FINAL REPORT

Rapid Environmental Flow Assessment for Ruvu River

A Consultancy Report submitted to iWASH

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EXECUTIVE SUMMARY

The Florida International Research iWASH Initiative Limited commissioned this study to conduct a rapid environmental flow assessment that will inform the ongoing environmental impact assessment work in the Ruvu sub-basin, as related to the proposed Kidunda Dam. The work utilizes the historical river flow data from Ruvu River at Morogoro Road Bridge in the sub-basin. The estimates from this work are initial estimates and will be followed by a detailed environmental flow assessment thereafter.

A desktop reserve model developed in South Africa that is purely hydrologic-based and which is intended to quantify environmental flow requirements in situations when a rapid appraisal is required and where there is limited ecological data was used to provide initial estimates of ecological flow requirements. Also Flow Duration Curve analysis was conducted. The flow requirements were evaluated considering the various Ecological Management Classes (A-D; A/B, B/C and C/D) at the selected site - Ruvu River at Morogoro Road Bridge.

The total maintenance flow requirement was estimated at 55.62% of the Mean Annual Runoff (1951-1977) for Ecological Management Class A and decreases to 15.23% for class D. These estimates are distributed appropriately across the year and take into consideration the high and low flow months provisioning. For the most dry months (September and October), the total maintenance flow requirement is estimated to be 15.03 and 14.86 m^3s^{-1} respectively for ecological management class A and 3.14 and 3.23 m^3s^{-1} for ecological management class D. Such a wide range provides the stakeholders, managers and decision makers a better idea of the possible range of required flows to maintain the river in different conditions.

This study was purely hydrological with limited social and ecological considerations. It is therefore recommended that a follow-up detailed environmental flow study should look onto the functional elements of the river ecosystem and socio-economic issues. As such, the study should established a relationship between the ecological characteristics and the river flow regimes, the geomorphological aspects, the effects of climate change on flow recommendations and the socio-economic aspect and a detailed analysis of Kidunda Dam regulation on environmental recommendations.

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ABBREVIATIONS AND ACRONYMS

°C	Degree centigrade
BBM	Building Block Methodology
BFI	Baseflow index
CV	Coefficient of variation
DRM	Desktop Reserve Model
DWAF	Department of Water Affairs
EF	Environmental Flow
EFA	Environmental Flow Assessment
EIA	Environmental Impact Assessment
EMC	Environmental management classes
FDC	Flow Duration Curve
IUCN	International Union for Conservation of Nature
JICA	Japan International Cooperation Agency
MAR	Mean Annual Runoff
Mm3	million cubic meters
MoW	Ministry of Water
WRMA	Water Resources Management Act

1.0 INTRODUCTION

1.1 Environmental flows-an overview

Water is essential to all kinds of human development and livelihood support systems including ecosystem management. There are many challenges towards sustainable water resource management which includes the assessment and the understanding of how much water can be taken from a river before its ability to meet social, ecological and economic needs is hindered (Kashaigili *et al*., 2007). Another challenge is how to estimate the ecological reserves and the mechanisms for allocation of water for highly regulated river as is the case for the Ruvu River (following proposed dam at Kidunda) while ensuring the water-dependent livelihoods of the poor are not affected.

An environmental flow (EF) is the water regime provided within a river, wetland or coastal zone to maintain ecosystems and their benefits (Dyson *et al.,* 2003; King *et al*., 2002; Tharme and King, 1998). It is also referred to as an ecologically acceptable flow regime designed to maintain a river in an agreed or pre-determined state. Therefore, EF is a compromise between water resources development on one hand, and river maintenance in a healthy or at least reasonable condition on another. Despite that, there are challenges on the actual estimation of EF values as there is hardly data on both understanding of and quantitative data on relationships between river flows and multiple components of river ecology.

From ecological point of view, the major criteria for determining EF should include the maintenance of both spatial and temporal patterns of river flow, i.e. the flow variability, which affects the structural and functional diversity of rivers and their floodplains, and which in turn influences the species diversity of the river (Bunn and Arthington, 2002). Thus EF should not only encompass the amounts of water needed but also when and how this water should be flowing in the river. All components of the hydrological regime have certain ecological significance (Knights, 2002). For example, high flows of different frequency are important for channel maintenance, species reproduction, wetland flooding and maintenance of riparian vegetation. Moderate flows may be critical for cycling of organic matter from river banks and for fish migration, while low flows of different magnitudes are important for algae control, water quality maintenance and the use of river resources by local people. Therefore many elements of flow variability have to be maintained in a modified EF regime.

Environmental Flow Assessments (EFAs) are used to estimate the quantity and timing of flows required to sustain aquatic ecosystems following infrastructural development like dams or water withdrawals. Water management planners and other natural resource planners use environmental flow assessments to make informed decisions about water management that protect the environment in order to foster sustainable social and economic development. An important measure for mitigating the potential negative impacts to river ecology caused by changes in the natural river flow is the planned releases of environmental flows downstream from dams, or limits on the amount of water that can be abstracted from a channel.

1.2 Environmental flow in Tanzania

Recognizing the importance of environmental flows to river health and functions, Tanzania has adopted the principle of environmental flows in the National Water Policy of 2002 (URT, 2002). It promulgates this principle 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 aquatic ecosystem in order to secure ecologically sustainable development and use of relevant water resources"

An Environmental Flow (EF) analysis 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"

Therefore, any abstraction from a water source must first account for the sustenance of the domestic and environmental water requirements.

Records on environmental flow studies in Tanzania show that EF estimations have been conducted in four out of nine water basins of Tanzania. These include Pangani, Rufiji, Mara Transboundary catchment between Tanzania and Kenya in the Lake Victoria Basin, and Wami-Ruvu basin in particular Wami sub-basin. Nevertheless, not all the rivers in basins have been studied. Therefore there is still a need for undertaking environmental flows studies to determine the water requirements for the environment. Consequently, this study contributes to the ongoing efforts on EFA.

2.0 OBJECTIVE AND SCOPE OF THE ASSIGNMENT

The objective of the assignment is to conduct a rapid environmental flow assessment that will inform the ongoing environmental impact assessment work in the Ruvu sub-basin, as associate with the proposed Kidunda Dam. The work utilizes the historical river flow data from a selected gauging station in the sub-basin. The estimates from this work are purely hydrology-based. They are expected to be initial estimates and will be followed by a detailed, holistic-method of EFA thereafter.

2.1 Specific Tasks

The specific tasks of the assignment include:

- Literature review on EFA with specific reference on Ruvu River. The review attempts to understand current water abstraction patterns, water utilization and water use efficiency and how they impact on water resources
- Undertaking a quick reconnaissance of the Ruvu river to understand the hydrology and biophysical condition of the sub basin and identify critical points relevant for this study
- Undertaking a study of existing data on hydrology for Ruvu River from possible sources that include Institute for Resource Assessment, Ministry of Water data base and Wami Ruvu Basin Water Office
- Carrying out a desktop reserve model customization and modeling, including checking data quality, flow naturalization, calibration, verification of model and its application
- Preparation of a comprehensive report and presenting study findings to a team of scientists for a review and comments before production of a final report
- Presenting study findings to the MoWI team undertaking the Environmental Impact Assessment study of the Kidunda Dam site

2.2. Deliverables

The main deliverable from this work is a Quick EFA report with a clear initial estimate of environmental flow recommendations for Ruvu River at selected gauging station(s).

3.0 DESCRIPTION OF THE RUVU SUB-BASIN

3.1 Location

The Ruvu River is one of the major rivers draining the Eastern Arc Mountains. The Ruvu sub-basin extends from Morogoro to the west of Dar es Salaam through the Coast and Dar es Salaam Regions (Figure 1), covering an area of about 17,700 km^2 of catchment which lies between latitudes 60° 05’ and 70° 45’ south and longitudes 37° 15’ and 39° 00’ east (IUCN, 2010). The Ruvu River basin can be subdivided into the following five main sub-catchments

i. Mgeta, including Msoro
ii. Ngerengere
iii. Upper Ruvu
iv. Middle Ruvu
v. Lower Ruvu.

Administratively, the Mgeta catchment, Ngerengere catchment and the Upper Ruvu fall in the Morogoro Region, while the Middle Ruvu and Lower Ruvu fall in the Coast Region extending southeastwards to cover the Dar es Salaam Region (IUCN, 2010). Except for the Uluguru Mountains in the extreme west, which has an elevation of 2000 m above mean sea level, the basin is mostly composed of low-lying areas along the Ruvu River and a slightly elevated hilly area with moderate undulation, which extends from west to east around Morogoro town. Isolated rolling hills are in the middle reach of the Ruvu River. The lowermost part of the river is the extreme eastern edge of the Basin, where low-lying alluvial flood-plains about 5–10 km wide are found at an elevation below 10m above mean sea level (JICA, 1994).

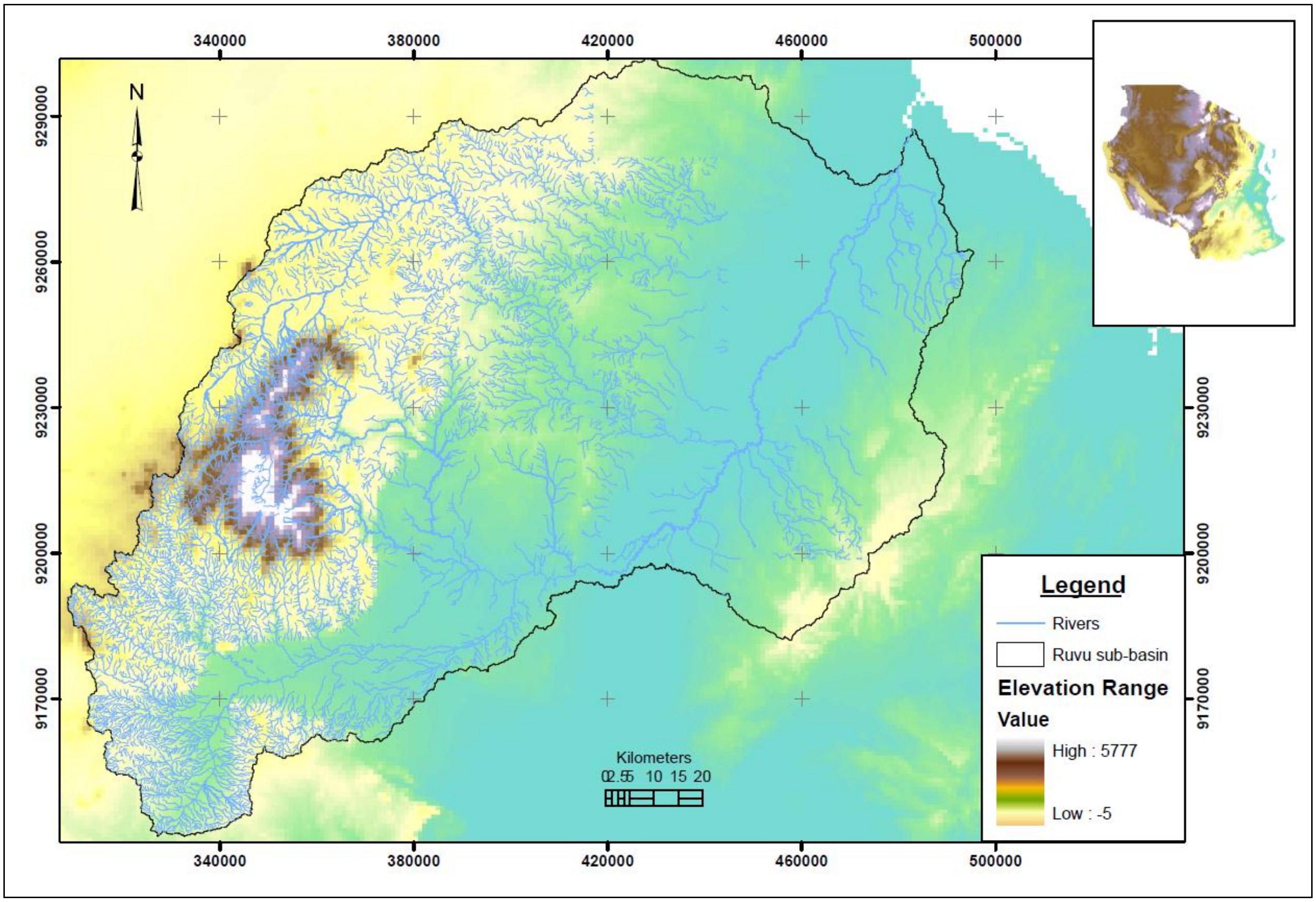


Figure 1: Ruvu-sub basin

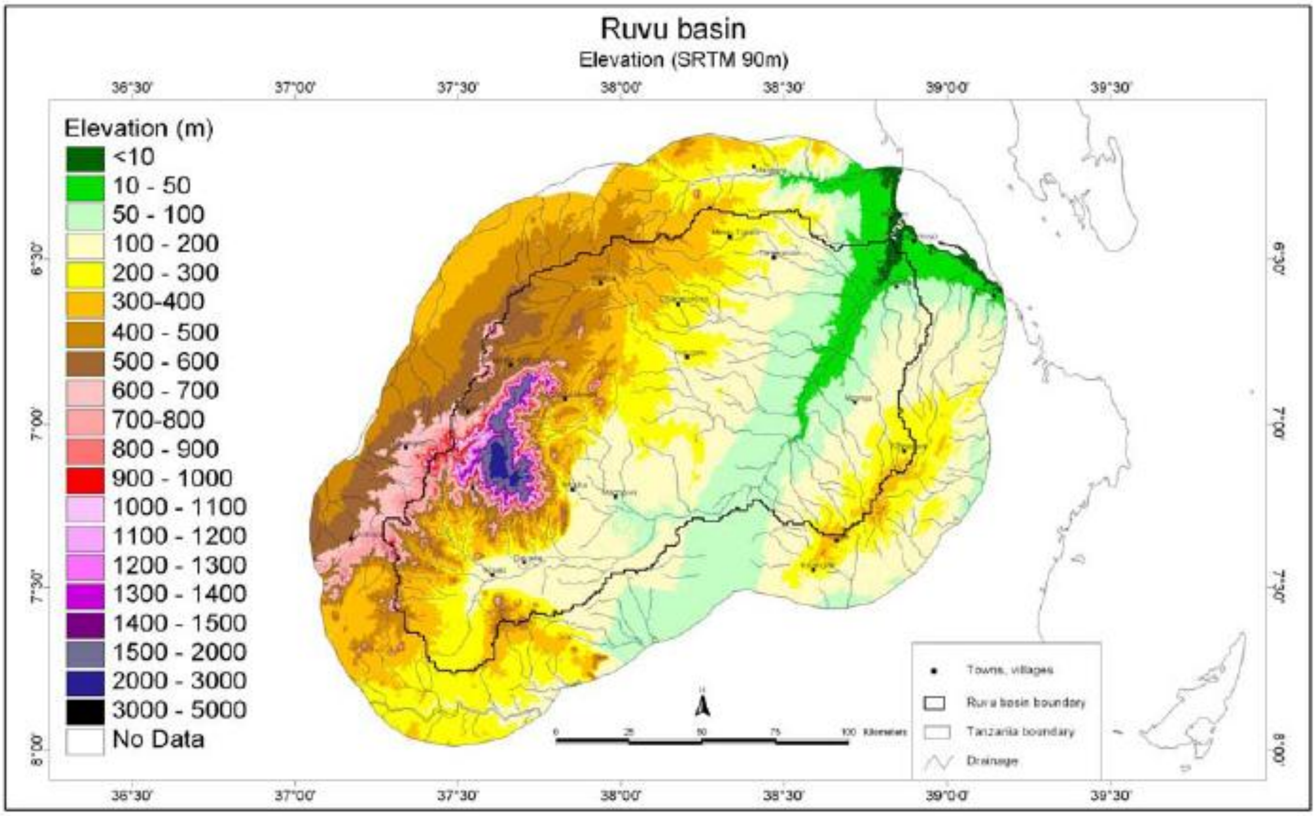
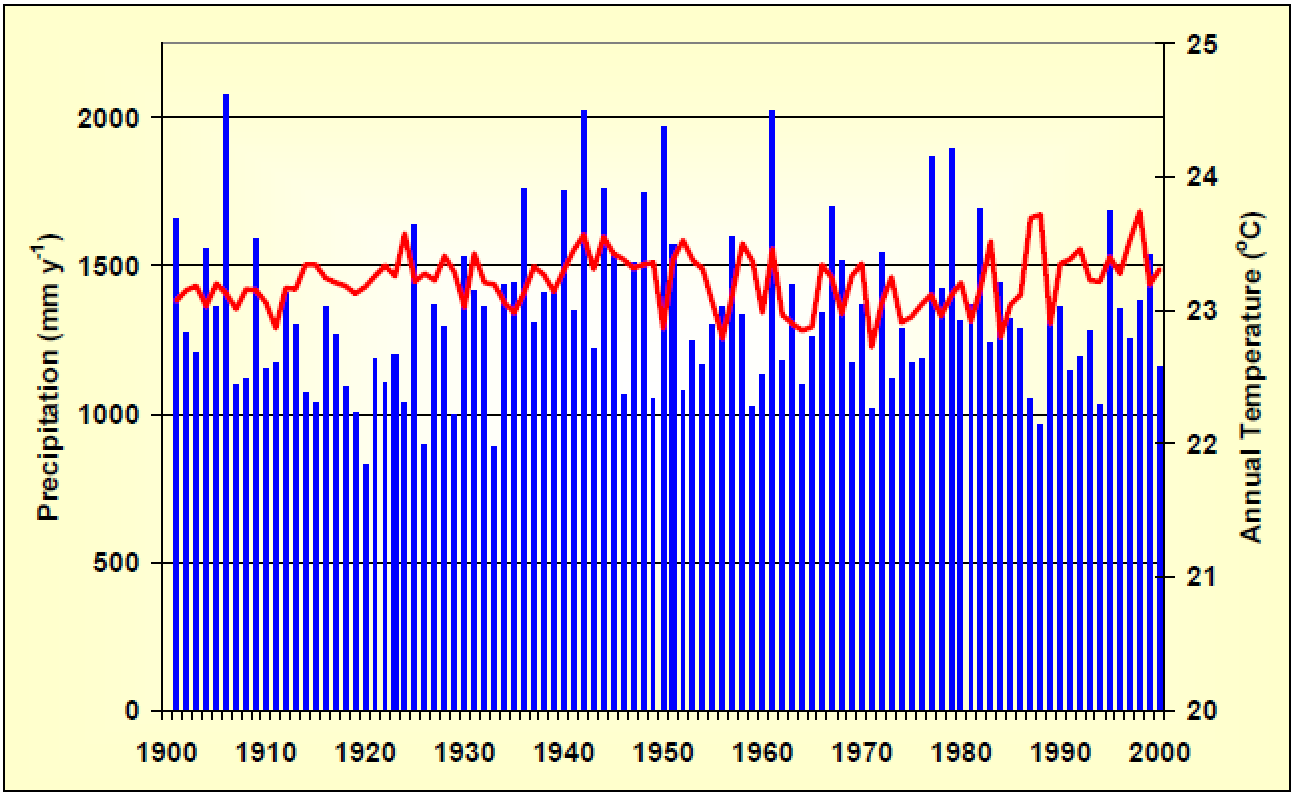


Figure 2: Ruvu Sub-basin elevations

3.2 Climate of the Ruvu Sub-basin

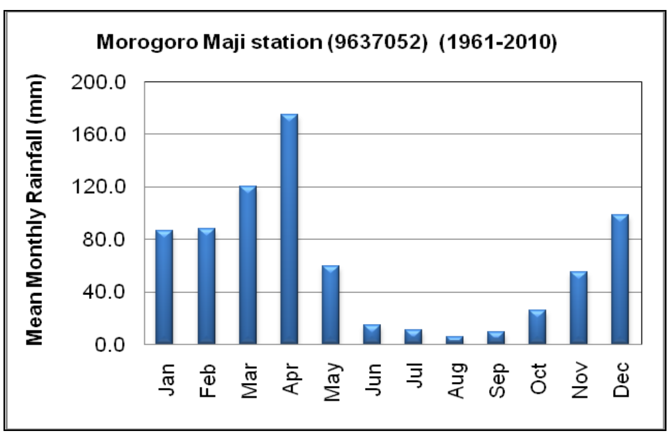
The climate of Ruvu sub-basin varies according to the topography. The high mountain ranges of Uluguru receive more rainfall as compared to the lowland areas and rainfall is also spatially variable in the mountains. The eastern slopes of the Uluguru Mountains have mean annual rainfall in excess of 2500 mm while the western slopes of the mountains receive less (WRBWO, 2008). The Nguru-Rubeho Mountains receive between 800-1200mm, and the Ukaguru Mountains 1000-1800mm annually. Rainfall is much less in the plains which ranges between 800 and 1000mm near the coast but only 500-600 mm inland towards Dodoma and north of Wami sub-basin (Droogers *et al*., 2006). The mean annual areal rainfall for the basin is presented in Figure 3 while Figure 4 depicts the mean monthly rainfall for stations in the highlands and lowland. Generally, the high rainfall month for both highland and lowland areas is April, with mean monthly rainfall amounting to about 300 mm in the highland and about 170 mm in the lowland.

Average monthly minimum and maximum temperatures are almost the same throughout the basin; the coldest month is August (about 18°C) and the hottest month is February (about 32°C). The annual average temperature is about 26°C.

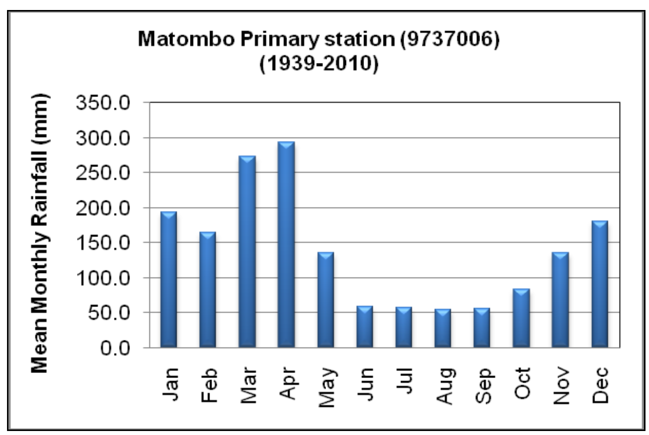


Source: Mitchell et al., (2003)

Figure 3: Mean annual rainfall and temperatures for Ruvu sub-basin



(a) Lowland station



(b) Highland station

Source: WRBWO

Figure 4: Mean Monthly Rainfall at one lowland and highland selected stations

3.3 Catchment hydrology

The hydrology of the catchment is influenced by the topography and climate. Most of the rivers in the sub-basin originate from the Uluguru Mountain ranges. Many rivers in the sub-basin are perennial although some dry up during the dry season and experience high flows during periods of heavy rainfall. The major tributaries into the Ruvu River are Ngerengere and Mgeta Rivers.

Table 1: Status of data availability for some river gauging stations in Ruvu basin

Sno.	No.	Name	River	Location	Catchment area (km^2)	Established	Status	Water Level	Discharge
1	33	1H8	Ruvu	Morogoro Road Bridge	15190	18-Nov-58	Operational	22/12/ 1958-30/6/ 1990	11/12/1958-27/10/2009
2	32	1H5	Ruvu	Kibungo	419.69	8-Oct-52	Operational	15 /10/1952 - 31 /12/ 1989	Oct 1952-Jun 1987; 26/3/2007-30/4/2010
3	57	1HA9/9A	Ngerengere	Konga	205	25-Mar-54	Operational	25/3/ 1954-31/12/1988	Mar 1954-26/4/2010
4	44	1HB2	Mgeta	Mgeta	101	1-Jun-54	Operational	1/6/ 1954-31/12/1989	1/6/1954-31/3/ 1988; 1/12/2006-6/5/2010

Note: *Table 1 provides a summary on status of key river gauging stations in the basin while Figure 5 shows the spatial location of the river gauging points in the basin. Most of the stations were established in the early 1950s and monitoring in these stations continued until late 1980s. The period from early 1990s until mid 2000s shows that there were no measurements taken.*

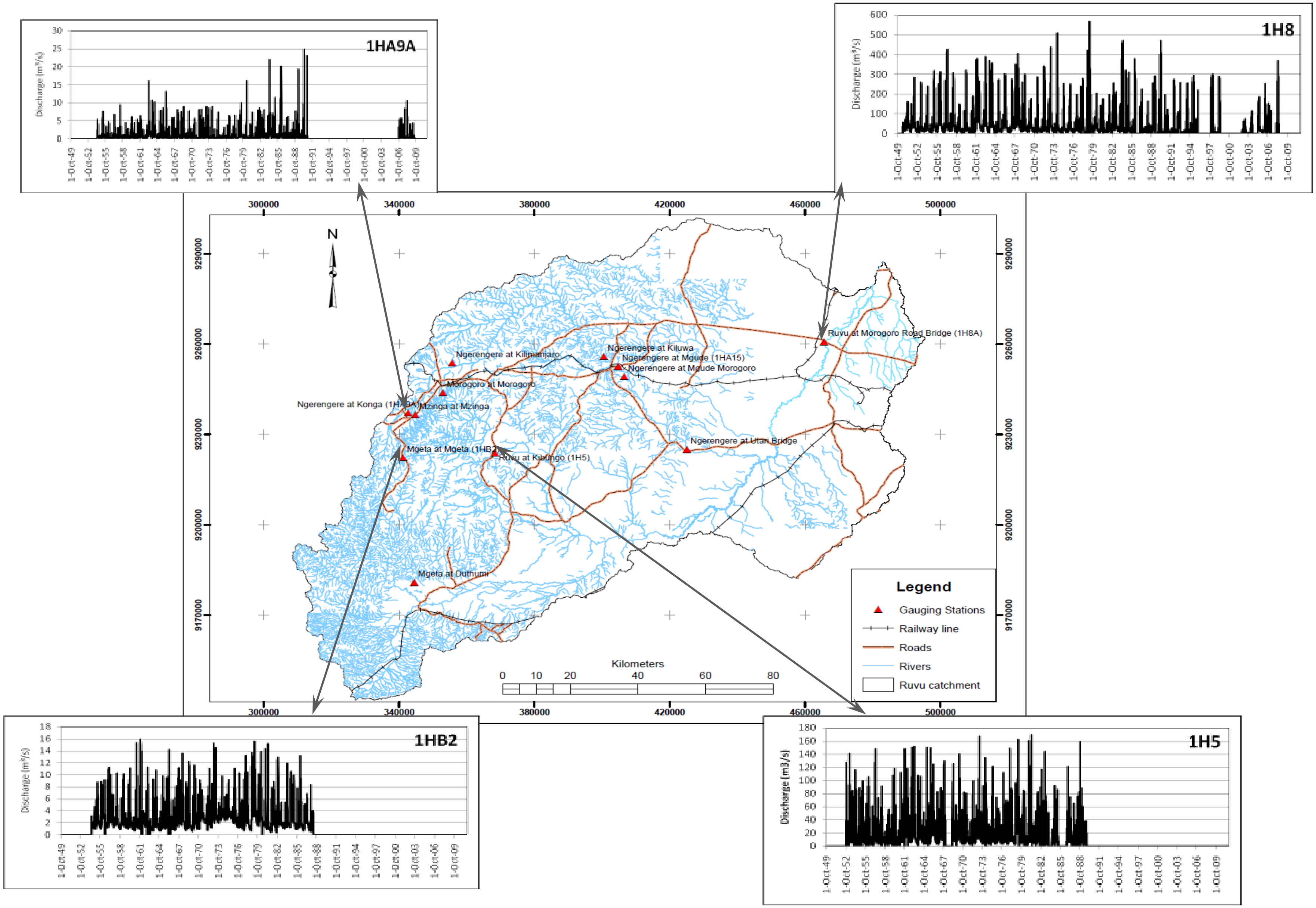
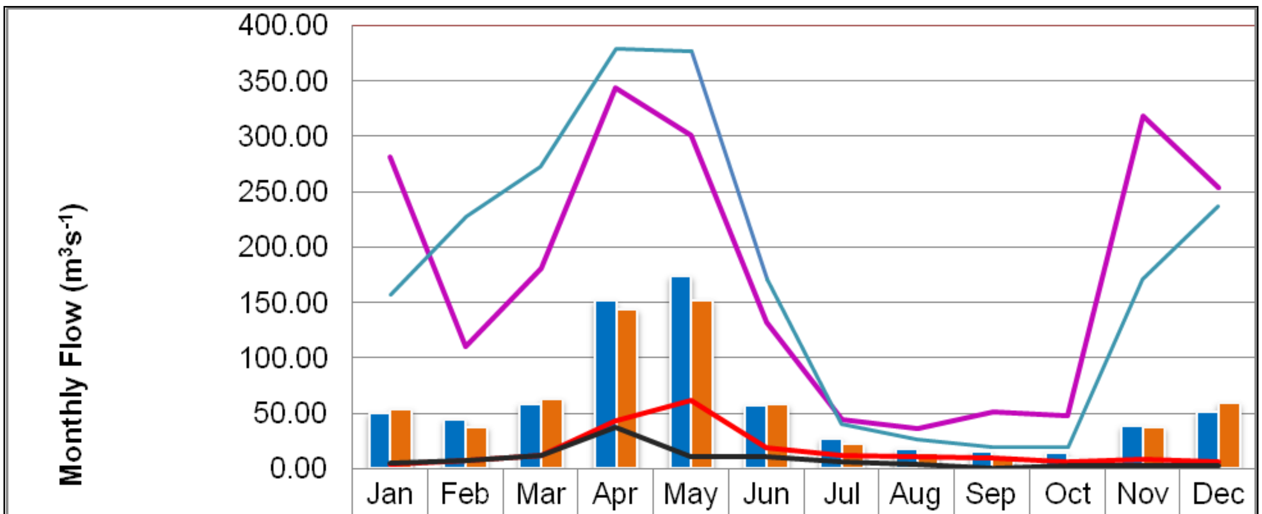


Figure 5: Location of river gauging stations in Ruvu sub-basin

Ruvu sub-basin has an area of about 13,300 km^2 above the most downstream river gauging station located at the Morogoro Road Bridge (1H8) which is about 75% of the entire sub-basin area. The mean annual flow is 61.9 m^3s^{-1} for the period 1951-1977 (e.g. before operation of the Mindu Dam and increased water withdrawals for anthropogenic activities) and 54 m^3s^{-1} for the 1978-2008 period. Figure 6 provides a comparison in mean monthly flows for the two periods under consideration. Generally, the mean monthly flow records indicate that the flows have been declining over the time during dry season namely July to October but increasing during the rainy season with a sharp recession thereafter. Such phenomenon could be attributed to changes in land use and land cover that mainly result into changes in runoff patterns (e.g. Kashaigili, 2008).



	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Mean (1951-1977)	49.9	43.9	58.3	151.	173.	56.6	26.6	17.5	15.0	14.5	38.0	51.2
Mean (1978-2008)	53.4	37.6	62.2	143.	151.	57.6	21.7	13.9	10.3	9.25	36.8	58.9
Max (1951-1977)	281.	109.	180.	343.	301.	132.	44.3	36.0	50.7	47.2	318.	253.
Min (1951-1977)	3.39	6.56	11.4	42.8	61.0	18.9	11.4	10.3	9.46	6.21	7.45	5.44
Max (1978-2008)	157.	227.	272.	378.	377.	170.	39.7	25.8	19.4	19.6	171.	236.
Min (1978-2008)	4.80	6.67	11.5	37.1	10.6	11.1	6.00	3.35	0.24	2.51	2.88	2.38

Figure 6: Comparison of mean monthly flows between the periods 1951-1977 and 1978-2008

3.4 Land cover and Land use

The major land cover includes natural forest, woodland, cultivated land, water, bushland, grassland, swamp and urban (Yanda and Munishi, 2007). Figure 7 presents the various land covers found in the Ruvu sub-basin. The major land use is agriculture. Irrigated agriculture is found in the lower Ruvu and the western slopes of the Uluguru Mountains. In Uluguru west, in the foot slopes of the Mgeta Mountains, there are 68 irrigation canals amounting to about 170 km, irrigating about 2060ha vegetables, maize, beans and fruit (Nnuduma, 2005). The expansion in agriculture to a greater extent contributed to the river flow changes in the catchment. According to Yanda and Munishi (2007) and Kashaigili (2008), land use change has a critical impact on hydrological regimes in Tanzania. For example, in the Uluguru Mountains, Yanda and Munishi (2007) observed that vegetation cover has changed considerably between 1995 and 2000, and this had contributed to the increased surface runoff and flash floods and reduced infiltration, ultimately resulting in reduced base flows in rivers.

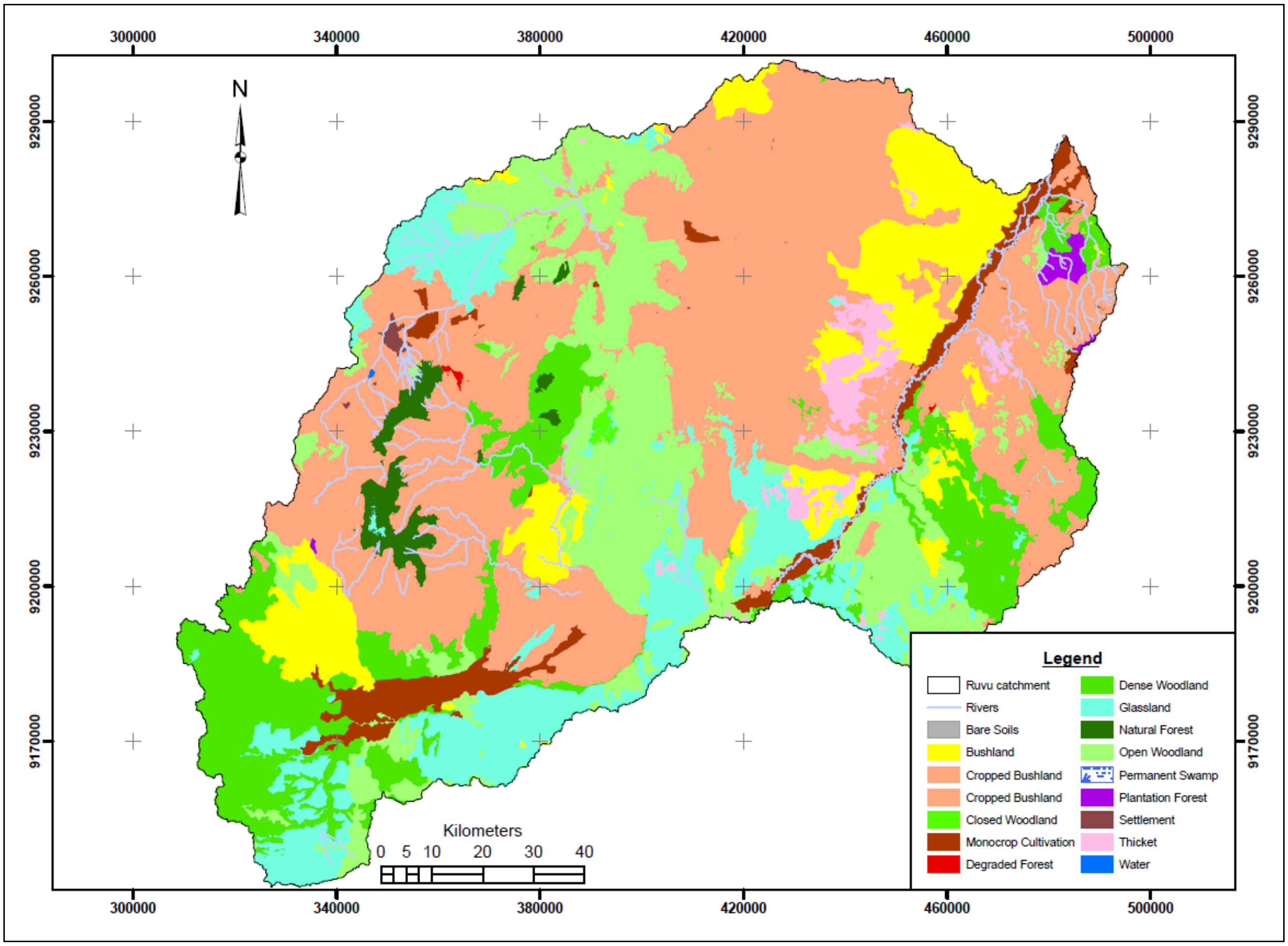


Figure 7: Land cover of the Ruvu sub-basin

3.5 Ecological aspects

Fish are the most important aquatic fauna in the Ruvu River. None of the aquatic biota found are listed as endangered or endemic. According to Norconsult (2008), 43 of the fish species are marine or estuary associated, mostly in the lower reaches. 39 freshwater species were found in the Ruvu sub-basin from the lower to the upper reaches. The estuarine environment in the Ruvu River has diverse zooplankton fauna, mostly of *Cycolpoides* and *Calanoides*.

Most riverine fishes in the Ruvu will spawn just prior to, or during periods of flooding. Spawning normally occurs on recently inundated vegetation when rivers break their banks, or on floodplains. Egg and juvenile survival is dependent on the maintenance of a consistent water level during the early stages. Rapidly receding water is known to leave eggs and juvenile fish stranded, reduce food availability and cause mass mortality (Norconsult, 2008).

For the optimal functioning of a floodplain, seasons of low and high flow, are required. It is therefore essential to maintain minimum Environmental Flow Requirements for successful fish reproduction. Large daily fluctuations can leave fish stranded, altering spawning behaviour and egg and juvenile survival. Natural flood heights, intensities and timing must match the natural (pre-dam) conditions to avoid reproductive failure (Norconsult, 2008).

3.6 Basin Water Abstraction and Uses

Understanding the amount of water abstracted from a source for different uses such as agriculture, domestic, and municipal water supplies is imperative in accounting for the amount of water that is available in downstream reaches of the river and in partitioning the river flow regime changes. Throughout the Ruvu River sub-basin, water abstractions are spatially non-uniformly distributed. Water abstractions in the sub-basin either withdraw water from the groundwater table or surface river network (including springs). The available information on legal water abstractions as of August 2011 indicates that there are about 82 licensed water use permits in the sub-basin with 39 abstracting water from different surface rivers, 29 from boreholes and wells, and 12 from springs and streams while 2 are from reservoirs (Table 2). There also 30 provisional titles of which 14 are for abstractions from rivers, 15 from springs and stream and 1 from boreholes with a total allocation of about 4.55 m^3s^{-1} (e.g. 4.27 m^3s^{-1} and 0.28 m^3s^{-1} for registered and provisional water use permits respectively – *for the available data*). Some information on permitted water abstractions from some rivers are provided in Table 3 with their corresponding dates of issue.

Table 2: Summary of registered and provisional water abstractions in the Ruvu sub-basin by August 2011

Water source	**No. of registered water use permits**
Rivers	39
Boreholes and wells	29
Springs/ stream	12
Reservoirs	2
Total	***82***
	No. of provisional water use permits
Rivers	14
Boreholes and wells	1
Springs/stream	15
Reservoirs	0
Total	***30***

Source: WRBWO Water User Database

Table 3: Licensed river water abstractions and corresponding dates of issue

River	Date of issue	Highest abstraction (l/s)	No. of abstractions	Total abstractions (l/s)
Mgolole River	1/24/2005	1.21	8	35.04
	1/24/2005	4.50		
	12/24/1988	5		
	7/16/1981	4.2		
	8/13/2001	8.49		
	5/31/2004	6.20		
	6/16/1981	4.21		
	3/19/2008	0.22		
	1/24/2005	1.01		
Ngerengere River	5/30/2006	4.56	16	346.88
	7/25/2006	3.50		
	12/16/1982	300.90		
	11/30/1996	9.9		
	11/18/1950	0.86		
	12/22/1997	6.25		
	4/18/2007	1.6		
	3/21/2003	1		
	8/7/1998	0.15		
	5/31/2004	4.3		
	5/31/2004	0.46		
	4/17/1982	4.23		
	4/25/1959	0		
	7/25/2006	7.54		
	7/25/2006	1.1		
	7/31/1971	0.53		
Ruvu River	1/30/1985	3156.3	1	3156.3
Morogoro	6/25/2007	0.11	5	6.86
	6/25/2007	3.60		
	6/25/2007	2		
	7/25/2006	1.1		
	7/23/2004	0.05		
Mlali River	2/26/1970	1.05	1	1.05
	6/25/2007	0.96	1	0.96
Kikundi River	2/23/2009	0.32	2	250.32
	6/16/1986	250.00		
Mzinga River	5/16/1974	13.67	1	13.67
Bigwa River	7/25/2006	0.03	1	0.03
Mgeta River	6/20/2009	0.06	1	0.06

Source: WRBWO Water User Database

3.6.1 Major water infrastructure impacting on the river sub-basin

Mindu Dam is one of the major water infrastructures in the Ruvu River sub-basin. The reservoir is located 7 km south of Morogoro along the Iringa road. The reservoir was constructed in 1983 and operations commenced in 1985 (IUCN, 2010). The reservoir, located at latitude 60° 51'S to 60° 52'S and longitude 37° 30'E to 37°40'EI, lies in the southeast of Ngerengere River valley, at a gap between the Uluguru and the Mindu Mountains. Table 4 presents the details on Mindu Dam reservoir characteristics.

Table 4: Mindu Dam characteristics

Description	**Dam characteristics**
Elevation of the dam location	500 m asl
Area of dam	508.4ha
Length of dam at full capacity	1.56 km
Width of spillway - ungated	100 m
Discharge capacity of ungated spillway	710 m^3s^{-1}
Deepest point of the dam during rainy season	12 m
Reservoir full level	507 m asl
Reservoir lowest point	501.1 m asl
Highest water level before spillage	507.6 m asl

Source: Kihila, 2005 in IUCN, 2010

The major rivers that feed the reservoir include the Mlali, Mgera, Lukulunge, Mzinga and the Ngerengere. Among the five rivers, Mzinga contributes more than 50% of the inflows into the dam. The outflow from the dam is a contribution of all inflowing rivers and emerges out of the dam as Ngerengere River that confluence with the Ruvu River in the downstream. The starting operation capacity of the dam was 20.7 million m^3 and the estimated current capacity of the reservoir is about 13 million m^3 (11.28 million m^3 is the active volume and 2.02 million m^3 is the dead volume or storage normally not accessed for use) (IUCN, 2010). The reservoir reaches its lowest level—50% of capacity—during the dry season due to the dry spell's demand levels (Kihila, 2005). The major observed impact of the dam has been the change in the river flow regime of the Ngerengere River downstream of the dam and increased salinity levels. The river that used to flow perennially has now become seasonal especially in the dry season.

Other major infrastructure projects in the Ruvu sub-basin are the lower and upper Ruvu intakes for the water supply to Dar es Salaam and the Bagamoyo, Mlandizi and Kibaha villages along the pipeline with 3156.25 l/s abstracted at Lower Ruvu intake. Also, the government of Tanzania intends to construct a dam that will control the Ruvu River at

Kidunda and will be a significant source of water supply for Dar es Salaam. An Environmental Impact Assessment (EIA) was carried out by Norconsult on the proposed Kidunda Dam. This EIA was based on the original dam specification that would hold a volume of 60 Mm^3. An additional study is being undertaken by JICA for a storage capacity of 150 Mm^3, and the spillway would be raised from 90 m to 92 m. Consequently, the dam area would increase from 27 km^2 to 43 km^2. The original dam of 27 km^2 would be operated only over a few months of the year (October to December) at approximately 0.8-1.25 Mm^3d^{-1}, to augment the flows of the Ruvu River to cater for the dry season water needs for the next 30 years for the 2.8 million people in Dar es Salaam, Bagamoyo, Kibaha and surroundings (Norconsult, 2008).

The justification for building the dam is that is that the Ruvu River is vulnerable to climate variability such as droughts. It is proposed that this vulnerability would be reduced by increased water storage upstream, which would help ensure water security for Dar es Salaam (Norconsult, 2008). The impact of no-action will mean increased water scarcity, and significant long-term consequences including environmental health disasters, a buildup of sewerage and industrial waste, and economic losses (Norconsult, 2008).

4.0 ENVIRONMENTAL FLOWS ASSESSMENT

4.1 The methods

A range of methods has been developed in various countries that can be employed to define environmental flow requirements. In broad terms, these can be classified into four categories (Table 4).

Table 4: Environmental Flow Assessment Methods and their Characteristics

S/N	Environmental Flow Assessment Method	Characteristics of Each Environmental Flow Assessment Method
1	Look-up tables (e.g. Tenant Method)	i. Worldwide the most commonly applied methods to define target river flows are empirical “Rules of Thumb” based on simple indices; ii. Based on hydrological analysis with limited ecological considerations; iii. Based on statistical properties of the natural flow regime; iv. An often used indicator is the Q_{95} Index, which is the flow that is equaled or exceeded for 95% of the time; v. Another indicator is the mean annual minimum flow; also the Tenant approach, which sets 10% of the mean annual minimum flow as the minimum required for poor quality of habitat and aquatic species survival, 30% is required for a satisfactory quality of habitat and aquatic species survival, and 60% for an excellent quality of habitat and aquatic species survival; and vi. Low confidence but quick.
2	Desk top analysis (e.g. Richter method, Lotic Invertebrate Index for Flow Evaluation (LIFE) in UK)	i. Use existing data such as river flows from gauging stations and/or fish data from regular surveys; ii. Can be sub-divided into those based purely on hydrological data, those that use hydraulic information (such as channel form) and those that employ ecological data; iii. Examine the whole river flow regime rather than pre-derived statistics; iv. Maintain integrity, natural seasonality and variability of flows, including floods and low flows;

S/N	Environmental Flow Assessment Method	Characteristics of Each Environmental Flow Assessment Method
		v. Long time series of data required.
3	Functional analysis or Holistic Methods (e.g. Building Blocks Method (BBM), Expert Panel Assessment Method, Scientific Panel Approach, Benchmarking Methodology, DRIFT)	i. Build an understanding of the functional links between all aspects of the hydrology and ecology of the river system; ii. Take a broad view and cover many aspects of the river ecosystem, using hydrological analysis, hydraulic rating information and biological data; iii. Take an integrated approach that uses a range of different experts (hydrologist, hydro-geologist and geomorphologist, and biological scientists, such as an aquatic entomologist, a botanist and a fish biologist) iv. Consider that riverine species are reliant on basic elements (building blocks) of the flow regime, including low flows and floods that maintain the sediment dynamics and geomorphological structure of the river; v. Expensive to collect all relevant data and to employ wide range of experts.
4	Habitat modeling (e.g. PHABSIM)	i. Use data on the habitat of target species to determine ecological flow requirements; ii. The relationship between flow, habitat and species can be described by linking the physical properties of river stretches, e.g. depth and flow velocity, at different measured or modeled flows, with the physical conditions that key animal or plant species require. iii. Established functional relationships between physical habitat and flow are linked to scenarios of river flow; iv. Evolved from steady-state analysis of flows for given levels of habitat to time-series analysis for the entire flow regime in the river; v. Expensive to collect the required hydraulic and ecological data; and vi. Data intensive and time consuming.

Source: Dyson *et al*., 2003

The choice of any of the methods depends on the objectives of the analysis, the resources available (both human and financial) and data. The objective, i.e. the conditions in which the aquatic ecosystem and its services are maintained, may be set by legislation or international conventions. An objective is set for ecological, economic or social reasons, and in such cases an environmental flow is defined to meet the objective. The environmental flow may also be a negotiated trade-off between different stakeholders and water users (Kashaigili *et al*., 2007). Hence, depending on the objective there are two different approaches to determining environmental flow:

i. How much water is needed to sustain the ecosystem in the desired condition? and
ii. How much water is allocated to the ecosystem and what will be the resulting ecosystem condition given that allocation of water?

International environmental flow practices and legislations vary a great deal from country to country. For example, using a Desktop Reserve Model (DRM) and BBM in South Africa a target is set for each river according to a classification system with target classes (Table 5). Depending on the management target, it is possible to define threshold flows.

Table 5: Environmental management classes (EMC)

EMC	Ecological description	Management perspective
A: Natural	Pristine condition or minor modification of in-stream and riparian habitat.	Protected rivers and basins. Reserves and national parks. No new water projects (dams, diversions etc.) allowed.
B: Slightly modified	Largely intact biodiversity and habitats despite water resources development and/or basin modifications.	Water supply schemes or irrigation development present and / or allowed.
C: Moderately modified	The habitats and dynamics of the biota have been disturbed, but basic ecosystem functions are still intact. Some sensitive species are lost and/or reduced in extent. Alien species present.	Multiple disturbances associated with the need for socio-economic development, e.g. dams, diversions, habitat modification and reduced water quality
D: Largely modified	Large changes in natural habitat, biota and basic ecosystem functions have occurred. A clearly lower than expected species richness. Much lowered presence of intolerant species. Alien species prevail	Significant and clearly visible disturbances associated with basin and water resources development, including dams, diversions, transfers, habitat modification and water quality degradation

EMC	Ecological description	Management perspective
E: Seriously modified	Habitat diversity and availability have declined. A strikingly lower than expected species richness. Only tolerant species remain. Indigenous species can no longer breed. Alien species have invaded the ecosystem.	High human population density and extensive water resources exploitation.
F: Critically modified	Modifications have reached a critical level and ecosystem has been completely modified with almost total loss of natural habitat and biota. In the worst case, the basic ecosystem functions have been destroyed and the changes are irreversible	This status is not acceptable from the management perspective. Management interventions are necessary to restore flow pattern, river habitats etc (if still possible / feasible). – to "move" a river to a higher management category.

Source: Modified from Smakhtin and Markandu, 2005

4.2 The Desktop Reserve Model

The Desktop Reserve Model (DRM) was developed to provide a method for generating initial estimates of ecological flow requirements for rivers in South Africa (Hughes and Münster 2000) and it has been used successfully in Swaziland, Zimbabwe and Mozambique (Hughes and Hannart, 2003). The model incorporates the concepts of the Building Block Method, which is widely recognized as a scientifically legitimate approach to setting environmental flow requirements (Hughes and Hannart, 2003). The approach is based on the fact that, under natural conditions, different parts of the flow regime play different roles in the ecological functioning of a river and, as such, it is necessary to retain fundamental differences between wet season and dry season flows. Hence, the Building Blocks (BBs) are different components of flow, which combined comprise an ecologically acceptable, modified flow regime. The major BBs are low flows (baseflows), small increases in flow (freshes) and larger high flows, required for river channel maintenance (Hughes, 2001). BBs differ between "normal years" and "drought years." The former are referred to as "maintenance requirements" and the latter as "drought requirements" (Hughes, 2001; Hughes and Hannart, 2003). The frequency with which maintenance and drought years occur is defined on the basis of the variability of the natural hydrological regime, which is largely a function of climatic conditions. Hence, maintenance years occur quite frequently (typically 60–70%) in wetter, more reliably flowing rivers, while they occur much less frequently in semi-arid and arid rivers (typically 20% or lower) (Hughes and Hannart, 2003). The set of BBs, therefore, includes maintenance low flows, maintenance high flows and drought flows, reflecting the natural variability of the flow. The desktop reserve model provides estimates of these BBs for each month of the year.

The major assumption of the Desktop Reserve Model, which emerged from an analysis of comprehensive environmental flow studies conducted in South Africa, is that rivers with more stable flow regimes (i.e., a higher proportion of their flow occurring as baseflow) have relatively higher low-flow requirements in normal years (i.e., "maintenance low-flow requirements") than rivers with more variable flow regimes. This assumption is founded on the premise that, in highly variable flow regimes, the biota will have adjusted to a relative scarcity of water, while in more reliably flowing rivers, the biota are more sensitive to reductions in the flow (Hughes and Hannart, 2003). The consequence is that, generally, the long-term mean environmental requirement is lower for rivers with more variable flow regimes.

The use of DRM to set flow requirements requires defining the desired ecological condition. This is done by making use of a river classification system that recognizes that while some rivers are environmentally important the requirements for socioeconomic development mean that not all rivers can be retained in a near natural state. Thus target "environmental management classes" (Table 5) are defined. For example, Class A rivers are largely unmodified and natural; Class D rivers are largely modified, with large loss of natural habitat, biota and basic ecosystem functioning (DWAF, 1999) and class F rivers critically modified with total loss of natural habitat and biota. Transitional categories (e.g., A/B and B/C) are also used to increase the range of possible environmental flows. This classification system is used within the desktop reserve model, and flow requirements computed accordingly; the higher the class, the more water is allocated for ecosystem maintenance and greater the flow variability preserved.

4.2.1 Application of Desktop Reserve Model for Ruvu River

In the current study the most downstream station Ruvu River at Morogoro Road (1H8) was selected as a representative site for Rapid Ruvu EFA. A desktop reserve model and Flow Duration Curve analysis were applied. The use of DRM to set flow requirements requires defining the desired ecological condition. In this case, since the desired flow condition has not been established, the flow requirements were evaluated considering the various Ecological Management Classes (A-D) at the selected site with an intention of giving the audience a better idea of the possible range of required flows to maintain the river in different conditions. The DRM is based on monthly time step data and, to estimate environmental flow requirements, a naturalized flow series must be entered. In this case, monthly flows from the Ruvu River at Morogoro Road for years 1951 to 1977 (i.e., the least modified period) before the commissioning of Mindu Dam and increased anthropogenic activities in the sub-basin were used as input after filling some data gaps.

The filling of missing monthly average flows used correlation modelling involving the use of correlation model. This model is given as:

$$Q_{k,i} = \left(\frac{\sigma_{Q_k}}{\sigma_{Q_{k+1}}} \right) \times r_{Q_k, Q_{k+1}} \times Q_{k+1,i}$$

- Eq.1-

where $Q_{k,i}$ is the missing flow in day i of month k, $Q_{k\pm1,i}$ is the recorded flow in day i of month $k\pm1$, σQ_k and $\sigma Q_{k\pm1}$ are standard deviations of daily flows in months k and $k\pm1$ respectively and $rQ_k,Q_{k\pm1}$ is the cross correlation coefficient between daily flows in months k and $k\pm1$.

Flow seasonality and rainfall-runoff relationships determined whether month-to-month correlation modelling was the appropriate filling option. High correlations between monthly average flows in consecutive months indicate the appropriateness of the month-to-month correlation modelling method. For higher correlations, the model of Eq 1 is used to fill missing monthly flows. The procedure using correlation model involved several repetitive runs to fill the gaps with the lower correlation limit of 0.65. This model effectively filled most of gaps in time series of monthly flows.

Within the DRM, two measures of hydrological variability are used. The first is a representation of long-term variability of wet and dry season flows and is based on calculating the coefficient of variation (CV) for all monthly flows. The average CVs for the three main months of both the wet and the dry season are then calculated and, the final CV-Index is the sum of these two season's averages (Hughes and Hannart, 2003). The second index is the proportion of the total flow that can be considered to occur as baseflow (i.e., baseflow index - BFI). Rivers with high BFI are less variable than those with low BFI values. The model computes the BFI from the monthly time series.

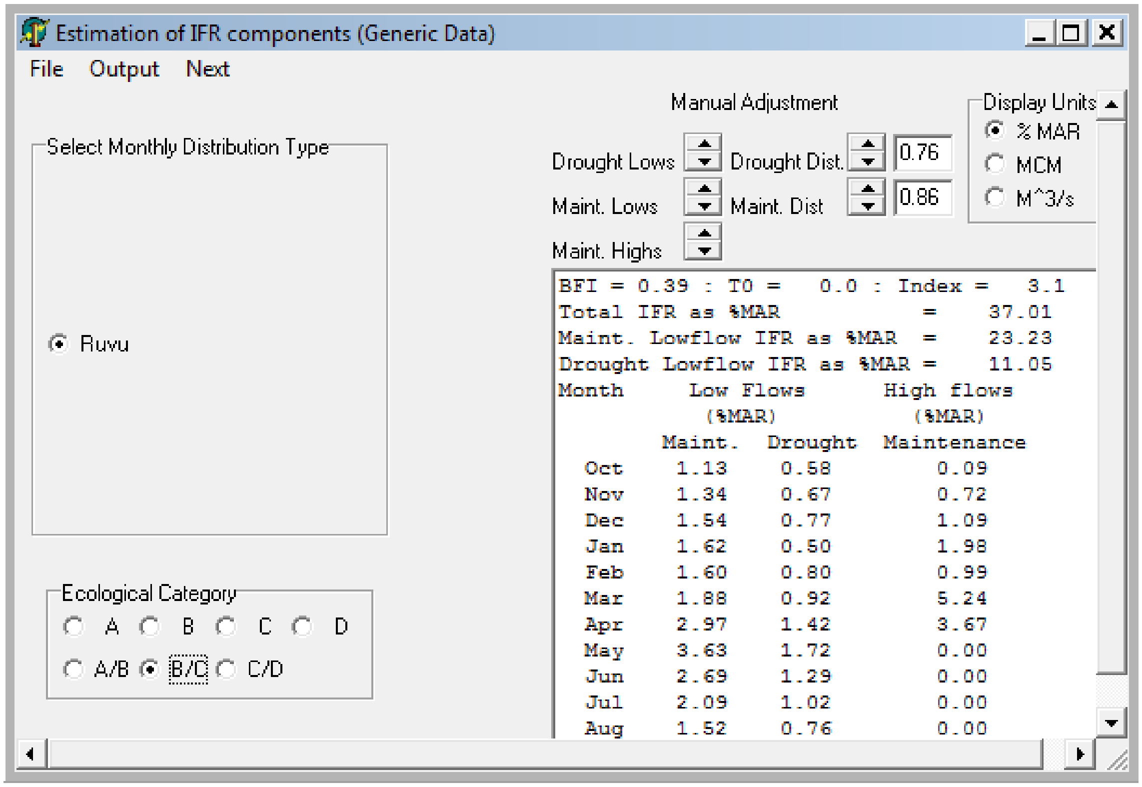


Figure 8: Ecological category for estimation of instream flow requirements

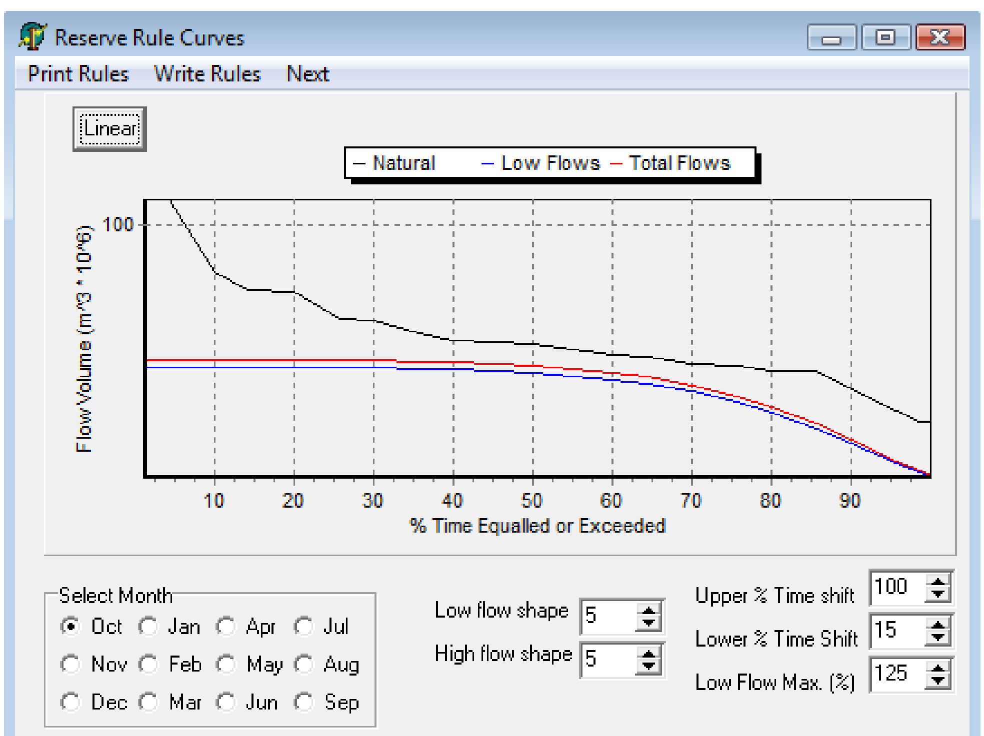


Figure 9: Defining reserve rule curves for different months

4.2.2 Result of the DRM

The model has enabled estimation of the water requirements at the selected site in consideration of the four EMCs (A, B, C and D) and transitional categories (A/B, B/C and C/D), making a total of seven estimates. Since the interpretation of the findings is generally similar, for all the seven classes, one class result (B/C) has been detailed discussed while others have been appended and cross-referred to.

Table 6 presents the model results for ecological management class B/C while for other classes; the results are presented in Appendix Table 1 through 6. The results indicate that (Table 6), to maintain the river at class B/C, requires an average annual environmental flow allocation of 677.176 Mm^3 (equivalent to 37.01% of MAR). This is the average annual "maintenance flow"; the sum of the maintenance low flows (i.e., 23.23 % MAR; 425.108 Mm^3) and the maintenance high flows (i.e., 13.78% of MAR; 252.069 Mm^3). The drought-low-flows correspond to 11.07% of MAR (i.e., 202.215 Mm^3). It is important noting that these flows are distributed appropriately across the year and takes into consideration the high and low flow months provisioning (e.g. Figure 11). Figure 10, presents a comparison of the observed time series and the desktop reserve model derived environmental flow series for ecological management class B/C, while Table 7 presents a comparison of environmental flow requirements computed by the desktop reserve model and actual mean monthly flows for the Ruvu River at Morogoro Road Bridge (1H8), between 1951 and 1977. As revealed in Table 7 the minimum total requirement occurs between September and October with estimated flows of 8.7 and 8.3 m^3s^{-1} respectively. The two months are known to be drier months; however October coincides with the onset of short rains in the catchment especially in the highlands of Uluguru Mountains.

Table 6: Summary of input and output from the desktop reserve model applied to the Ruvu River at Morogoro Road Bridge (1H8), based on 1951–1977 monthly flow series

Annual flows (Mm^3 or index values)					
MAR	=	1829.61	Total Environmental flow	= 677.176	(37.01% MAR)
S.D.	=	805.70	Maintenance Low flow	= 425.108	(23.23% MAR)
CV	=	0.44	Drought Low flow	= 202.215	(11.05% MAR)
Q_{75}	=	41.16	Maintenance High flow	= 252.069	(13.78% MAR)
Q_{75}/MMF	=	0.27			
BFI	=	0.39			
CV(JJA+JFM)	=	1.22			

Month	Observed flow (Mm^3)			Environmental flow requirement (Mm^3)			
				Low-flows			
	Mean	SD	CV	Maintenance	Drought	High-flows Maintenance	Total-flows Maintenance
Jan	133.75	154.69	1.16	29.73	9.08	36.22	65.94
Feb	107.28	68.78	0.64	29.34	14.56	18.11	47.45
Mar	156.21	107.03	0.69	34.34	16.83	95.81	130.15
Apr	391.96	201.72	0.52	54.34	25.91	67.20	121.54
May	464.70	179.97	0.39	66.40	31.39	0.00	66.40
Jun	146.71	77.08	0.53	49.20	23.58	0.00	49.20
Jul	71.36	22.80	0.32	38.29	18.62	0.00	38.29
Aug	46.95	15.57	0.33	27.77	13.85	0.00	27.77
Sep	38.96	20.33	0.52	22.45	11.43	0.00	22.45
Oct	39.80	23.24	0.58	20.62	10.60	1.70	22.32
Nov	97.46	158.18	1.62	24.43	12.33	13.13	37.55
Dec	134.46	181.30	1.35	28.21	14.04	19.91	48.12

Source: Own analysis using desktop reserve model

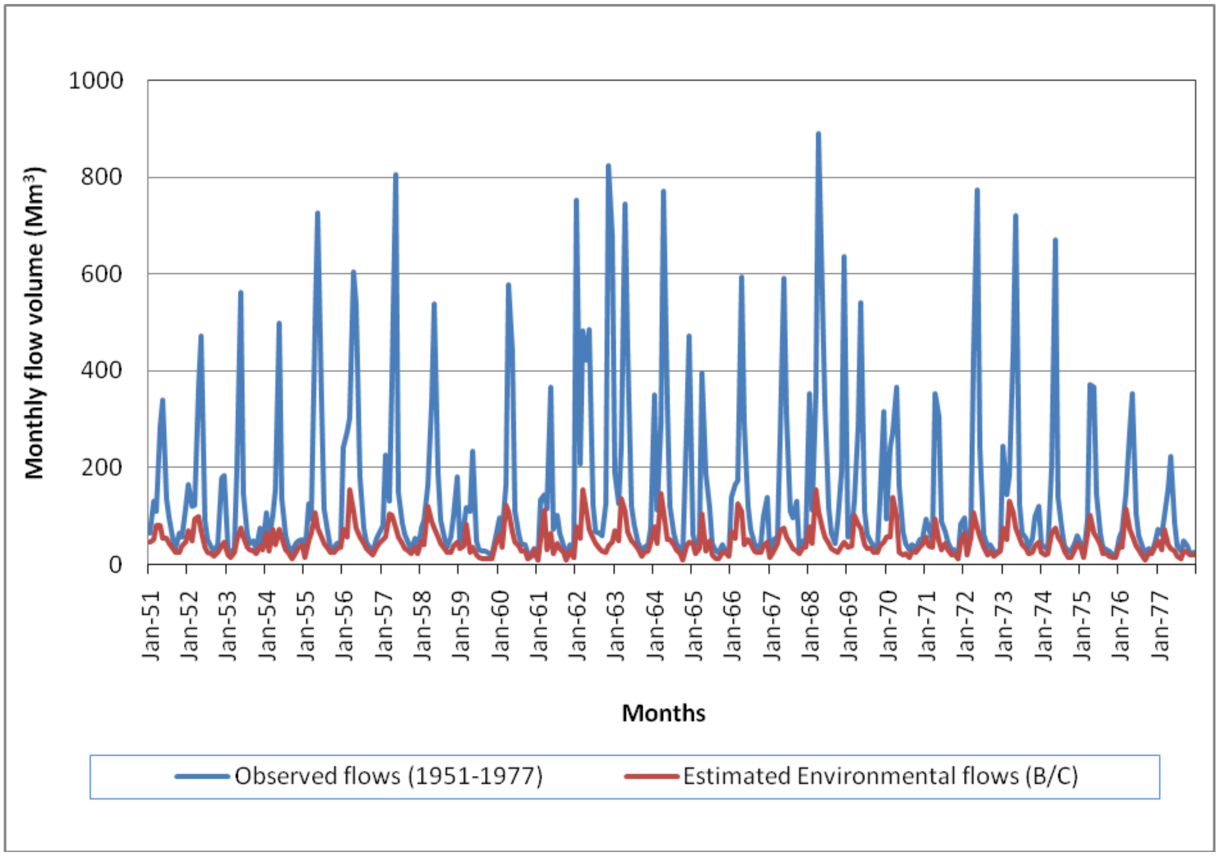


Figure 10: Estimated environmental flows and observed flows for the period (1951-1977) for Ruvu River at Morogoro Road Bridge (EMC = B/C)

Table 7: Comparison of environmental flow requirements computed by the desktop reserve model and actual mean monthly flows for the Ruvu River at Morogoro Road Bridge (1H8), between 1951 and 1977 (EMC=B/C)

Month	Total-flow Maintenance requirement		Observed flow		Ratio of observed to environmental flow requirement
	Mm^3	m^3s^{-1}	Mm^3	m^3s^{-1}	
January	65.94	24.62	133.75	49.94	2.03
February	47.45	19.61	107.28	44.34	2.26
Mar	130.15	48.59	156.21	58.32	1.20
April	121.54	46.89	391.96	151.22	3.22
May	66.40	24.79	464.70	173.50	7.00
June	49.20	18.98	146.71	56.60	2.98
July	38.29	14.30	71.36	26.64	1.86
August	27.77	10.37	46.95	17.53	1.69
September	22.45	8.66	38.96	15.03	1.74
October	22.32	8.33	39.80	14.86	1.78
November	37.55	14.49	97.46	37.60	2.60
December	48.12	17.96	134.46	50.20	2.79

Figure 11 compares the various flow recommendations based on different EMCs. Generally, higher classes (e.g. A and A/B, B) require more water allocation than lower ones. As revealed in Figure 11 and Appendix Tables 1-6, the total maintenance flow requirement is 55.62% of the Mean Annual Runoff for class A and decreases to 15.23% for class D. For the most dry months (September and October), the total maintenance flow requirement is estimated to be 15.03 and 14.86 m^3s^{-1} respectively for ecological management class A and drops to 3.14 and 3.23 m^3s^{-1} for ecological management class D. Such a wide range provides a broad spectrum of choice for the desired flow recommendations by the stakeholders after considering the socio-economic and ecology of the ecosystem.

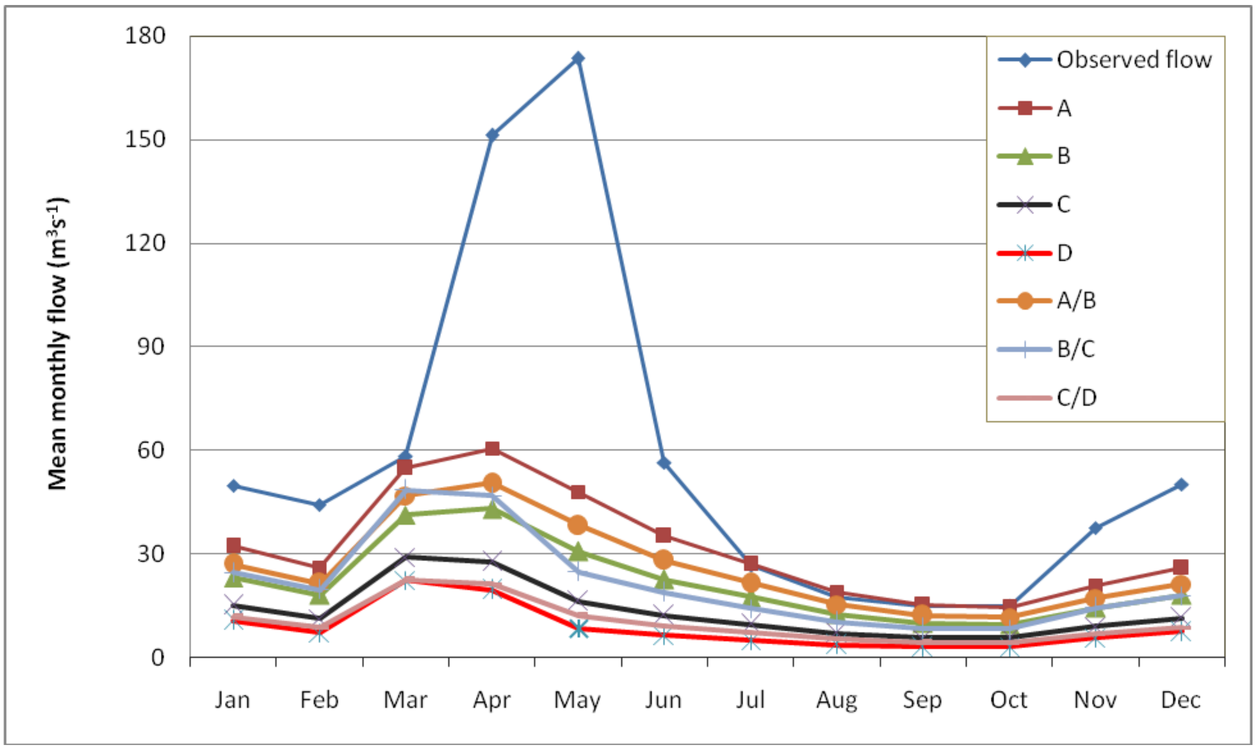


Figure 11: Comparison between observed and estimated total maintenance flows for different ecological management classes for the Ruvu River at Morogoro Road Bridge

Limitation and accuracy of the DRM estimates

It is important to recognize that the DRM parameters have been regionalized for South Africa case studies based on past experience of IFR determinations, where there has been a considerable amount of input from ecologists and geomorphologists. Therefore the DRM estimates cannot be seen as definitive. The extrapolation to other areas, like Tanzania (Ruvu River), is expected to produce initial estimates and the accuracy of the model results cannot be substantiated without further study. Nonetheless, in the absence of any specialist knowledge on the relationships between hydrology and the ecological functioning of the river and limited time, it was felt to be the most appropriate method for use in the current study. It is however important noting that this study was an initial attempt to estimate the environmental flow for the Ruvu River at the selected study site. A more comprehensive study is necessary to account for ecology and socio-economic aspects that were not considered in this initial assessment.

The DRM uses monthly time series of flow data to estimate the environmental flow recommendations. Such course resolution data may have implications on the quality of the outputs due to data aggregation.

4.2.3 The Flow Duration Curve analysis

The flow duration curve (FDC) is a cumulative frequency distribution that shows the percent of time that a specified discharge is equaled or exceeded during a period of interest. The "design" low flow range of a flow duration curve is generally in the Q_{70} to Q_{99} (i.e., flow exceeded 70% and 90% of the time) range (Smakhtin, 2001). The Q_{95} and Q_{90} are frequently used as indicators of low flow and have been widely used to set minimum environmental flows (i.e., Smakhtin, 2001; Tharme, 2003; Pyrce, 2004).

The FDC for the two time windows were developed using average daily flows for Ruvu River at Morogoro Road Bridge. From the flow duration curves for the 1951-1977 and post-1977 periods, flow percentiles were extracted. Figures 12 and 13 show the flow duration curves of one day duration for Ruvu River at Morogoro Road Bridge for the periods 1951-1977 and post-1977 periods drawn on a log scale, while Table 8 presents the indices extracted from the FDC for the two time windows. The comparison of the two curves show a progressive decline in flows lower than Q_{50} in the latter period unlike the former indicating reduction in low flows in the post-1977 period. Between 1951-1977 and post-1977 windows, Q_{95} and Q_{90} decreased from 6.29 m^3s^{-1} and 8.04 m^3s^{-1} to 5.32 m^3s^{-1} and 7.52 m^3s^{-1} respectively.

Figure 12: 1-Day Flow Duration Curve for Ruvu River at Morogoro Road Bridge (1H8) for the period 1951 to 1977 (before commissioning of Mindu Dam) on log-scale

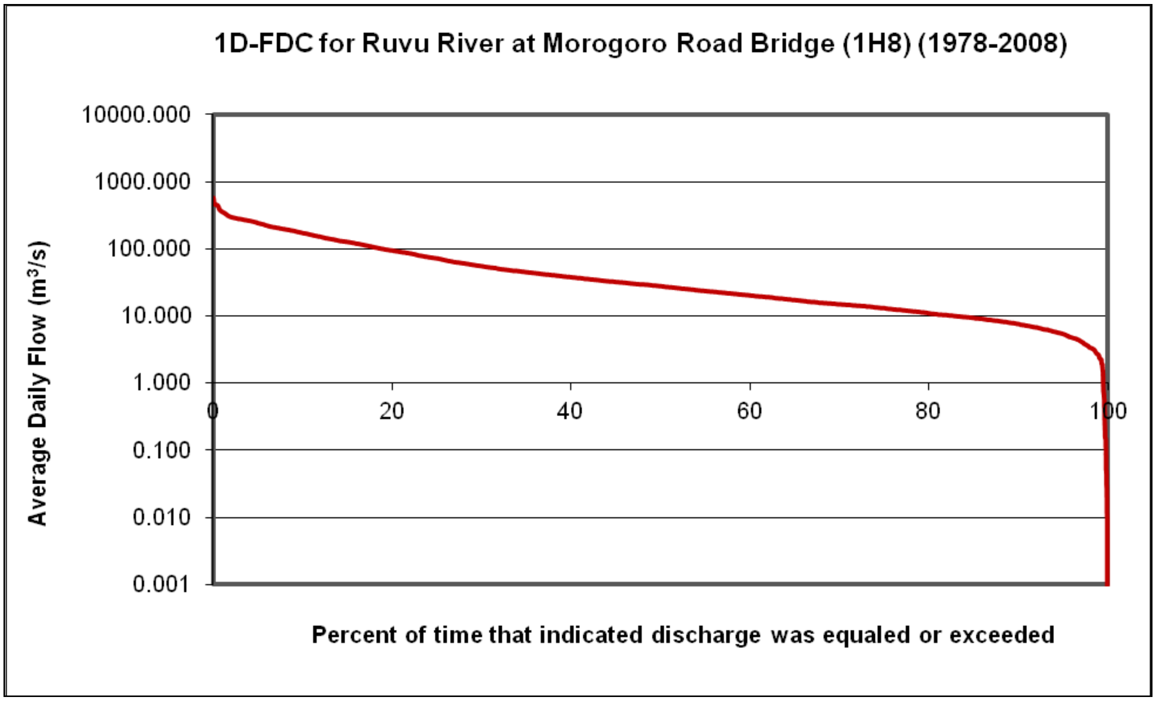


Figure 13: 1-Day Flow duration curve for Ruvu River at Morogoro Road Bridge (1H8) for the period 1978 to 2008 (after commissioning of Mindu Dam)

Table 8: Comparison of flow indices from Flow Duration Curves for the two time periods

	Discharge (m^3s^{-1})	
Flow Indices	1951-1977	1978-2008
Q_{99}	4.45	2.57
Q_{95}	6.29	5.32
Q_{90}	8.04	7.52
Q_{75}	13.02	12.93
Q_{50}	25.40	27.44
Q_{25}	60.60	71.20
Q_{10}	160.73	169.29
Q_{5}	252.58	238.09

5.0 CONCLUSIONS

In the absence of ecological data, this study enabled determination of the initial estimates of the environmental flows for the Ruvu River at Morogoro Road Bridge using the Desktop Reserve Model and FDC approach based solely on hydrological data. The assessment was done by considering the four EMCs (A, B, C and D) and transitional categories (A/B, B/C and C/D). The total maintenance flow requirement was estimated at 55.62% of the Mean Annual Runoff (1951-1977) for EMC (A) and decreases to 15.23% for class D. These estimates are distributed appropriately across the year and take into consideration the high and low flow months provisioning. For the most dry months (September and October), the total maintenance flow requirement is estimated to be 15.03 and 14.86 m^3s^{-1} respectively for ecological management class A and 3.14 and 3.23 m^3s^{-1} for ecological management class D. Such a wide range provides the stakeholders, managers and decision makers a better idea of the possible range of required flows to maintain the river in different conditions.

It is important noting that where water withdrawals are essential for livelihoods, there is a need to consider trade-offs in water provision to different ecosystems. It is worth noting that informed decisions are only possible with at least a basic understanding of the requirements of all, including the environmental components of the water system. Although preliminary, and requiring verification through further research, the results provide a credible scientific basis for decision-making on water resource allocation.

This study was purely hydrological with limited social and ecological considerations. It is therefore recommended that a follow-up detailed study should look onto the functional elements of the river ecosystem and socio-economic issues. As such, the study should established a relationship between the ecological characteristics and the river flow regimes, the geomorphological aspects, the effects of climate change on flow recommendations and the socio-economic aspect and a detailed analysis of Kidunda Dam regulation on environmental recommendations.

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APPENDICES

Appendix Table 1: Summary of input and output from the desktop reserve model applied to the Ruvu River at Morogoro Road Bridge, based on 1951–1977 monthly flow series for **Ecological Management Class = A**

		Annual flows (Mm^3 or index values)			
MAR	=	1829.611	Total Environmental flow =	1017.719	(55.62% MAR)
S.Dev.	=	805.699	Maintenance Low flow =	801.004	(43.78% MAR)
CV	=	0.44	Drought Low flow =	154.52	(8.45% MAR)
			Maintenance High flow =	216.715	(11.84% MAR)
Q75	=	41.16			
Q75/MMF	=	0.27			
BFI	=	0.39			
CV(JJA+JFM)	=	1.22			

	Observed flow (Mm^3)			Environmental flow requirement (Mm^3)			
				Low-flows		High-flows	Total-flows
Month	Mean	SD	CV	Maintenance	Drought	Maintenance	Maintenance
Oct	39.804	23.235	0.584	37.228	8.239	1.458	38.687
Nov	97.464	158.177	1.623	44.816	9.476	11.284	56.100
Dec	134.464	181.299	1.348	52.352	10.705	17.118	69.470
Jan	133.75	154.688	1.157	55.385	9.08	31.137	86.522
Feb	107.276	68.781	0.641	54.61	11.074	15.569	70.178
Mar	156.205	107.028	0.685	64.58	12.699	82.376	146.956
Apr	391.955	201.716	0.515	104.467	19.204	57.774	162.240
May	464.701	179.973	0.387	128.513	23.125	0	128.513
Jun	146.713	77.081	0.525	94.226	17.534	0	94.226
Jul	71.362	22.804	0.32	72.467	13.986	0	72.467
Aug	46.953	15.57	0.332	51.491	10.565	0	51.491
Sep	38.963	20.334	0.522	40.87	8.833	0	40.870

Appendix Table 2: Summary of input and output from the desktop reserve model applied to the Ruvu River at Morogoro Road Bridge, based on 1951–1977 monthly flow series for **Ecological Management Class = B**

		Annual flows (Mm^3 or index values)	
MAR	=	1829.611	Total Environmental flow = 702.747 (38.41% MAR)
S.Dev.	=	805.699	Maintenance Low flow = 522.033 (28.41% MAR)
CV	=	0.44	Drought Low flow = 151.139 (8.26% MAR)
Q75	=	41.16	Maintenance High flow = 180.715 (9.88% MAR)
Q75/MMF	=	0.27	
BFI	=	0.39	
CV(JJA+JFM)	=	1.22	

	Observed flow (Mm^3)			Environmental flow requirement (Mm^3)			
Month	Mean	SD	CV	Low-flows Maintenance	Drought	High-flows Maintenance	Total-flows Maintenance
Jan	133.75	154.688	1.157	36.318	9.08	25.965	62.283
Feb	107.276	68.781	0.641	35.828	10.797	12.982	48.811
Mar	156.205	107.028	0.685	42.131	12.4	68.692	110.822
Apr	391.955	201.716	0.515	67.345	18.809	48.176	115.521
May	464.701	179.973	0.387	82.545	22.673	0	82.545
Jun	146.713	77.081	0.525	60.871	17.163	0	60.871
Jul	71.362	22.804	0.32	47.116	13.667	0	47.116
Aug	46.953	15.57	0.332	33.857	10.296	0	33.857
Sep	38.963	20.334	0.522	27.143	8.59	0	27.143
Oct	39.804	23.235	0.584	24.841	8.004	1.216	26.057
Nov	97.464	158.177	1.623	29.637	9.224	9.41	39.047
Dec	134.464	181.299	1.348	34.401	10.435	14.274	48.675

Appendix Table 3: Summary of input and output from the desktop reserve model applied to the Ruvu River at Morogoro Road Bridge, based on 1951–1977 monthly flow series for **Ecological Management Class = C**

Annual flows (Mm^3 or index values)			
MAR	=	1829.611	Total Environmental flow = 432.089 (23.62% MAR)
S.Dev.	=	805.699	Maintenance Low flow = 287.462 (15.71% MAR)
CV	=	0.44	Drought Low flow = 151.139 (8.26% MAR)
Q75	=	41.16	Maintenance High flow = 144.627 (7.9% MAR)
Q75/MMF	=	0.27	
BFI	=	0.39	
CV(JJA+JFM)	=	1.22	

	Observed flow (Mm^3)			Environmental flow requirement (Mm^3)			
				Low-flows		High-flows	Total-flows
Month	Mean	SD	CV	Maintenance	Drought	Maintenance	Maintenance
Jan	133.75	154.688	1.157	20.262	9.08	20.78	41.042
Feb	107.276	68.781	0.641	20.011	10.797	10.39	30.401
Mar	156.205	107.028	0.685	23.25	12.4	54.974	78.224
Apr	391.955	201.716	0.515	36.209	18.809	38.556	74.765
May	464.701	179.973	0.387	44.022	22.673	0	44.022
Jun	146.713	77.081	0.525	32.882	17.163	0	32.882
Jul	71.362	22.804	0.32	25.812	13.667	0	25.812
Aug	46.953	15.57	0.332	18.997	10.296	0	18.997
Sep	38.963	20.334	0.522	15.547	8.59	0	15.547
Oct	39.804	23.235	0.584	14.363	8.004	0.973	15.337
Nov	97.464	158.177	1.623	16.829	9.224	7.531	24.359
Dec	134.464	181.299	1.348	19.277	10.435	11.424	30.701

Appendix Table 4: Summary of input and output from the desktop reserve model applied to the Ruvu River at Morogoro Road Bridge, based on 1951–1977 monthly flow series for **Ecological Management Class = D**

Annual flows (Mm^3 or index values)					
MAR	=	1829.611	Total Environmental flow	= 278.64	(15.23% MAR)
S.Dev.	=	805.699	Maintenance Low flow	= 152.98	(8.36% MAR)
CV	=	0.44	Drought Low flow	= 151.12	(8.26% MAR)
Q75	=	41.16	Maintenance High flow	= 125.66	(6.87% MAR)
Q75/MMF	=	0.27			
BFI	=	0.39			
CV(JJA+JFM)	=	1.22			

	Observed flow (Mm^3)			Environmental flow requirement (Mm^3)			
				Low-flows		High-flows	Total-flows
Month	Mean	SD	CV	Maintenance	Drought	Maintenance	Maintenance
Jan	133.75	154.688	1.157	10.843	9.08	18.054	28.898
Feb	107.276	68.781	0.641	10.713	10.713	9.027	19.741
Mar	156.205	107.028	0.685	12.385	12.385	47.764	60.148
Apr	391.955	201.716	0.515	19.07	19.07	33.499	52.569
May	464.701	179.973	0.387	23.101	23.101	0	23.101
Jun	146.713	77.081	0.525	17.354	17.354	0	17.354
Jul	71.362	22.804	0.32	13.707	13.707	0	13.707
Aug	46.953	15.57	0.332	10.191	10.191	0	10.191
Sep	38.963	20.334	0.522	8.41	8.41	0	8.41
Oct	39.804	23.235	0.584	7.8	7.8	0.846	8.646
Nov	97.464	158.177	1.623	9.072	9.072	6.543	15.615
Dec	134.464	181.299	1.348	10.335	10.335	9.925	20.26

Appendix Table 5: Summary of input and output from the desktop reserve model applied to the Ruvu River at Morogoro Road Bridge, based on 1951–1977 monthly flow series for **Ecological Management Class = A/B**

Annual flows (Mm^3 or index values)					
MAF	=	1829.61	Total Environmental flow	= 836.397	(45.71% MAR)
S.D.	=	805.70	Maintenance Low flow	= 641.568	(35.07% MAR)
CV	=	0.44	Drought Low flow	= 151.139	(8.26% MAR)
Q75	=	41.16	Maintenance High flow	= 194.829	(10.65% MAR)
Q75/MMF	=	0.27			
BFI	=	0.39			
CV(JJA+JFM)	=	1.22			

Month	Observed flow (Mm^3)			Environmental flow requirement (Mm^3)			
				Low-flows		High-flows	Total-flows
Month	Mean	SD	CV	Maintenance	Drought	Maintenance	Maintenance
Jan	133.75	154.688	1.157	44.414	9.08	27.993	72.407
Feb	107.276	68.781	0.641	43.797	10.797	13.996	57.794
Mar	156.205	107.028	0.685	51.736	12.4	74.057	125.793
Apr	391.955	201.716	0.515	83.495	18.809	51.939	135.434
May	464.701	179.973	0.387	102.641	22.673	0	102.641
Jun	146.713	77.081	0.525	75.341	17.163	0	75.341
Jul	71.362	22.804	0.32	58.016	13.667	0	58.016
Aug	46.953	15.57	0.332	41.314	10.296	0	41.314
Sep	38.963	20.334	0.522	32.858	8.59	0	32.858
Oct	39.804	23.235	0.584	29.958	8.004	1.311	31.269
Nov	97.464	158.177	1.623	35.999	9.224	10.144	46.143
Dec	134.464	181.299	1.348	42	10.435	15.389	57.389

Appendix Table 6: Summary of input and output from the desktop reserve model applied to the Ruvu River at Morogoro Road Bridge, based on 1951–1977 monthly flow series for **Ecological Management Class = C/D**

Annual flows (Mm^3 or index values)					
MAF	=	1829.61	Total Environmental flow	= 330.576	(18.07% MAR)
S.D.	=	805.70	Maintenance Low flow	= 216.740	(11.85% MAR)
CV	=	0.44	Drought Low flow	= 142.674	(7.8% MAR)
Q75	=	41.16	Maintenance High flow	= 113.836	(6.22% MAR)
Q75/MMF	=	0.27			
BFI	=	0.39			
CV(JJA+JFM)	=	1.22			

Month	Observed flow (Mm^3)			Environmental flow requirement (Mm^3)			
				Low-flows		High-flows	Total-flows
Month	Mean	SD	CV	Maintenance	Drought	Maintenance	Maintenance
Jan	133.75	154.688	1.157	15.341	9.08	16.356	31.697
Feb	107.276	68.781	0.641	15.155	10.12	8.178	23.333
Mar	156.205	107.028	0.685	17.542	11.652	43.27	60.812
Apr	391.955	201.716	0.515	27.09	17.784	30.347	57.437
May	464.701	179.973	0.387	32.846	21.481	0	32.846
Jun	146.713	77.081	0.525	24.639	16.21	0	24.639
Jul	71.362	22.804	0.32	19.43	12.865	0	19.43
Aug	46.953	15.57	0.332	14.409	9.64	0	14.409
Sep	38.963	20.334	0.522	11.867	8.008	0	11.867
Oct	39.804	23.235	0.584	10.995	7.448	0.766	11.761
Nov	97.464	158.177	1.623	12.811	8.614	5.927	18.738
Dec	134.464	181.299	1.348	14.615	9.773	8.992	23.607