmental guilds in the Usangu Wetland**

| Fish community type | Ecological guild | Representative fish genera/species in the Mara | Sensitivity to flow |
|---|---|---|---|
| Rhithronic communities | Riffle guild | No representative species in the Usangu Wetland | Critical |
| | Pool guild | *Barbus, Brycinus* | High |
| | Lotic guild | *Labeo* | Very high |
| Potamonic communities | Lentic guild | No representative species in the Mara | Moderate |
| | Eurytopic guild | *Clarias gariepinus, Tilapia, Oreochromis, Haplochromis,* Mormyrids (*Marcusenius & Petrocephalus*) | Low |

It can be inferred from the information presented in Table 76 that the lower percent (25%; i.e. 2 out of 8 representative genera) of resident fish species in the Usangu Wetland comprise the flow-sensitive guilds. The eurytopic guild has the highest percent (75%) of individuals in the catch. This suggests the wetland is not in a very good condition, and corrective measures are indeed critical to maintain a rich and diverse fish fauna.

## *6.5. Recommended flows and depths*

The flows required to meet the desired stated objectives were assessed for all WBBM sites in the Usangu wetland. The following flows were considered:

i) Dry season low flows for drought years

ii) Wet season low flows for drought years

iii) Dry season low flows for maintenance years

iv) Wet season low flows for maintenance years

v) Wet season high flows for maintenance years (2 floods)

vi) Wet season high flows for drought years

### 6.5.1. Riparian vegetation

The vegetation communities in the Usangu wetland need a minimum water level of 0.81m. This level is required to support the ecological functions in the wetland, regardless of the seasonal changes that might occur throughout the year, or the climatic changes over a number of years. However, some plant species such as *Azolla nilotica, Azolla filiculoides, Ceratophyllum demersum, Vosia cuspidate, Trapa natans, Lagarosiphon ilicifolius, Utricularis foliosa, Aeschynomene elaphroxylon, Typha capensis,* and *Fragmites mauritiana* needed higher levels of water flows than others (Table 77).

**Table 77: The minimum water requirements for specific plant species in the Usangu wetland**

| Name | Depth of water needed (metres) | Family |
|---|---|---|
| *Achyranthes aquatica* | 0.2 | Amaranthaceae |
| *Aeschynomene elaphroxylon* | 0.81 | Papilionaceae |
| *Aeschynomene pfundi* | 0.3 | Papilionaceae |
| *Azola nilotica* | 0.3 | Azollaceae |
| *Ceratophyllum demersum* | 1.2 | Ceratophyllaceae |
| *Centrostachys aquatica* | 0.3 | Amaranthaceae |
| *Cyperus mundtii* | 0.6 | Cyperaceae |
| *Cyperus anabilis* | 0.4 | Cyperaceae |
| *Echnocloa scabra* | 0.3 | Poaceae |
| *Echnocloa stagnina* | 0.5 | Poaceae |
| *Fimbristylis hispidula* | 0.2 | Poaceae |
| *Fuirena ochresta* | 0.3 | Cyperaceae |
| *Hygrophila auriculata* | 0.2 | Acanthaceae |
| *Ipomoea aquatica* | 0.3 | Convolvulaceae |
| *Lagarosiphon ilicifolius* | 2.0 | Hydrocharitaceae |
| *Leersia denudata* | 0.3 | Poaceae |
| *Leersia hexandra Swartz* | 0.2 | Poaceae |
| *Marsilea minuta* | 1.0 | Marsileaceae |
| *Nymphaea capensis* | 0.4 | Nympeceae |
| *Nymphaea lotus* | 0.3 | Nympeceae |
| *Nymphaea nouchali* | 0.8 | Nympeceae |
| *Oryza longistaminate* | 0.4 | Poaceae |
| *Phragmites mauritianum* | 0.6 | Poaceae |
| *Polygonum senegalensis* | 0.2 | Polygonaceae |
| *Pteridium aquilinum* | 0.3 | Dennstaedtiaceae |
| *Sesbania greenwayi* | 0.3 | Papilionaceae |
| *Trapa natans* | 0.8 | Trapaceae |
| *Typha capensis* | 0.2 | Typhaceae |
| *Urena lobata* | 0.1 | Malvaceae |
| *Utricularia foliosa* | 0.8 | Lentibulariaceae |
| *Vosia cuspidate (Roxb.) Grif* | 0.6 | Poaceae |

### 6.5.2. Fish

Comparing fish species list generated during the March 2010 field sampling in the Usangu Wetland, *Labeo cylindricus* caught at WBBM1 is the only species requiring fairly fast flowing waters. According to

Water for Africa (2008), *Chiloglanis* (which were not found in the Usangu wetland) are the most flow-sensitive fishes falling in the category of fast-rheophilic fishes and requiring fast-flowing water (≥ 0.3 m/s) during most phases of their life cycle.

Down below this scale are the lotic guild fishes including *Labeo* which require fairly fast-flowing water (≥ 0.2 m/s) during most phases of their life cycle, although they can survive the dry season drought years at velocities lower than 0.2 m/s. *Labeo* which were found in the Usangu wetland are longitudinal migrants that move within the main river channel or up and down tributaries as juveniles seek riffle/rapid habitats and adults inhabit both riffles and pools. They require relatively high dissolved oxygen levels (second to riffle guilds) and as such they are sensitive to reductions in water quality and may locally disappear under eutrophic conditions or when their river is dammed and prevents migration.

Fish requirements for various flows were set in terms of velocity, which was then converted to depth and discharge using hydraulic simulations generated by the Hydraulic Engineer, who was also a member of EFA Team. The motivations for each flow and the consequences of not providing them are also described for each site.

### 6.5.3. Invertebrates

There is a positive correlation between the river current and population density of sensitive macroinvertebrates. Out of 21 macroinvertebrate taxa collected in this study, 14 were highly tolerant to pollution, 6 were moderately tolerant, and 1 was a very low tolerance/highly sensitive taxa. *Helodidae* (Coleoptera) caught at WBBM2 was the only highly sensitive taxa encountered in this study. While nymphs of these species are favoured by high flow conditions (> 0.2 m/s), adults rely on marginal vegetation and are favoured by periodic inundation of the banks.

The recommended flows for WBBM1, 2, and 3 are given in Table 78 to Table 95.

### 6.5.4. WBBM Site 1 Nyaluhanga

**Dry season low flows for maintenance years (November) at WBBM 1**

**Table 78: Recommended flows for the dry season low flows for maintenance years (November) at WBBM1**

| Indicator | Average Velocity (m/s) | Average Depth (m) | Discharge ($m^3/s$) | Motivation | Consequences of not providing this flow |
|---|---|---|---|---|---|
| Fish | 0.20 | 1.11 | 40.0 | The low flows during the driest month of a mainrenance year are required to<br>• inundate more wetland habitats to increase habitat diversity<br>• inundate a greater area of the wetland channels to permit fish passage over obstacles<br>• inundate pools to improve water quality (more favourable habitats for fish).<br>Increased inundation of the main channel will provide a variety of habitats for resident fish species. This would provide more resources (space, food, etc) than that available during the dry season. This allows fish to grow faster. | Limit available habitats for *Labeo* and juveniles of *Barbus* sp occurring in that part of the river.<br>It may result in lowering fish standing biomass in that reach of the river. |
| Invert. | 0.15 | | | The low flows during the driest month of a mainrenance year are required to<br>• inundate more wetland habitats to increase habitat diversity.<br>• Enhance downstream drift of animals and flush out areas of poor quality water accumulated during the dry season. | Could curtail downstream drift of invertebrates and enhance mortalities due to poor water quality.<br>It may result in lowering macroinvertebrate standing biomass in that reach of the river. |
| Wetland vegetation** | | **1.11m** | $40m^3/s$ | • Nyaluhanga is a defined river with banks covered with riparian vegetation. | Lack of this flow diminishes the flow dependent species in the channel |

| | | | | | |
|---|---|---|---|---|---|
| | | | | • A specific flow with depth of 1.11m is required to allow the flow dependent riparian vegetation such as *Vosia cuspidata, Polygonum senegalensis Phragmites mauritianun, Ipomoea aquatica* and *Ceratophylum demerseum* to survive in the channel<br>• The most sensitive species in Nyaluhanga sites were *the Ipomoea aquatica* and *Ceratophylum demerseum*<br>• The riparian functions can be supported by this type of flow during maintenance years.<br>• At this flow there will be food resources available for aquatic life. | |

## Wet season low flows for maintenance years (April) at WBBM 1

**Table 79: Recommended flows for the wet season low flows for maintenance years (April) at WBBM1**

| Indicator | Average Velocity (m/s) | Average Depth (m) | Discharge ($m^3/s$) | Motivation | Consequences of not providing this flow |
|---|---|---|---|---|---|
| Fish | 0.24 | 1.12 | 50.0 | The low flows during the wettest month of a maintenance year are required to<br>• provide cue for migration and spawning in fishes such as *Labeo* and *Schilbe* found at this site.<br>• inundate vast areas of macrophytes and emergent vegetation along banks and increase habitat diversity (some fish and invertebrates need vegetation to deposit their eggs).<br>Increased habitat diversity would provide ample resources (shelter, food, hiding from predators, etc) enabling fish to attain good body condition index, fast growth rates and accumulate enough energy for successful spawning in the coming season. | Will curtail optimal growth rate for all fish species in the river reach and resulting in stunting growth and low fish standing biomass.<br><br>Adult fish which are poorly fed during resting period would have poor spawning and therefore poor recruitment success.<br><br>Failure in recruitment success of the resident fish species requiring upstream spawning migration such as *Labeo* and *Schilbe* found at this site. |
| Invert. | | | | • displace dominant competitors such as *chironomidae* found at this site and allow drift of species into new habitats.<br>The velocities and discharges described for fish are well above the requirements of most macroinvertebrate species found at the site, including the all moderately flow-sensitive species | Result in low macroinvertebrate species diversity due to uneven distribution of species (Community dominated by pollution tolerant species – *oligochaetes* and *chironomidae*). |
| Wetland vegetation** | | **1.12** | **50$m^3$/s** | • This depth is sufficient to support all plant species in the banks and the flood plains.<br>• A specific flow with depth of 1.12m | Lack of this flow will affect the survival of vegetation in seasonally flooded areas in the wetland. |

| | | | | | |
|---|---|---|---|---|---|
| | | | | (50m3/s). is required to allow the flow dependent riparian vegetation such as *Polygonum senegalensis Phragmites mauritianun, Ipomoea aquatica* and *Ceratophylum demerseum* to survive in the channel and trees pecies in the bank before the river enters the eastern Usangu wetland. | |

## Wet season high flows for maintenance years (April) at WBBM 1

**Table 80: Recommended flows for the wet season high flows for maintenance years – two floods (April) at WBBM1**

| Indicator | Average Velocity (m/s) | Average Depth (m) | Discharge ($m^3/s$) | Motivation | Consequences of not providing this flow |
|---|---|---|---|---|---|
| Fish | 0.31 | 1.12 | 65.0 | Two floods are required, one in March (one-time breeders) and another one in mid-wet season (April-May) for repeated breeders.<br>This flow is required to:<br>• maintain macro channel features and provide diversity of physical habitats for many species of fish found in the Usangu Wetland<br>• scour and flush the bed of sediment deposits.<br>• cue spawning migrants such as *Labeo* found at this site to start upstream spawning migration.<br>• inundate and recharge larger higher banks, allowing for nutrient transfer into the main wetland channel (increase primary productivity).<br>Three fish species caught at this site (*Labeo, Schilbe* and *Barbus*) have one breeding season a year that is closely linked to peak flows. *Labeo* and *Barbus* also rely on increased flow as cues for migration and maturation. For these species, one flood would be necessary at the beginning of rainy season to bring about maturation of gonads and trigger upstream spawning migration into suitable spawning grounds (e.g. small tributaries for *Labeo*). Another flood towards the end of wet season will be necessary to allow | Failure in recruitment success of the resident fish species such as *Labeo* and *Schilbe* requiring upstream spawning migration.<br><br>Less physical habitat due to sediment deposition on the river channel bed. |

| | | | | | |
|---|---|---|---|---|---|
| | | | | spawners and their young to drift back into the main river channel. | |
| Invert. | | | | The velocities and discharges described for fish are well above the requirements of most macroinvertebrate species found at the site, including the most sensitive species. | |
| Wetland vegetation** | | 1.120 | 65 | This flow is is needed for short periods in the rainy season and is important for:<br>• Flow dependant plant species that can perform at depth of 1.12m, including *Mimosa pygra, Ipomoea aquatica, Vosia cuspidata, Azolla nilotica, Polygonum senegalensis* and *Phragmites mauritianum*.<br>• Expansion of populations of flow dependant plant species.<br>• support and regeneration of woody plant species such as *A. albida, T. indica, C. apiculata, Acacia polyacantha* and *Ficus sur* in the bank. | Some of the woody species in the upper reach cannot perform and reproduce if this depth is not met |

## Dry season low flows for drought years (November) at WBBM 1

**Table 81: Recommended flows for the dry season low flows for drought years (November) at WBBM1**

| Indicator | Average Velocity (m/s) | Average Depth (m) | Discharge ($m^3/s$) | Motivation | Consequences of not providing this flow |
|---|---|---|---|---|---|
| Fish | 0.11 | 0.53 | 5.87 | The low flow during the driest month of a drought year are required to:<br>• maintain hydrological connectivity in the system (upstream-downstream)<br>• inundate an appreciable area of the wetland habitats (e.g. channels and pools), to sustain fairly flow-sensitive species of fish such as *Labeo cylindricus* and *Barbus* sp.<br><br>*Labeo* has a requirement for moderately swift flowing water with recommended minimal flow for survival given as ≥ 0.2 m/s, although they can survive the dry season drought years at velocities lower than that.<br>*Labeo cylindricus* was caught only from this site | Impaired upstream-downstream hydrological connectivity could threaten survival of *Labeo*<br><br>Young and immature stages of *Labeo* do not tolerate pools, and once inundation of riffles and channel connectivity is not maintained, their survival is threatened. |
| Invert. | 0.10 | | | The low flows during the driest month of a drought year are required to<br>• to inundate appreciable area of the critical wetland habitats to, at least, sustain moderately flow-sensitive species of macroinvertebrates such as freshwater shrimps (Actyidae), creeping water bugs (Naucoridae) and small minnow flies (Baetidae) which were collected from this site<br><br>Many of these moderately flow-sensitive | If these minimum flows cannot be met, some species will be lost. Some flow in the channel is necessary. |

| | | | | | |
|---|---|---|---|---|---|
| | | | | macroinvertebrates are eliminated when water flow (velocities) drops to 0.10 | |
| Wetland vegetation** | | **0.53m** | **5.87m/$^3$** | Nyaluhanga is a defined river and its banks are covered with riparian vegetation. A specific flow with a depth of 0.53m is required to allow the flow dependent riparian vegetation such as *Vosia cuspidata*, *Polygonum senegalensis,s Ipomoea aquatica* and *Ceratophylum demerseum* to survive in the channel.<br>The most sensitive species in Nyaluhanga sites were the *Ipomoea aquatica* and *Ceratophylum demerseum*<br>The riparian functions can be supported by this type of flow.<br>At this flow there will be food resources available for aquatic life. | Lack of this flow will affect much of the vegetation population on the banks and in the channelof the GRR. |

## Wet season low flows for drought years (April) at WBBM 1

**Table 82: Recommended flows for the wet season low flows for drought years (April) at WBBM1**

| Indicator | Average Velocity (m/s) | Average Depth (m) | Discharge ($m^3/s$) | Motivation | Consequences of not providing this flow |
|---|---|---|---|---|---|
| Fish | 0.20 | 1.11 | 40.0 | The low flows during the wettest month of a drought year are required to<br>• inundate more wetland habitats to increase habitat diversity<br>• inundate a greater area of the wetland channels to permit fish passage over obstacles<br>• inundate pools to improve water quality (more favourable habitats for fish).<br>Increased inundation of the main channel will provide a variety of habitats for resident fish species. This would provide more resources (space, food, etc) than that available during the dry season. This allows fish to grow faster. | Limit available habitats for *Labeo* and juveniles of *Barbus* sp occurring in that part of the river.<br>It may result in lowering fish standing biomass in that reach of the river. |
| Invert. | 0.15 | | | The low flows during the wettest month of a drought year are required to<br>• inundate more wetland habitats to increase habitat diversity.<br>• Enhance downstream drift of animals and flush out areas of poor quality water accumulated during the dry season. | Could curtail downstream drift of invertebrates and enhance mortalities due to poor water quality.<br>It may result in lowering macroinvertebrate standing biomass in that reach of the river. |
| Riparian vegetation** | | **1.11** | **40** | This is needed for short periods in the rain season and is important for:<br>• The survival of the woody species in the banks<br>• Population expansion of flow | Lack of this flow will affect the performance of woody species. |

| | | | | | |
|---|---|---|---|---|---|
| | | | | dependant plant species.<br>• A. albida, T. indica, C. apiculata, Acacia polyacantha, Ficus sur in the bank to continue to access water for photosynthesis.<br>The flow depended plant species that can perform at this depth include *Mimosa pygra*, *Polygonum senegalensis* and *Phragmites mauritianum*. | |

## Wet season high flows for drought years (April) at WBBM 1

**Table 83: Recommended flows for the wet season high flows for drought years (April) at WBBM1**

| Indicator | Average Velocity (m/s) | Average Depth (m) | Discharge ($m^3/s$) | Motivation | Consequences of not providing this flow |
|---|---|---|---|---|---|
| Fish | 0.29 | 1.12 | 60.0 | Small pulses of high flow that occur in the wet months are necessary to:<br>• prevent sediment build-up on river bed, thus increasing habitat variability for fish and invertebrates<br>• maintain active channel features<br>• flush out organic matter, thus improving water quality<br>• facilitate nutrient transfer between floodplains and the river<br>The floods will also help to flush out organic matter deposited on lower banks and small pools that would otherwise impact on water quality. | Curtail optimal growth rates of moderately flow-sensitive fish found here in terms of less living habitats and poor water quality. |
| Invert. | | | | The velocities and discharges described for fish are well above the requirements of most macroinvertebrate species found at the site, including the most sensitive species. | |
| Riparian vegetation** | | **1.12** | 60 | This flow is needed for short periods in the rain season, and is important for:<br>• the survival of the woody species<br>• population expansion of flow dependant plant species.<br>At this point some of the exposed roots of the wood plant species will be inundated in water allowing woody plant species such as *A. albida, T. indica, C. apiculata, Acacia polyacantha, Ficus sur* in the bank to continue to access water for | Lack of these flows will affect the riparian vegetation population on the river bank of the upper reach, with the loss of the major functions it performs. |

| | | | | | |
|---|---|---|---|---|---|
| | | | | photosynthesis.<br>The flow dependant plant species that can perform at this depth include *Vosia cuspidata*, *Ipomoea aqautica*, *Azolla nilotica*, *Polygonum senegalensis* and *Phragmites mauritianum*. | |

### 6.5.5. WBBM Site 2 Ruaha Ponds

**Dry season low flows for maintenance years (November) at WBBM2**

**Table 84: Recommended flows for the dry season low flows for maintenance years (November) at WBBM2**

| Indicator | Average Velocity (m/s) | Average Depth (m) | Discharge ($m^3/s$) | Motivation | Consequences of not providing this flow |
|---|---|---|---|---|---|
| Fish | 0.00 | 0.64 | 5.0 | The low flows during the driest month of a maintenance year are required to<br>• inundate more wetland habitats to increase habitat diversity<br>• inundate a greater area of the wetland channels to permit fish passage over obstacles<br>• inundate pools to improve water quality (more favourable habitats for fish).<br>Increased inundation of the main channel will provide a variety of habitats for resident fish species such as *Oreochromis rukwaensis*. This would provide more resources (space, food, etc) than that available during the dry season. This allows fish to grow faster. | Threatened survival of fish in the situations where flows are curtailed and ponds are not deep enough to prevent rising water temperatures.<br><br>Limit available habitats for resident fish occurring in that part of the river.<br><br>It may result in lowering fish standing biomass in that reach of the river. |
| Invert. | 0.00 | 0.64 | 5.0 | The low flows during the driest month of a maintenance year are required to<br>• inundate more wetland habitats to increase habitat diversity.<br>• enhance downstream drift of animals and flush out areas of poor quality water accumulated during dry season low flow | Could curtail downstream drift of invertebrates and enhance mortalities due to poor water quality.<br><br>It may result in lowering macroinvertebrate standing biomass in that reach of the river. |
| Wetland | | **0.64** | 5 .0 | Perennial swamps including seasonally | The wetland vegetation functions |

| | | | | | |
|---|---|---|---|---|---|
| vegetation** | | | | flooded areas act as a reservoir in the dry season, supporting a variety of vegetation communities which cover most of the open waters.<br>Flow is needed throughout the season to maintain the performance of hydrophytes and high diversity of flow dependent species<br>A depth of 0.64m and to allow hydrophytes such as *Trapa natans, Urtica masaica*, *Utricularia foliosa*, *Vosia cuspidata*, *Polygonum senegalensis Lagarosiphone ilicifolius* and *Ceratophylum demersum* to survive in the shrinking swamps.<br>Most of these species are sensitive to change in volume of water in the swamps. | cannot be supported if this type of flow is not maintained. |

## Wet season low flows for maintenance years (April) at WBBM2

**Table 85: Recommended flows for the wet season low flows for maintenance years (April) at WBBM2**

| Indicator | Average Velocity (m/s) | Average Depth (m) | Discharge ($m^3/s$) | Motivation | Consequences of not providing this flow |
|---|---|---|---|---|---|
| Fish | 0.00 | 0.82 | 9.00 | The low flows during the wettest month of a maintenance year are required to<br>• inundate vast areas of macrophytes and emergent vegetation along banks and increase habitat diversity for *Oreochromis rukwaensis* and *Clarias gariepinus* found at this site.<br>Increased habitat diversity would provide ample resources (shelter, food, hiding from predators, etc) enabling fish to attain good body condition index, fast growth rates and accumulate enough energy for successful spawning in the coming season. | Will curtail optimal growth rate for all fish species in the river reach and resulting in stunting growth and low fish standing biomass.<br><br>Adult fish which are poorly fed during resting period would have poor spawning and therefore poor recruitment success. |
| Invert. | | | | • displace dominant competitors such as *chironomidae* found at this site and allow drift of species into new habitats.<br>The velocities and discharges described for fish are well above the requirements of most macroinvertebrate species found at the site, including the all moderately flow-sensitive species | Result in low macroinvertebrate species diversity due to uneven distribution of species (Community dominated by pollution tolerant species – *oligochaetes* and *chironomidae*). |
| Wetland vegetation** | | **0.820m** | **9** | This flow is required to maintain communities in the perennial swamps. Water can now spill over the edges of swamps to the rest of the wetland where the seasonally inundated vegetation communities can rejuvenate.<br>Other plants that need less turbidity can | This flow is suitable to support sedge communities that form mats in the areas closer to the perennial swamps. Lack of this flow will result in decreased plant communities in the perennial swamps and biodiversity is threatened in that regard |

| | | | | | |
|---|---|---|---|---|---|
| | | | | regenerate successful. Species such as *Trapa natans, Urtica masaica*, *Utricularia foliosa*, *Vosia cuspidata*, *Polygonum senegalensis Lagarosiphone ilicifolius* and *Ceratophylum demersum* in the swamps *and Nymphaea lotus, Sesbania greenwayi, and Oryza longistaminata* can get the minimum water they require for growth and reproduction. | |

## Wet season high flows for maintenance years (April) at WBBM2

**Table 86: Recommended flows for the wet season high flows for maintenance years – two floods (April) at WBBM2**

| **Indicator** | **Average Velocity (m/s)** | **Average Depth (m)** | **Discharge ($m^3/s$)** | **Motivation** | **Consequences of not providing this flow** |
|---|---|---|---|---|---|
| Fish | 0.00 | | 11.0 | Two floods are recommended, one in March (one-time breeders) and another one in mid-wet season (April-May) for repeated breeders.<br>This flow is required to:<br>• maintain macro channel features and provide diversity of physical habitats for many species of fish found in the Usangu Wetland<br>• scour and flush the bed of sediment deposits.<br>• inundate and recharge larger higher banks, allowing for nutrient transfer into the main wetland channel (increase primary productivity).<br>*Oreochromis* sp caught at this site are generally repeat breeders, although in drought years may even breed during low flow phases of the hydrograph.<br>For *Oreochromis*, 2 flood flows in the wet season would be advantageous for their repeated spawning habits. | Failure in recruitment success of the resident fish species such as *Oreochromis rukwaensis* found at this site.<br><br>Less physical habitat due to sediment deposition on the river channel bed. |
| Invert. | | | | The velocities and discharges described for fish are well above the requirements of most macroinvertebrate species found at the site, including the most sensitive species. | |
| Wetland | | **1.5** | 35 | The swamps are covered with water lilies | At this point wetland vegetation |

| | | | | | |
|---|---|---|---|---|---|
| vegetation** | | | | (hydrophytes).<br>The high diversity of flow dependent species needs flow for growth and population expansion.<br>The wet seasonal conditions are suitable for growth and reproduction. The depth of 1.5m allows hydrophytes such as *Trapa natans, Urtica masaica*, *Utricularia foliosa*, *Vosia cuspidata*, *Polygonum senegalensis Lagarosiphone ilicifolius* and *Ceratophylum demersum* to grow and expand in their populations when their area cover has increased<br>Most of these species are sensitive to changes in the volume of water in the swamps and hence during the wet season the volume increases and habitat conditions are met for their performance. Also seasonally inundated vegetation can luxuriantly grow, expand and perform under flooding conditions | needs to be flooded by this type of flow.<br>This flow helps to flush organic matter from the system and hence diminishes the effect of oxygen reduction through microbial activities.<br>This organic debris flushed downstream becomes available as a food resource for aquatic life including macroinvertebrates<br>Lack of all these will significantly affect the functions mentioned. |

## Dry season low flows for drought years (November) at WBBM2

**Table 87: Recommended flows for the dry season low flows for drought years (November) at WBBM2**

| Indicator | Average Velocity (m/s) | Average Depth (m) | Discharge ($m^3/s$) | Motivation | Consequences of not providing this flow |
|---|---|---|---|---|---|
| Fish | 0.00 | 0.52 | 3.0 | The low flow during the driest month of a drought year are required to:<br>• maintain hydrological connectivity in the system (upstream-downstream)<br>• inundate an appreciable area of the wetland habitats (e.g. channels and pools), to sustain fish species such as *Oreochromis rukwaensis* caught at this site.<br>In the worst drought years *Oreochromis* and *Clarias gariepinus* can grow well in ponds with "zero" flow for several months during the dry season. What is important, in this case, is to have appreciable water depth in the ponds to cushion rises in water temperature. | Threatened survival in the situations where flows are curtailed and ponds are not deep enough to prevent rising water temperatures. |
| Invert. | 0.00 | 0.52 | 3.0 | The low flows during the driest month of a drought year are required to<br>• to inundate appreciable area of the critical wetland habitats to sustain highly flow-sensitive species of macroinvertebrates which was only caught at this site - *Helodidae*.<br>*Helodidae* are found under rocks, stones and amongst dead leaves in swift flowing streams. | Could have catastrophic effect in the event when flows drop below 0.15 m/s for prolonged period of time. |
| Wetland vegetation** | | **0.52m** | **3m³/s** | Swamps are water reservoirs along the Ruaha channel and are covered with hydrophytes. | Lack of this flow will decrease significantly the permanent water dependent plant species in the |

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| | | | | The high diversity of flow dependent species need low flows for survival.<br>This flow assists in the reduction of organic matter, as most wetland vegetation will not be inundated with water, allowing decomposition of debris to take place.<br>The drought year conditions are only suitable for survival at depth of 0.52m (3**m**$^3$/**s**) allowing hydrophytes such as *Trapa natans, Utricularia foliosa*, *Polygonum senegalensis*, *Lagarosiphone ilicifolius* and *Ceratophylum demersum* to survive in the shrinking swamps. | system. |

## Wet season low flows for drought years (April) at WBBM2

**Table 88: Recommended flows for the wet season low flows for drought years (April) at WBBM2**

| **Indicator** | **Average Velocity (m/s)** | **Average Depth (m)** | **Discharge ($m^3/s$)** | **Motivation** | **Consequences of not providing this flow** |
|---|---|---|---|---|---|
| Fish | 0.00 | 0.64 | 5.0 | The low flows during the wettest month of a drought year are required to<br>• inundate more wetland habitats to increase habitat diversity<br>• inundate a greater area of the wetland channels to permit fish passage over obstacles<br>• inundate pools to improve water quality (more favourable habitats for fish).<br>Increased inundation of the main channel will provide a variety of habitats for resident fish species such as *Oreochromis rukwaensis*. This would provide more resources (space, food, etc) than that available during the dry season. This allows fish to grow faster. | Survival of fish is threatened in situations where flows are curtailed and ponds are not deep enough to prevent rising water temperatures.<br><br>Limited available habitats for resident fish occurring in that part of the river.<br><br>It may result in lowering fish standing biomass in that reach of the river. |
| Invert. | 0.00 | 0.64 | 5.0 | The low flows during the wettest month of a drought year are required to<br>• inundate more wetland habitats to increase habitat diversity.<br>• enhance downstream drift of animals and flush out areas of poor quality water accumulated during dry season low flow | Could curtail downstream drift of invertebrates and enhance mortalities due to poor water quality.<br><br>It may result in lowering macroinvertebrate standing biomass in that reach of the river. |
| Riparian vegetation** | | **0.64m** | **$5m^3/s$** | The swamps are covered with water lilies (hydrophytes).<br>The high diversity of flow dependent | The wetland vegetation persistence is supported by this type of flow.<br>At this flow there will be available for |

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| | | | | species needs this flow for growth and population expansion.<br>The wet seasonal conditions are suitable for growth and reproduction.<br>The depth of 0.64m (**5m3/s**) allows populations of hydrophytes such as *Trapa natans, Urtica masaica*, *Utricularia foliosa*, *Vosia cuspidata*, *Polygonum senegalensis Lagarosiphone ilicifolius* and *Ceratophylum demersum* to grow and expand when the area covered has increased<br>Most of these species are sensitive to changes in volume of water. During the wet season, the volume increases and habitat conditions are met for their performance.<br>The wetland vegetation functions are supported by this type of flow. | source for aquatic life.<br>Lack of these flows can lead to a serious negative consequence in terms of abundance of water lilies |

## Wet season high flows for drought years (April) at WBBM2

**Table 89: Recommended flows for the wet season high flows for drought years (April) at WBBM2**

| Indicator | Average Velocity (m/s) | Average Depth (m) | Discharge ($m^3/s$) | Motivation | Consequences of not providing this flow |
|---|---|---|---|---|---|
| Fish | 0.00 | 0.82 | 9.00 | Small pulses of high flow that occur in the drier months are necessary to:<br>• prevent sediment build-up on river bed, thus increasing habitat variability for fish and invertebrates<br>• maintain active channel features<br>• flush out organic matter, thus improving water quality<br>• facilitate nutrient transfer between floodplains and the river<br>The floods will also help to flush out organic matter deposited on lower banks and small pools that would otherwise impact on water quality. | Curtail optimal growth rates of *Oreochromis rukwaensis* found here in terms of fewer habitats and poor water quality. |
| Invert. | | | | The velocities and discharges described for fish are well above the requirements of most macroinvertebrate species found at the site, including the most sensitive species. | |
| Wetland vegetation** | | **0.82** | **9$m^3$/s** | The swamps are covered with water lilies (hydrophytes).<br>The high diversity of flow dependent species needs this flow for growth and population expansion.<br>The wet seasonal conditions are suitable for growth and reproduction.<br>The depth of 0.82m allows hydrophytes such as *Trapa natans, Urtica masaica*, | The system can underperform if the recommended depth is not reached.<br>The wetland vegetation functions are supported by this type of flow. |

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|---|---|---|---|---|---|
| | | | | *Utricularia foliosa*, *Vosia cuspidata*, *Polygonum senegalensis* *Lagarosiphone ilicifolius* and *Ceratophylum demersum* to grow and expand in their populations when the area covered has increased<br>Most of these species are sensitive to change in the volumes of water in the swamps<br>During the wet season, the volumes increase and habitat conditions are met for their performance. | |

### 6.5.6. WBBM Site 3 Ng'iriama

**Dry season low flows for maintenance years (November) at WBBM3**

**Table 90: Recommended flows for the dry season low flows for maintenance years (November) at WBBM3**

| Indicator | Average Velocity (m/s) | Average Depth (m) | Discharge ($m^3/s$) | Motivation | Consequences of not providing this flow |
|---|---|---|---|---|---|
| Fish | 0.01 | 0.42 | 8.1 | The low flows during the driest month of a maintenance year are required to<br>• inundate more wetland habitats to increase habitat diversity<br>• inundate a greater area of the wetland channels to permit fish passage over obstacles<br>• inundate pools to improve water quality (more favourable habitats for fish).<br>Increased inundation of the main channel will provide a variety of habitats for resident fish species such as *Oreochromis urolepis*. This would provide more resources (space, food, etc) than that available during the dry season. This allows fish to grow faster. | Threatened survival of fish in the situations where flows are curtailed and ponds are not deep enough to prevent rising water temperatures. |
| Invert. | 0.01 | 0.42 | 8.1 | The low flows during the driest month of a maintenance year are required to<br>• inundate more wetland habitats to increase habitat diversity.<br>• enhance downstream drift of animals and flush out areas of poor quality water accumulated during dry season low flow | Could curtail downstream drift of invertebrates and enhance mortalities due to poor water quality.<br><br>It may result in lowering macroinvertebrate standing biomass in that reach of the river. |
| Wetland vegetation** | | **0.42** | **8.10** | Ng'iriama contains a very low diversity of flow dependent species. During the dry | Lack of this flow causes the vegetation functions in the lower |

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| | | | | season this site experiences unfavourable conditions to support plants for an extended period of time.<br>The dry season low flow conditions for maintenance years that are suitable for survival wetland plant species requires a depth of 0.33m.<br>This can support the survival of hydrophytes such as *Vosia cuspidata, Nymphaea capensis,* and *Aeschynomene indica* at this site. Most of these species are sensitive to flow change, and die back during the dry seasonal because conditions do not favour their survival and performance.<br>For survival and performance of these species, a flow of 8.10m3/s is recommended. | reaches to be significantly affected. The plant species diversity cannot increase on this site |

## Wet season low flows for maintenance years (April) at WBBM3

**Table 91: Recommended flows for the wet season low flows for maintenance years (April) at WBBM3**

| Indicator | Average Velocity (m/s) | Average Depth (m) | Discharge ($m^3$/s) | Motivation | Consequences of not providing this flow |
|---|---|---|---|---|---|
| Fish | 0.01 | 0.75 | 20.1 | The low flows during the wettest month of a maintenance year are required to<br>• inundate vast areas of macrophytes and emergent vegetation along banks and increase habitat diversity for *Oreochromis urolepis* and *Clarias gariepinus* found at this site.<br>Increased habitat diversity would provide ample resources (shelter, food, hiding from predators, etc) enabling fish to attain good body condition index, fast growth rates and accumulate enough energy for successful spawning in the coming season. | Will curtail optimal growth rate for all fish species in the river reach and resulting in stunting growth and low fish standing biomass.<br><br>Adult fish which are poorly fed during resting period would have poor spawning and therefore poor recruitment success. |
| Invert. | | | | • displace dominant competitors such as *oligochaetes* and *chironomidae* found at this site and allow drift of species into new habitats.<br>The velocities and discharges described for fish are well above the requirements of most macroinvertebrate species found at the site, including the all moderately flow-sensitive species | Result in low macroinvertebrate species diversity due to uneven distribution of species (Community dominated by pollution tolerant species – *oligochaetes* and *chironomidae*). |
| Wetland vegetation** | | 0.**75** | **20.10** | This flow is sufficient to allow flow sensitive hydrophytes e.g. *Vosia cuspidata*, *Nymphaea capensis*, *Aeschynomene indica* to perform at a reasonable rate.<br>This flow which should be sustained for most of the period | The most sensitive species will be affected largely at this point |

## Wet season high flows for maintenance years (April) at WBBM3

**Table 92: Recommended flows for the wet season high flows for maintenance years – two floods (April) at WBBM3**

| Indicator | Average Velocity (m/s) | Average Depth (m) | Discharge ($m^3/s$) | Motivation | Consequences of not providing this flow |
|---|---|---|---|---|---|
| Fish | 0.31 | 1.12 | 65 | Two floods, one in March (one-time breeders) and another one in mid-wet season (April-May) for repeated breeders.<br>This flow is required to:<br>• maintain macro channel features and provide diversity of physical habitats for many species of fish found in the Usangu Wetland<br>• scour and flush the bed of sediment deposits.<br>• inundate and recharge larger higher banks, allowing for nutrient transfer into the main wetland channel (increase primary productivity).<br>*Oreochromis* sp caught at this site are generally repeat breeders, although in drought years may even breed during low flow phases of the hydrograph.<br>For *Oreochromis*, 2 flood flows in the wet season would be advantageous for their repeated spawning habits. | Failure in recruitment success of the resident fish species such as *Oreochromis urolepis* found at this site.<br><br>Less physical habitat due to sediment deposition on the river channel bed. |
| Invert. | | | | The velocities and discharges described for fish are well above the requirements of most macroinvertebrate species found at the site, including the most sensitive species. | |

| | | | | | |
|---|---|---|---|---|---|
| Wetland vegetation** | | **1.03m** | **35.10** | The vegetation at Ng'iriama is supported by water filling the small pools in the watercourse and expanding their coverage<br>The low diversity of flow dependent species is due to unfavourable habitats caused by rock outcrops and lack of flows.<br>The wet season provides conditions suitable for the expansion of the few available flow dependent species such as *Nymphaea capensis* and *Aeschynomene indica*.<br>The recommended depth of **1.03m** (**35.10m$^3$/s)** allows these species to survive and perform at Ng'iriama. | Lack of this flow will cause he population of these species to be arrested. |

## Dry season low flows for drought years (November) at WBBM3

### Table 93: Recommended flows for the dry season low flows for drought years (November)

| Indicator | Average Velocity (m/s) | Average Depth (m) | Discharge ($m^3/s$) | Motivation | Consequences of not providing this flow |
|---|---|---|---|---|---|
| Fish | 0.01 | 0.28 | 4.10 | The low flow during the driest month of a drought year are required to:<br>• maintain hydrological connectivity in the system (upstream-downstream)<br>• inundate an appreciable area of the wetland habitats (e.g. channels and pools), to sustain fish species such as *Oreochromis urolepis* caught at this site.<br>In the worst drought years *Oreochromis urolepis* and *Clarias gariepinus* can grow well in ponds with “zero” flow for several months during the dry season. What is important, in this case, is to have appreciable water depth in the ponds to cushion rises in water temperature. | Threatened survival in the situations where flows are curtailed and ponds are not deep enough to prevent rising water temperatures. |
| Invert. | 0.01 | 0.28 | 4.10 | The low flows during the driest month of a drought year are required to inundate appreciable area of the critical wetland habitats to, at least, sustain moderately flow-sensitive species of macroinvertebrates such as Elmidae, Hydracarina and small minnow flies (Baetidae) which were collected from this site. | Could have catastrophic effect in the event when flows drop below 0.15 m/s for prolonged period of time. |
| Wetland vegetation** | | **0.28m** | **4.10** | Ng’iriama is a sloping area with rocky outcrops which lacks flow in the dry season.<br>The small pools in the watercourse have | The vegetation functions in these lower reaches can be supported by this type of flow.<br>Lack of this flow will be a problem in |

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| | | | | very little vegetation cover.<br>There is a low diversity of flow dependent species, as this area experiences unfavourable conditions to support plants for extended period of time.<br>The drought year conditions are suitable for survival only at a depth of 0.28m (**4.10$m^3$/s)** allowing hydrophytes such as *Vosia cuspidata*, *Nymphaea capensis, Aeschynomene indica* to survive.<br>Most of these species are sensitive to changes in flow and die back during the dry season since the area is not suitable for their survival and performance at such times.<br>For survival and performance of these species, the recommended depth above needs to be maintained. | terms of biodiversity at Ng'iriama |

## Wet season low flows for drought years (April) at WBBM3

**Table 94: Recommended flows for the wet season low flows for drought years (April)**

| **Indicator** | **Average Velocity (m/s)** | **Average Depth (m)** | **Discharge ($m^3/s$)** | **Motivation** | **Consequences of not providing this flow** |
|---|---|---|---|---|---|
| Fish | 0.01 | 0.42 | 8.1 | The low flows during the wettest month of a drought year are required to<br>• inundate more wetland habitats to increase habitat diversity<br>• inundate a greater area of the wetland channels to permit fish passage over obstacles<br>• inundate pools to improve water quality (more favourable habitats for fish).<br>Increased inundation of the main channel will provide a variety of habitats for resident fish species such as *Oreochromis urolepis*. This would provide more resources (space, food, etc) than that available during the dry season. This allows fish to grow faster. | Threatened survival of fish in the situations where flows are curtailed and ponds are not deep enough to prevent rising water temperatures. |
| Invert. | 0.01 | 0.42 | 8.1 | The low flows during the wettest month of a drought year are required to<br>• inundate more wetland habitats to increase habitat diversity.<br>• enhance downstream drift of animals and flush out areas of poor quality water accumulated during dry season low flow | Could curtail downstream drift of invertebrates and enhance mortalities due to poor water quality.<br><br>It may result in lowering macroinvertebrate standing biomass in that reach of the river. |
| Riparian vegetation** | | **0.42m** | **5** | The vegetation cover at Ng'iriama is supported by water filling the small pools in the watercourse and expanding their coverage. | The survival of the species named in this table can be threatened if the above needs are not maintained. |

| | | | | | |
|---|---|---|---|---|---|
| | | | | The low diversity of flow dependent species is due to unfavourable habitats caused by rock outcrops and lack of flows.<br>The wet season provides conditions suitable for the expansion of the few available flow dependent species such as *Vosia cuspidata*, *Nymphaea capensis, Aeschynomene indica*.<br>The depth of 0.42m (**5m$^3$/s**) allows these species to survive and perform at Ng'iriama. | |

## Wet season high flows for drought years (April) at WBBM3

**Table 95: Recommended flows for the wet season high flows for drought years (April) at WBBM3**

| Indicator | Average Velocity (m/s) | Average Depth (m) | Discharge ($m^3/s$) | Motivation | Consequences of not providing this flow |
|---|---|---|---|---|---|
| Fish | 0.01 | 0.50 | 10.1 | Small pulses of high flow that occur in the drier months are necessary to:<br>• prevent sediment build-up on river bed, thus increasing habitat variability for fish and invertebrates<br>• maintain active channel features<br>• flush out organic matter, thus improving water quality<br>• facilitate nutrient transfer between floodplains and the river<br>The floods will also help to flush out organic matter deposited on lower banks and small pools that would otherwise impact on water quality. | Curtail optimal growth rates of *Oreochromis urolepis* found here in terms of less living habitats and poor water quality. |
| Invert. | | | | The velocities and discharges described for fish are well above the requirements of most macroinvertebrate species found at the site, including the most sensitive species. | |
| Riparian vegetation** | | **0.5m** | **10.10** | The vegetation cover at Ng'iriama is supported by water filling the small pools in the watercourse and expanding in their coverage.<br>The low diversity of flow dependent species is due to unfavourable habitats caused by rock outcrops and lack of flows.<br>The wet season provides conditions suitable for the expansion of the few | For survival and performance of these species, the recommended depth above needs to be maintained.. Below it will cause a very significant decreased in diversity in the lower reaches |

| | | | | | |
|---|---|---|---|---|---|
| | | | | available flow dependent species such as *Vosia cuspidata*, *Nymphaea capensis, Aeschynomene indica*. The depth of 0.5m (**10.10m³/s)** will allow these species to survive and perform at Ng'iriama. | |

## 6.6. *Confidence in the wetlands assessment*

Table 96 shows the level of confidence in the assessment of riparian vegetation, fish and invertebrates at WBBM1, 2, and 3 in during the Eastern Wetland survey. Confidence is rated on a scale of 1 to 5, where 5 represents very high confidence, and 1 represents very low confidence.

**Table 96: Confidence in the assessment of riparian vegetation, fish and invertebrates at WBBM1, 2, and 3**

| Site | Component | Confidence rating | Motivation |
|---|---|---|---|
| WBBM1 Nyaluhanga | | | |
| | Riparian vegetation | 5 | The information gathered at this site fully describes the riparian vegetation upstream of the Eastern Usangu wetland. The plant species on the riverbank and in the channel were exhaustively identified and the riparian functions they perform in this area were assessed fully: No further data collection is required |
| | Fish<br>Invertebrates | 4<br>4 | Only one season (flow) was sampled and few hours (less than 5 hours) were spent in each sampling site<br>Experience in Tanzania show that the number of fish caught in wetland systems differ between wet and dry season when the area of inundation of the wetland shrinks. |
| WBBM2 Ruaha Ponds | | | |
| | Riparian vegetation | 5 | Data gathering was done in the wet season which is best for the identification of most of the flow-dependent plant species. The EMC and recommended flows for WBBM2 are realistic, since the representative hydrophytes that persist in the channel or swamps were thoroughly sampled. The relationships between the wetland plant species compositional response to the current flows and habitat conditions were established, with no need for further data collection. |
| | Fish<br>Invertebrates | 4<br>4 | Just one season (flow) was sampled and few hours (less than 5 hours) were spent in each sampling site<br>Experience in Tanzania show that the number of fish caught in wetland systems |

| | | | |
|---|---|---|---|
| | | | differ between wet and dry season when the area of inundation of the wetland shrinks. |
| WBBM3 Ng'iriama | | | |
| | Riparian vegetation | 3 | The diversity index and vegetation communities represent the characteristics of the WBBM site. Therefore the flows recommended in this site are adequate, and will be the basis for restoring the modified habitat in WBBM3 due to extended lack of flows. There is no need to collect more data to enrich the present information since the data gathered at WBBM3 is suitable for monitoring changes in the system. |
| | Fish<br>Invertebrates | 4<br>4 | Just one season (flow) was sampled and few hours (less than 5 hours) were spent in each sampling site<br>Experience in Tanzania show that the number of fish caught in wetland systems differ between wet and dry season when the area of inundation of the wetland shrinks. |

## *6.7. Priorities for further information*

### 6.7.1. Hydrology

**Data**

Several data sets were used in this study to carry out different analyses. However, long reliable data sets, including the climatic data used in the analyses, had to be taken from a farther location in Dodoma. No flow record was available for the Kimbi River, and groundwater records around the Ihefu wetlands were missing.

This study used data from several sources that required a close analysis of quality before they could be used. Despite such rigorous checks, the quality of some discharge data was affected by the period of rating measurements as well as daily stage observations that would have led to underestimation of discharges. This was particularly the case for very important locations, i.e. the inflow point at Nyaluhanga, and the outflow at Ng'iriama.

The number of rating measurements at these two key flow measurement locations need to increase in order to improve the quality and reliability of the rating curves for the Ihefu wetlands. The recommended measurements must include as many measurements as possible during the high flows and, if possible, during all major floods.

Moreover, the available data contained a number of missing values, as well as flow gauges were located at upstream reaches This left a significant part of the catchment ungauged, necessitating the use of extrapolation methods to determining catchment outflows. For this, some spot measurements at catchment outlets could assist as benchmarks for checking the quality of estimated discharges.

Owing to several estimations carried out in this study, there is an urgent need to harmonise data, observations and analysis methods to produce single data series of good quality for the future refinement of the wetlands hydrological analyses. This could include additional bathymetric surveys to eliminate errors in the estimation of wetlands area and storage, variables which are important for wetlands water balance studies.

### Monitoring

The accurate estimation of wetlands inflows and outflows requires that the various components of the wetlands water balance are in turn accurately measured and/or estimated. It is therefore recommended that the observation network should be improved to monitor the water balance components around the Ihefu wetlands. The improvements should include:

i) Continuous flow measurements of the Kimbi River upstream of the fan (flow gauging station recommended)

ii) Flow measurements of the Kioga River downstream of the Ruaha/Hukuni confluence (flow gauging station or periodic spot measurements for all flow seasons recommended)

iii) Groundwater observation wells around the Ihefu wetlands (at least two, and preferably four, on either side of the wetlands)

iv) Climate monitoring station close to wetlands (preferably at Rujewa)

### Additional studies

Groundwater flows and evapotranspiration were estimated based respectively on water balance modelling and on the Thornthwaite/Penman-Monteith methods. Owing to several deficiencies in data that was used in the analyses, the accuracy of the estimated values of these two components would be questionable pending thorough verification and refinement.

Therefore, further studies are recommended to accurately establish the groundwater contributions/losses (seepage, percolation, etc.) from field plot investigations. Similarly, field evapotranspiration measurements are recommended to establish the daily amount of water that is lost from the wetlands in different seasons of the year, and the impact of alien invasive plant species on this.

### 6.7.2. Hydraulics

All the analyses in this report assume a steady flow conditions, and that the state of flow in the study reach is classified as subcritical. However, it has been observed that the sill at Ng'iriama (WBBM3) is not effective as weir or dam during low to medium flow conditions. It is also acknowledged by the hydraulic specialist that higher resolution topographic data is still required as the left floodplain of the wetland is fairly represented. Such data could not be readily retrieved from SMUWC database as anticipated.

The DEM, even after calibrating, could not capture the typical terrain of the wetlands. Therefore, in order to improve the performance of the model, detailed fieldwork in terms of a topographic data survey on the flood plains and main channels in some parts of the river reach is recommended.

Another limitation in this study comes from the fact that water quality analysis relied entirely upon secondary data, sampled a decade ago. Considering that there have been significant changes in catchment management and social economic activities it is obvious that recent data on water quality is inevitably required and therefore sampling programme recommended.

Further fieldwork to undertake additional geometry measurements, especially in the western side of the wetland, are recommended. This would improve the geometric representation and hence the accuracy of the developed relationships in the entire wetland, as such data could not be readily retrieved from SMUWC database as anticipated.

### 6.7.3. Geomorphology

Much of the available geomorphological data and information appears to be outdated, giving rise to the need for surveys that will reflect recent changes in the geomorphology of the wetland.

### 6.7.4. Riparian vegetation

The open water areas should be used for long term monitoring of the wetland vegetation changes, i.e. changes in area covered, community composition, and cover of water lilies.

The typical wetland species composition at the perennial swamps was high. The data on which the current status of the wetland is based should be used as a baseline for future monitoring of the wetland in terms of vegetation community changes that can be easily identified through changing in area cover in the open waters.

It is presumed that the system community has been highly transformed (due to disturbances) as compared to its historical state. The representative permanent flow dependent plant species should be monitored for changes in their populations once the recommended minimum volume is available in the wetland.

### 6.7.5. Fish and invertebrates

Sampling in different flows (wet and low flows in a calendar year), is still required, as well as a few more hours of sampling (possibly 2 days of sampling spent in one site).

### 6.7.6. Water quality

The water quality analysis relied entirely upon the secondary data that was sampled a decade ago. Considering that there have been significant changes in catchment management and social economic activities it is obvious that recent data on water quality is inevitably required, and therefore a water quality sampling programme is recommended.

One aspect of this concerns the effects of fertilisers on the wetland: In addition to data on soil properties, more sampling aimed at providing a better understanding of the sources, levels and impacts of both organic and inorganic fertilisers, which may lead to eutrophication.

## *6.8. Findings*

The low flow period in catchment of Ihefu wetlands varies between years, and usually occurs within one year (between June and December) although the low flow period extended between years as observed in 1966/67. Thresholds differentiating wet, normal and dry years indicated several drier than normal years particularly in the 2000s and few wet years including the 1967/68. The extended drier than normal conditions were attributed mainly to delayed rainfall resulting into progressively declined low flows through January and sometime February.

Wet years on the other hand resulted into higher low flow discharges. The size of the wetlands during the low flow period has varied between 18 and 68 $km^2$ while its stored volume has varied between 16 and 97 $Mm^3$. The lowest annual size of the wetlands depended on the classification of year whether it is a normal, wet or dry year. Wet years with slowly receding flow hydrograph resulted in larger wetland size during the low flow than the size at the end of a prolonged drier low flow period in a dry year.

Low flow water balancing of the Eastern wetlands indicated the dominance of inflows of the GRR and evapotranspiration as the major components controlling the wetlands hydrology during the period between 1999 and 2009. An attempt to estimate the contribution of groundwater into wetlands water balance indicated a small net loss of 0.002-2.559 $m^3/s$ during the low flow periods over the 1999-2009 analysis period.

A total inflow into Eastern wetland of 5.52-6.81 $m^3/s$ is required to sustain an outflow of 1-2 $m^3/s$ past N'Giriama.

### 6.8.1. Impact of construction of an impoundment on the Ndembera River (Lugoda Dam)

The option of supplying the wetland with flows from the proposed Lugoda reservoir (to be located on the Ndembera River) was explored for the drought low flow conditions, as achieving a satisfactory flow during drought low flow conditions will guarantee sufficient flows during low flow periods in normal and wet years.

The requirement to maintain a minimum outflow discharge of 1 $m^3/s$ at Ng'iriama was investigated by computing the total daily outflows from the Ihefu wetlands that must be balanced by the total inflow into the wetlands. For the fixed wetlands water surface elevation at 1009.704 masl that produce a Ng'iriama outflow discharge of 1 $m^3/s$, the total outflows from the wetlands between 1st July and 31st December 2003 varied between 5.08 and 5.52 $m^3/s$.

For an outflow of 2 $m^3/s$ that would reliably ensure availability of at least 1 $m^3/s$ at RNP EF site, the total inflows into the wetlands for the 2003 conditions would be between 6.31 and 6.81 $m^3/s$.

Therefore, to maintain an outflow at Ng'iriama of at least 1 $m^3/s$, a total surface water inflow of at least 5.52 $m^3/s$ is required. However, for a 1 $m^3/s$ flow through the RNP, an inflow of at least 6.81 $m^3/s$ should enter the wetlands to account for within-the-reach system losses.

It is therefore recommended to provide at least 6.81 $m^3/s$ to the wetlands in order to sustain the EF requirement at RNP. At the presumed existing flow regime of the GRR at Nyaluhanga, all the 6.81 $m^3/s$ should be supplied from the reservoir during the zero inflows of the GRR at Nyaluhanga.

### 6.8.2. Impact of transfer from the Ndembera River

The water transfer can be considered to take place either on-channel through the Eastern wetland or off-channel (or canal transfer) using the shortest aerial distance before the wetlands. (See Figure 20) The EFA for the GRR at Nyaluhanga indicated a lowest required discharge of 5.87 $m^3/s$ for ecological maintenance. If this GRR inflow discharge could be assured, the remained inflow of 0.93 $m^3/s$ (6.81 – 5.87 $m^3/s$) would come from the Ndembera River.

However, the existing situation of zero GRR inflows into Ihefu indicates that the entire 6.81 $m^3/s$ would be required to come from the Ndembera River, which could not be assured without the reservoir.

The first option of on-channel transfer of water would require a minimum of 0.93 $m^3/s$ and a maximum of 6.81 $m^3/s$ from the Lugoda reservoir under the situation of 5.81 and 0.0 $m^3/s$ inflows of the GRR at Nyaluhanga respectively. This will ensure a minimum discharge of 1.0 $m^3/s$ at the BBM sites. Any required high flow (> 1 $m^3/s$) at the BBM sites would require a much higher discharge (> 0.93 – 6.81 $m^3/s$) from the Ndembera River.

The second option for canal transfer of water before the wetlands would require that 0.93– 6.81 $m^3/s$ be left into the river to flow into the wetlands. This amount left to cater for instream flow requirements would result in a discharge of 1 $m^3/s$ flowing through the BBM sites downstream of the Eastern wetland. If the canal fully supplies this 1 $m^3/s$, the required inflow into the Eastern wetlands from the Ndembera River would vary between 0.93 and 4.65 $m^3/s$ depending on the amount of inflows of the GRR.

The latter value was computed from the estimated total outflow volume from the wetlands that should equal the total inflow in order to maintain the wetlands at its full level.

# 7. Way forward

The following points, which complement the findings of the EFA and Options studies, are drawn from the outcomes of various stakeholder workshops that were held during the course of the project.

- The findings of the GRR and Ihefu wetland EFAs should be considered when the Terms of Reference for the Lugoda Dam are written.
- RBWO, with the support of the Ministry of Natural Resources and Tourism, should arrange workshops at which the findings of the GRR and wetland EFAs and the Options Analysis can be shared and discussed, with the purpose of finding ways forward for consultative implementation.
- The proposed drilling of nine boreholes for irrigation and monitoring in the GRR catchment area by RBWO has great merit, but should be shared and discussed with other stakeholders in the interests of consultative IWRM, and to ensure that the EF requirements are taken into account.
- Proper conservation management of the wetland, including the control of alien invader species, must be planned in consultation and with the involvement of the local communities.
- The capacity of the local government and conservation organisations to manage water resources and water-related environment in the Usangu landscape needs to be strengthened.
- It appears that much water is used inefficiently, by both large and small scale rice farmers in the Usangu plains and catchments; therefore it is recommended that irrigation efficiency should be improved through regulatory control and participatory management.
- Water rights should be established and properly administered, and pollution standards should be established for the Usangu wetland.
- Awareness needs to be created and raised among water users in the Usangu wetlands regarding the consequences of their actions on the wetland ecology, and the implications of this for the future of the wetlands and its users.
- Conservation organisations such as TANAPA and other interest groups need financial support to properly perform their duties.
- Rainwater harvesting should be encouraged throught the GRR catchment area.

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