FINAL REPORT

Rapid Environmental Flow Assessment for IRRIP2 Rivers in Kilombero River Basin

Consultancy Report submitted to CDM

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EXECUTIVE SUMMARY

The CDM INTERNATIONAL INC commissioned this study to conduct a rapid domestic water needs and environmental flow assessment that will inform the ongoing feasibility studies for the development of the four IRRIP2 irrigation areas and the associated ongoing environmental impact assessment work covering the same areas in the Kilombero sub-basin. The work utilizes the historical river flow data from the available gauging stations in the sub-basin.

The domestic water needs for villages surrounding the Mpanga, Udagaji, Mgugwe, Chuwachuwa and Ruipa rivers in the IRRIP2 irrigation project have been estimated based on information collected from the project beneficiary villages, namely Kisegese, Udagaji, Mgugwe and Mpanga. The domestic water uses was found to comprise of water for cooking, watering flowers and home gardens, flushing the toilets, mopping, washing utensils, washing clothes, constructing houses, brick making, pottery, cooling the milling engine, washing motorcycle/bicycles, local wine making (*Komoni*), watering animals (cows, goats, poultry, pigs), construction of brick kilns, bathing and drinking. In annual terms, the annual total domestic water need was estimated at 348,380,024 liters/annum for Ruipa River, 144,163,722 liters/annum for Mgugwe River, 363,192,621 liters/ annum for Mpanga River and 93,544,720 liters/annum from Udagaji River.

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This study applied a Desktop Reserve Model (DRM) to provide initial estimates of environmental flows for all rivers in IRRIP2 project area based solely on hydrological data. Detailed presentation of the findings is provided for Mnyera River for the Ecological Management Classes A to D, and they could be implied too for other rivers (e.g. Mpanga, Mgugwe, Kihansi, Udagaji, Chiwa Chiwa, Londo and Ruipa). Findings show that to maintain the Mnyera River at class A, an average annual environmental flow allocation of 1616.16 Mm^3 (equivalent to 65.58% of MAR) is required. This is the average annual “maintenance flow”; the sum of the maintenance low flows (i.e., 54.87 % MAR; 1352.21 Mm^3) and the maintenance high flows (i.e., 10.71% of MAR; 263.95 Mm^3). The drought-low-flows correspond to 10.17% of MAR (i.e., 250.58 Mm^3). These flows are distributed appropriately across the year and take into consideration the high and low flow months provisioning. For lower class, EMC = D, the total annual maintenance flow is estimated at 17.37% MAR; 428.09 Mm^3. Such a wide range in environmental water provisioning provides the stakeholders, managers and decision makers a better idea of the possible range of required flows to maintain the river in different desired river flow conditions. Therefore, if stakeholders decide to go for EMC=A, it means, more water will have to be left flowing in the rivers. In other words, it does not entertain river abstractions/ or development for other uses such as

irrigation. Going for EMC=D, means you will have more water available in the river for other uses, such as to meet irrigation water needs but with a bit of a compromise with the ecological conditions of the river. Therefore, a tradeoff is required between river development and environmental provisioning. As such, this can be achieved by making use of the generated information on monthly available discharge in relation to desired EMC.

More importantly is a realization of the fact that where water withdrawals are essential for livelihoods, there is a need to consider trade-offs in water provision to different ecosystems. It is also 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 carry out detailed analysis of possible irrigable area based on available water after accounting for EF allocation for different EMCs and domestic water needs.

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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
IUCN	International Union for Conservation of Nature
JICA	Japan International Cooperation Agency
MAR	Mean Annual Runoff
Mm^3	million cubic meters
MoW	Ministry of Water
WRMA	Water Resources Management Act

1.0 INTRODUCT ION

1.1 Overview on Environmental Flows

Developing water resources without degrading ecosystems is a challenging but prudent goal, given that a large proportion of rural Africans depend directly on the ecological services of rivers and river corridors (McClain, Kashaigili and Ndomba, 2013). These services include the provision of water, fish, and other food sources (e.g. mollucks and crabs) that contribute to meeting basic nutritional needs. A recent study by the International Union for Conservation of Nature (IUCN) found that people harvest 45% of all known African fish species, mainly for human consumption. People also harvest 58% of aquatic plant species, mainly for non-food uses such as fibre and building materials (Darwall *et al.*, 2011). Other important ecosystem services include groundwater recharge, assimilation of contaminants (especially nutrients and organic wastes), and storage of carbon. To protect these services, water managers must ensure that sufficient flows are preserved in rivers. But how much flow is “sufficient”? How much water does a river need to be ecologically healthy? And equally important is how much water can be taken from a river before its ability to meet social, ecological and economic needs is hindered? Another challenge is on how to estimate the ecological reserves and the mechanisms for allocation of water for regulated river while ensuring the water-dependent livelihoods of the poor are not affected. River scientists have examined these issues in great detail over the past 25 years, and a number of methodologies have been developed to assist in addressing them (Arthington *et al*., 2010; Tharme, 2003). Different names and definition have been used for environmental flow, such as in-stream flow, minimum flow requirements, ecological flow, ecological reserve, environmental reserve and riparian flow.

An environmental flow (EF) which is referred to in other literature as in-stream flow, minimum flow requirements, ecological flow, ecological reserve, environmental reserve and riparian flow, 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 (Kashaigili *et al*., 2007). 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 (Kashaigili *et al*., 2007). 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 flows in Tanzania

Recognizing their importance to river health and function, Tanzania has adopted the principle of environmental flows in the National Water Policy (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.

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 namely (i) hydrological index methodology; (ii) hydraulic rating methodology; (iii) habitat simulation methodology and (iv) holistic methodology. Each method has advantages and disadvantages and the applicability of any method is in accordance to the task to be undertaken; e.g. scoping, river basin planning or detailed assessment. The choice of any of the methods depends on the objectives of the analysis, the resources available (both human and financial) and data.

2.0 OBJECTIVE AND SCOPE OF THE ASSIGNMENT

The objective of the assignment was to conduct a rapid domestic water needs and environmental flow assessment that will inform the ongoing feasibility studies for the development of the four IRRIP2 irrigation areas and the associated ongoing environmental impact assessment work covering the same areas in the Kilombero sub-basin. The work utilizes the *historical river flow data* from the available gauging stations in the sub-basin.

2.1 Specific Tasks

The specific tasks of the assignment include:

- Literature review on EFA with specific reference on Kilombero River. The review will attempt to understand current abstraction patterns, water utilization and water use efficiency and how they impact on water resources;
- Undertake a quick reconnaissance of the Kilombero River to understand the hydrology and biophysical condition of the sub basin and identify critical points relevant for this study;
- Undertake a study of existing data on ecology and hydrology for Kilombero River. Possible sources may include Institute for Resource Assessment, Ministry of Water data base and Rufiji Basin Water Office in Iringa;
- Carry out a desktop reserve model customization and modeling including checking data quality, flow naturalization, calibration, verification of model and its application;
- Prepare a comprehensive report and present study findings to a team of scientists for a review and comments before production of a final report;
- Present study findings to stakeholders (USAID, MoW, Basin Office, CDM Smith, MAFC, ZIO).

2.2 Irrigation and Rural Roads Infrastructure Project

Under the Irrigation and Rural Roads Infrastructure Project (IRRIP 2), four areas are to be developed for irrigated rice production in the Kilombero valley. All four areas use rivers which arise in the Udzungwa mountain range and are tributaries leading to the Kilombero River. From north to south these are:

- Kisegese using the Ruipa, Chiwa Chiwa and possibly Londo rivers with catchment areas of 792, 436 and 270 km^2 respectively;
- Udagaji using the Udagaji and Kihansi rivers and adjacent ephemeral streams. The Udagaji River has a catchment area of 25 km^2 and the Kihansi River has a catchment area of 621 km^2;
- Mgugwe using the Mgugwe river which has a catchment area of 213 km^2; and
- Mpanga – Ngalimila using the Mpanga River which has a catchment area of 2515 km^2.

2.3 Deliverables

The deliverables from this assignment include:

i. A brief Trip Report documenting the activities undertaken during the field visit and submitted upon completion of the field work.

ii. Quick EFA report with clear initial estimate of domestic water needs and environmental flows for rivers feeding the IRRIP 2 project areas with specific estimates for the Mpanga, Mgugwe, Kihansi, Udagaji, Chiwa Chiwa, Londo and Ruipa rivers.

3.0 DESCRIPTION OF THE KILOMBERO CATCHMENT

3.1 Location and general characteristics

The Kilombero River catchment is situated in Morogoro Region in eastern Tanzania and lies between longitudes 34.563° and 37.797° east and latitudes 7.654° and 10.023° south (Figure 1). Administratively, Kilombero catchment falls between two districts which are Ulanga and Kilombero. Ifakara is the headquater of Kilombero district and Mahenge for the case of Ulanga. Kilombero River Catchment is one of the four sub basins forming the Rufiji basin. The Kilombero River catchment is surrounded by high mountains on both sides and mountains extend from a flat and wide plain on the side of Great Ruaha and slope abruptly down into the Kilombero valley, covering an area of about 40 330 km^2 of the catchment (RBWO, 2010). To the north and west of the Kilombero Valley are the Udzungwa Mountains, and to the east, the Mahenge highlands. The ridge drops from an elevation of more than 1,800 m asl to about 300 m asl in a few kilometers (WREM International, 2012), forming the Kilombero floodplain with wide spread wetland. The Kilombero valley contains one of the largest freshwater wetlands in East Africa, forms part of the Great Selous Ecosystem, a World Heritage Site, and was recently designated a Ramsar Site (Ramsar Bulletin Board, 2002). The Kilombero floodplain covers an area of approximately 260 km by 52 km (Ramsar Bulletin Board, 2002), and areas for irrigation sum up to 329600ha for surface water irrigation (Kato, 2007).

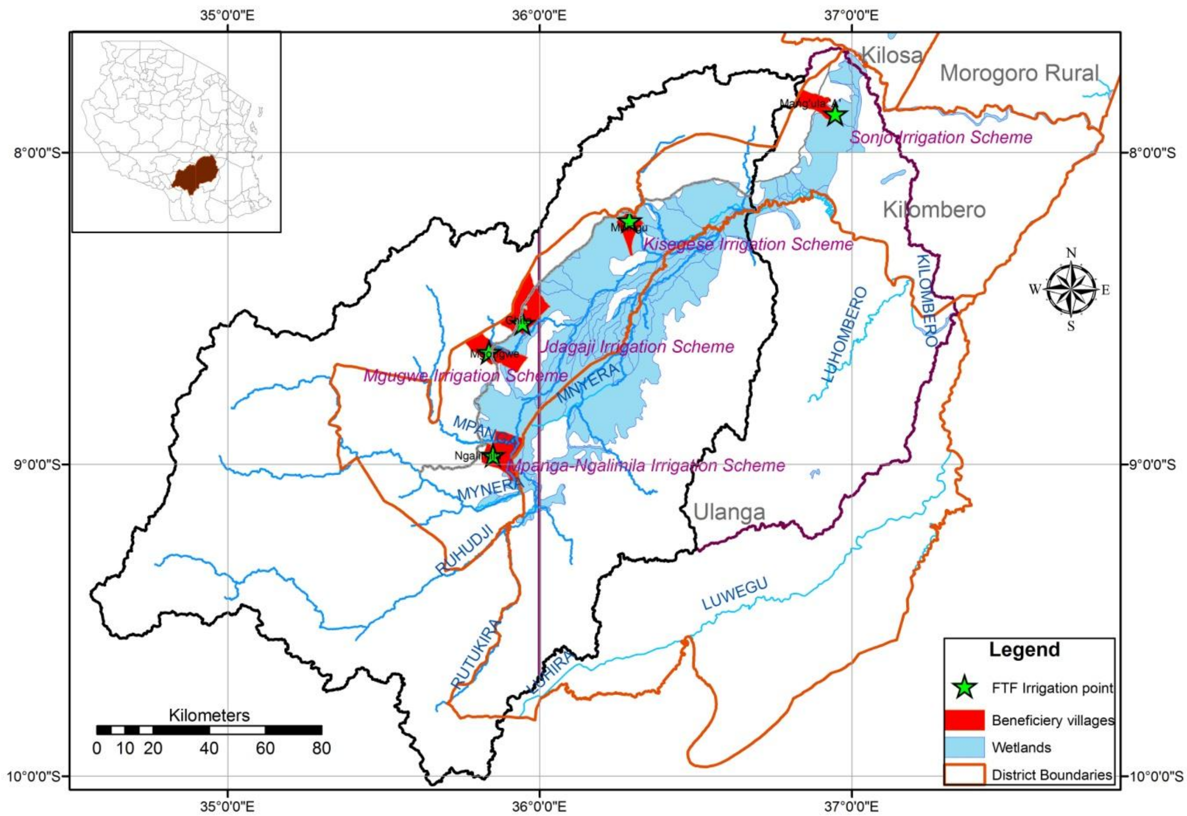


Figure 1: Location of the study areas in Kilombero Catchment

3.2 Climate of the Kilombero catchment

Rainfall

The climate of Kilombero catchment varies depending to the topography and it is hot and humid in the valley. There are more rainfall stations in the highland as compared to lowland areas (Figure 2). The analysis of mean monthly rainfall data indicates that Kilombero River catchment experiences bimodal rainfall regime (Figure 3 a-f). The mean annual rainfall within the catchment varies from 1100 – 2100mm (WREM International, 2012). The eastern Mahenge and Central Udzungwa Mountains receive the highest rainfall between 1500 – 2100mm as well as the low altitude southwest plains. The Kilombero plains receive annual rainfall between 1200 – 1400mm. Rainy seasons is between December and April while June to September experiences dry season. The rainy season constitutes the largest part of annual rainfall for about 80 – 90% and it is below 10mm monthly rainfall in dry periods, excluding in the Udzungwa Mountains.

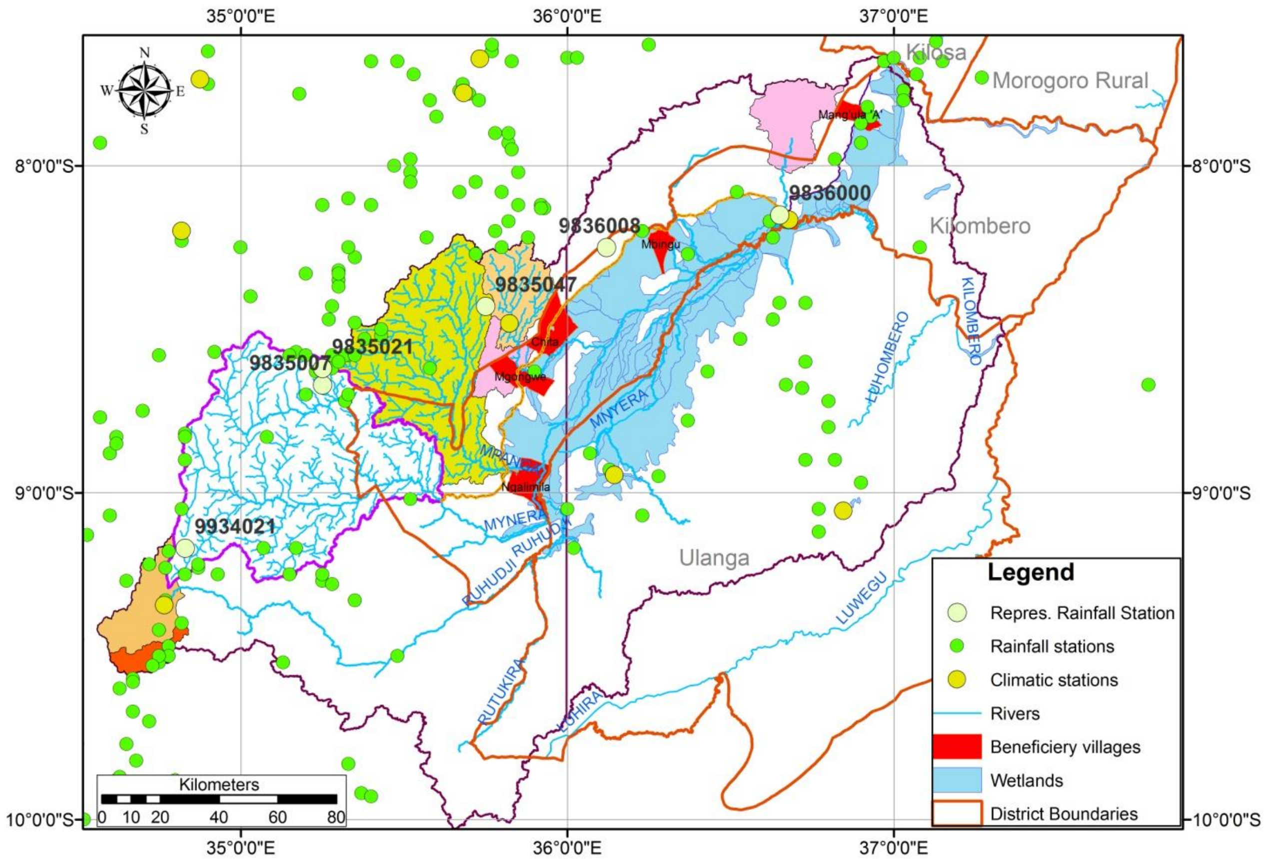
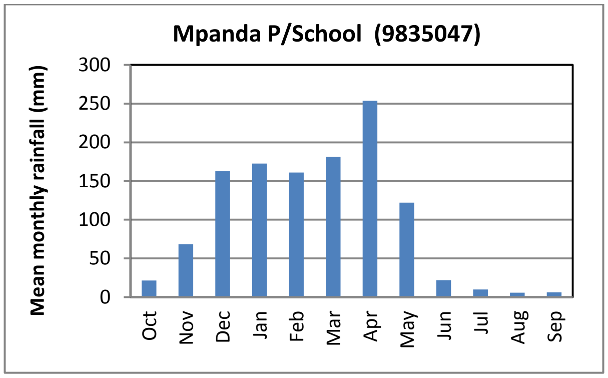
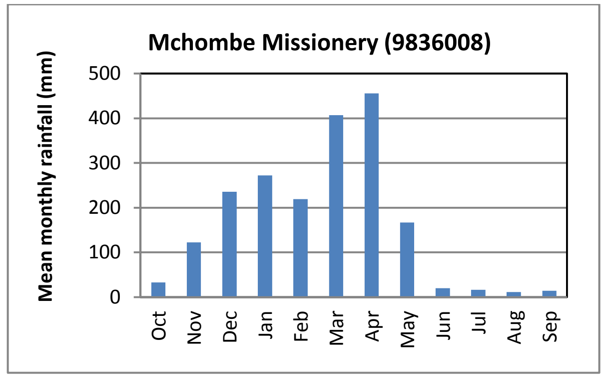


Figure 2: Spatial distribution of rainfall stations and climatic stations in Kilombero catchment. (Representative rainfall stations (whitish in color) stand for stations with plotted mean monthly rainfall in different catchment zones)



(a)



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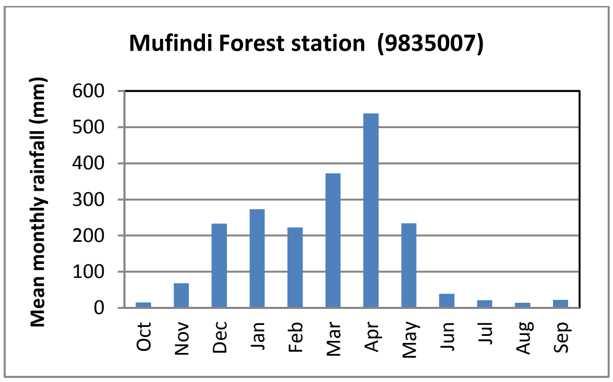

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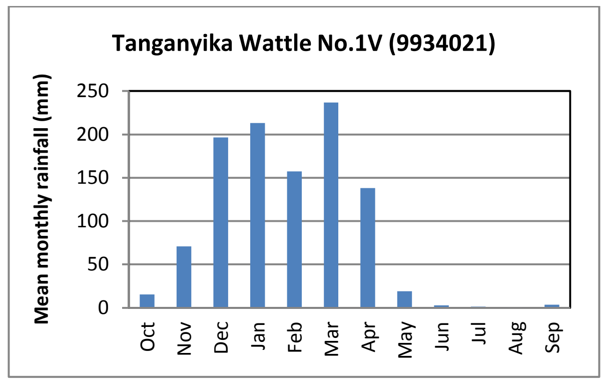

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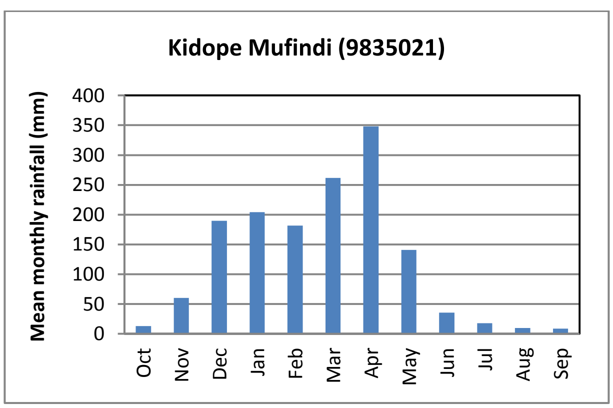
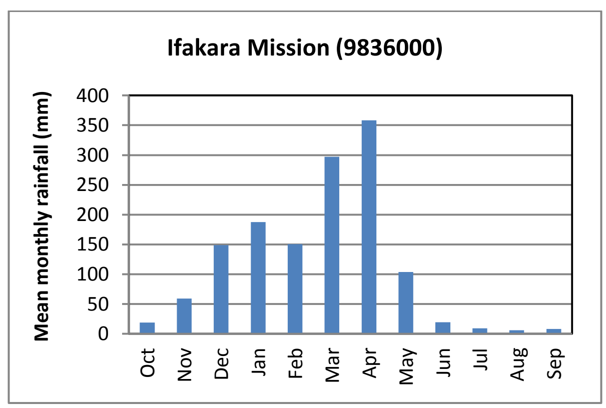


(e)



(f)

Figure 3: Mean monthly rainfall for different rainfall stations in the Kilombero River Catchment

Temperature and wind

Temperature also varies within the catchment. In the lowlands, the annual mean daily temperature is 24°C while in the highlands; the annual mean daily temperature is 17°C. The temperature is at the warmest peak in December and January where in the lowlands the day temperature exceeds 27^{o}C and 19^{o}C in the highlands. The coldest month is July with temperature around 14^{o}C and 21^{o}C in the highlands and lowlands respectively. In the Udzungwa Mountains, the relative humidity is between 70 – 87% and in the lowlands experience 58 – 85%. Estimated annual potential evaporation is about 1800mm per annum in Kilombero.

The wind blows calmly in this area despite two months of October and November where there is occurrence of strong wind and that little risks of crop damage are often observed (Kilombero farm, 2004). The area can therefore be regarded as a free windy area.

3.4 Catchment hydrology

3.4.1 Drainage patterns

The hydrology of the catchment is influenced by the topography and climate. Several rivers drain large headwater watersheds (Figure 4) that support extensive agricultural developments and eventually discharge into the Kilombero valley floodplain. The floodplain is fed by many rivers and with huge seasonal variations in the water dynamics. A huge and impressive floodplain is created, the Kilombero (*Kibasila*) Wetland. The Wetland itself is made up of a mosaic of swamps, small ponds and Valleys, grasslands and riverside forests. As it crosses the wetland, the Kilombero River disappears into a number of small meandering channels meaning that there is no distinct, main river channel. To the north and west of the Valley are the Udzungwa Mountains, with the Mahenge highlands to the east, making up its catchment area that is so crucial to the hydrology of the ecosystem. The catchment area is largely forested with extensive Miombo woodlands. Most of the rivers in the catchment originate from the Udzungwa Mountains and some from Mahenge Mountains. Many rivers in Kilombero are perennial even though some experience high flows during periods of heavy rainfall and dry up during the dry season. The major rivers (perennial) in the sub-basin include Mpanga, Kisegese, Kihansi, Mgugwe, Chiwachiwa and Ruipa rivers (USAID, 2012) and are among of the rivers which drain mainly from Udzungwa Mountains. The river Ruhudji drains the south Udzungwa and east Livingstone Mountains (WREM International, 2010). These rivers have varying catchment areas; Chiwachiwa (110km^2), Ruipa (183km^2), Mgugwe (213 km^2), Mpanga (1203km^2) and Udagaji is 25km^2 (USAID, 2012). The Ruhudji and Mnyera rivers are the two major tributaries that form the main Kilombero (Figure 4). Thereafter, the Kilombero flows for about 250 km north-eastwards within the seasonally flooded Kilombero plains where several small and medium sized tributaries such as Kihansi, Udagaji, Chita, Mngeta, Lwipa, Lumemo and Mchilipa and Sofi join the river before reaching the perennial Kilombero wetlands. Near the wetland outlet at Ifakara, the Kilombero is joined by Sonjo, flows southeast, and is joined by its last tributary, the Luhombero River which drains the eastern Mahenge Mountains. Finally, the Kilombero turns north-eastward to meet the Luwegu and form the Rufiji River (WREM International, 2012).

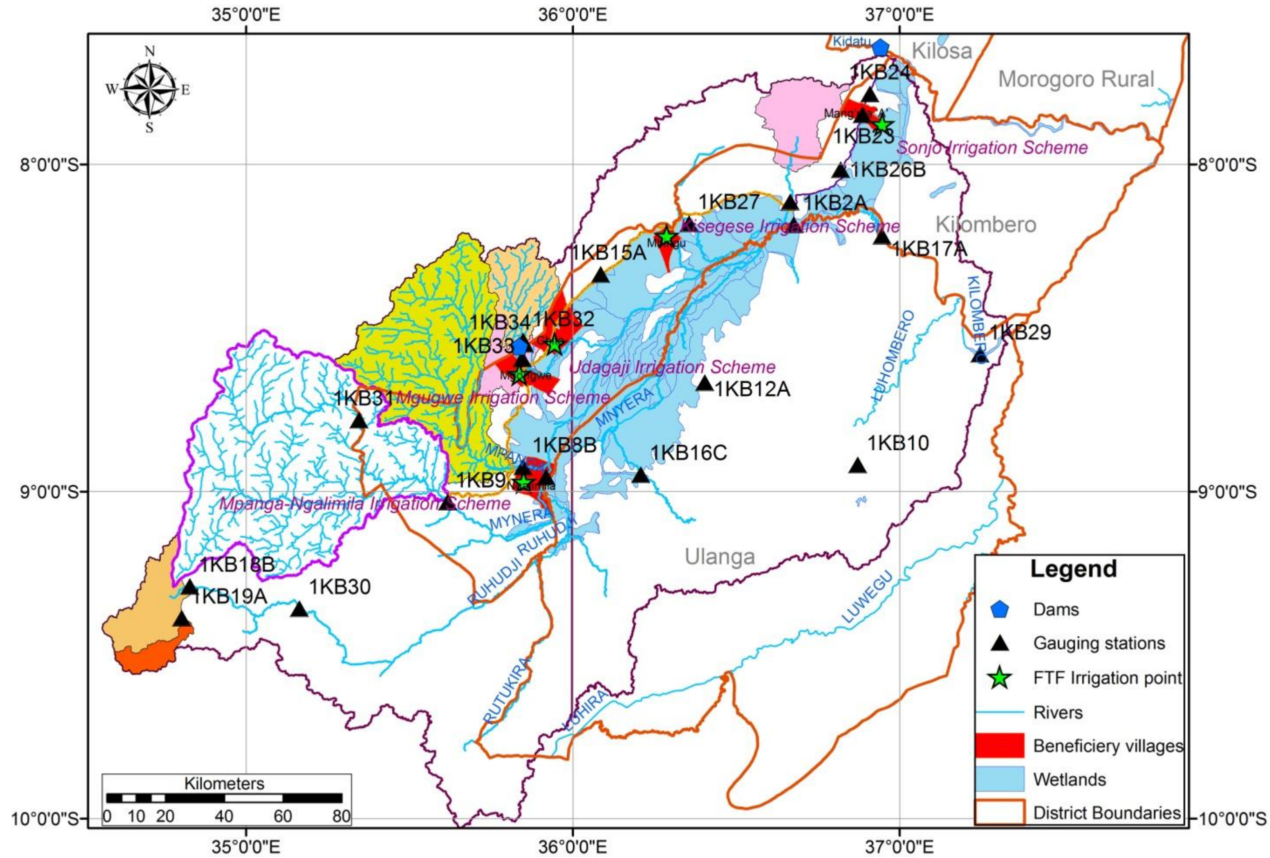


Figure 4: River network and spatial distribution of flow gauging stations in Kilombero catchment

3.4.2 River stages and discharges

Available information on hydrometric observations in the Kilombero River catchment indicate existence of flow gauging stations that have been operational in different periods (Table 1). With some exceptions of the Kihansi dam catchment gauging stations, most of the stations in Kilombero catchment were established between 1950s and 1960s and operated up to between late 1970s early 1990s. There is no reliable information to enable concrete assessment of the present flow situation in most of the stations. For Kihansi catchment, most of the gauging stations within the catchments have been established to provide the needed flow data for the design of Kihansi dam in the early 1990s and operation of the Kihansi reservoir since 1999. Consequently, the records at these stations span mainly the period since 1995. However, the longest and earliest at 1KB28, which is operated by RBWO, started in January 1974 through to 2008. Figures 5-9 present the time series of average daily flows for some rivers in the Kilombero catchment while Figure 10 presents the long term mean monthly flows for rivers in the project area and the measured discharges for respective rivers that were conducted in June 2013. The magnitude of the mean monthly flow correlated with the size of the catchment and the amount of rainfall. For example, the long term mean monthly discharge for Mnyera River (a large catchment in the study area) was found to be 155.53 m^3s^{-1} for April while for Udagaji River catchment (a smallest catchment) was 1.23 m^3s^{-1} for April. The measured discharges during the fieldwork in June 2013 were found to be within the June flow ranges thus giving confidence on the estimated discharges.

Table 1: Status of data availability for some river gauging stations in the Kilombero River Catchment

S/No	Reg. No.	River	Location	Location		Years of Record		Years
				Lat	Long	Start	End	
1	1KB2	Kilombero	Ifakara	-8.15	36.63	1954		
2	1KB4	Kilombero	Ifwema	-8.91	35.94	1955	1976	22
3	1KB8	Mpanga	Mpanga Mission	-8.94	35.81	1957	1978	22
4	1KB9	Mnyera	U/S Taveta Mission	-9.17	35.52	1956	1976	21
5	1KB10	Ruhudji	Mwayamulungu	-8.98	35.95	1960	1976	17
6	1KB12	Mchilipa	Itete D/S	-8.66	36.42			
7	1KB14A	Lumemo	Kiburubutu	-8.01	36.66	1967	1989	23
8	1KB15	Mgeta	D/S Mchombe Mis	-8.33	36.12	1958	1977	20
9	1KB15A	Mgeta	U/S Bridge	8.36	36.09	1960	1975	16
10	1KB16	Furua	Malinyi Mission	-8.95	36.00			
11	1KB17	Kilombero	Swero	-8.26	37.00	1957	1976	20
12	1KB18A	Ruhudji	Njombe	-9.33	34.76	1958	1973	16
13	1KB18B	Ruhudji	Below Kifung'a Falls	9.28	34.83	1976	1991	16
14	1KB19	Hagafiro	Hagafiro	-9.40	34.82	1961	1980	20
15	1KB20	Ijunilo	Kibena	-9.32	34.76	1960	1970	11
16	1KB23	Sonjo	Sonjo	-7.80	36.97	1962	1986	25
17	1KB24	Sanje	Sanje	-7.71	36.97	1961	1987	27
18	1KB26	Kiberege	Kiberege U/S	-7.95	36.96	1966	1989	24
19	1KB27	Ruipa	Mbingu	-8.24	36.29			
20	1KB28	Kihansi	Lugoda	-8.62	-35.85	1974	2002	29
21	1KB29	Luhombero	Luhombero	-8.58	37.12			
22	1KB32	Kihansi	Lutaki	-8.55	-35.85	1984	2002	19
23	1KB33	Kihansi	Below Kihansi			2007	2009	3
24	1KB34	Kihansi	Uhafiwa Bridge	-8.48	-35.82	1982	2002	21
25	FSU7	Kihansi	D/S Muhu Conf.	-8.42	-35.80	2000	2002	3
26	FSU8	Kihansi	U/S Muhu Conf.	-8.42	-35.80	2000	2002	3
27	FSU1	Kihansi	Ilogombe	-8.35	-35.80	1996	2000	5
28	FSU4	Muhu	Ilogombe	-8.35	-35.83	1996	2000	5
29	FSU3	Mkalasi	Kipanga	-8.40	-35.87	1996	2000	5
30	FSU2	Ruaha	Uhafiwa	-8.53	-35.85	1996	2000	5
31	FSU5	Ruaha	Kipanga	-8.45	-35.92	1996	2000	5
32	FSU6	Luvala	Kipanga	-8.43	-35.90	1996	2000	5

Source: (WREM International, 2012)

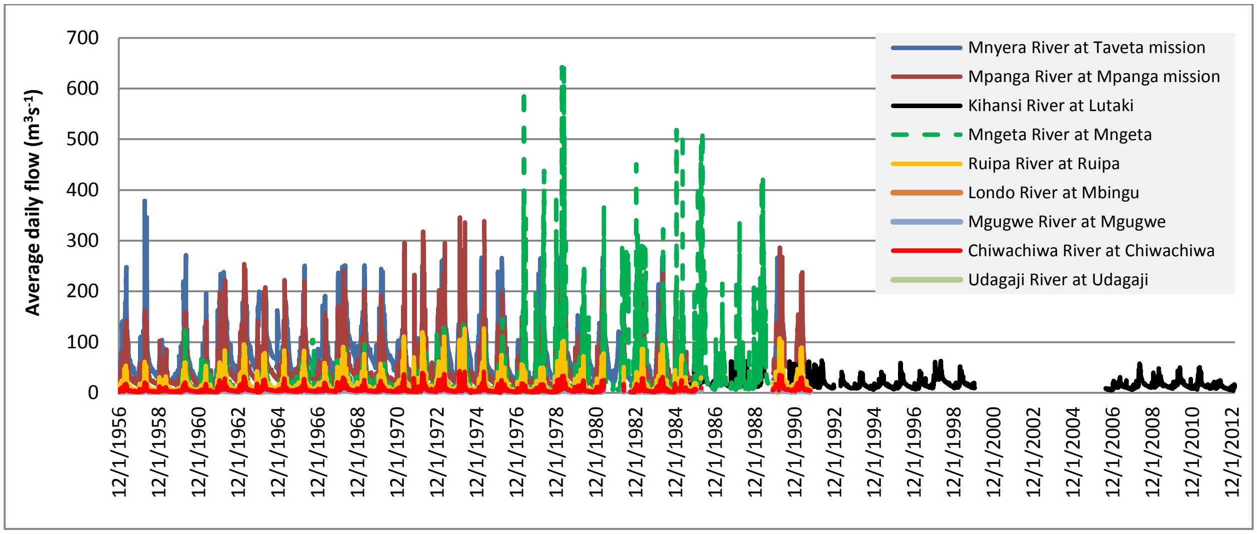


Figure 5: Time series of average daily flows for different rivers in the project area (*Note: data for Mngeta River between 1976 and 1988 portray a different pattern, which is inconsistent*)

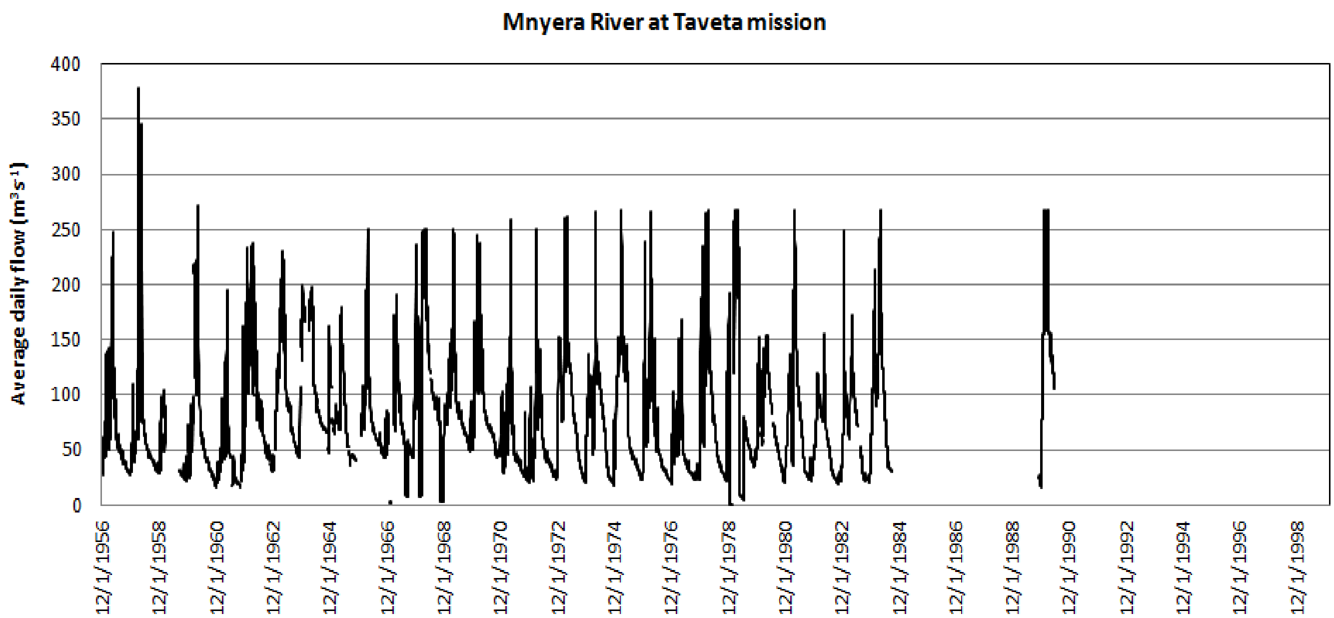


Figure 6: Time series of average daily flows for Mnyera River at Taveta mission (1KB9)

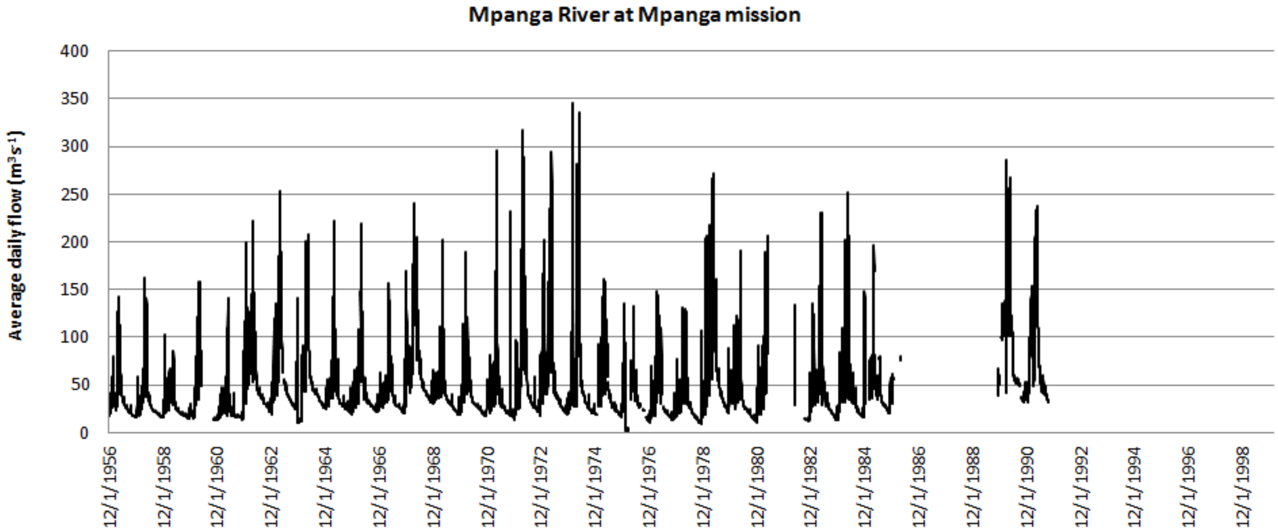


Figure 7: Time series of average daily flows for Mpanga River at Mpanga Mission (1KB8)

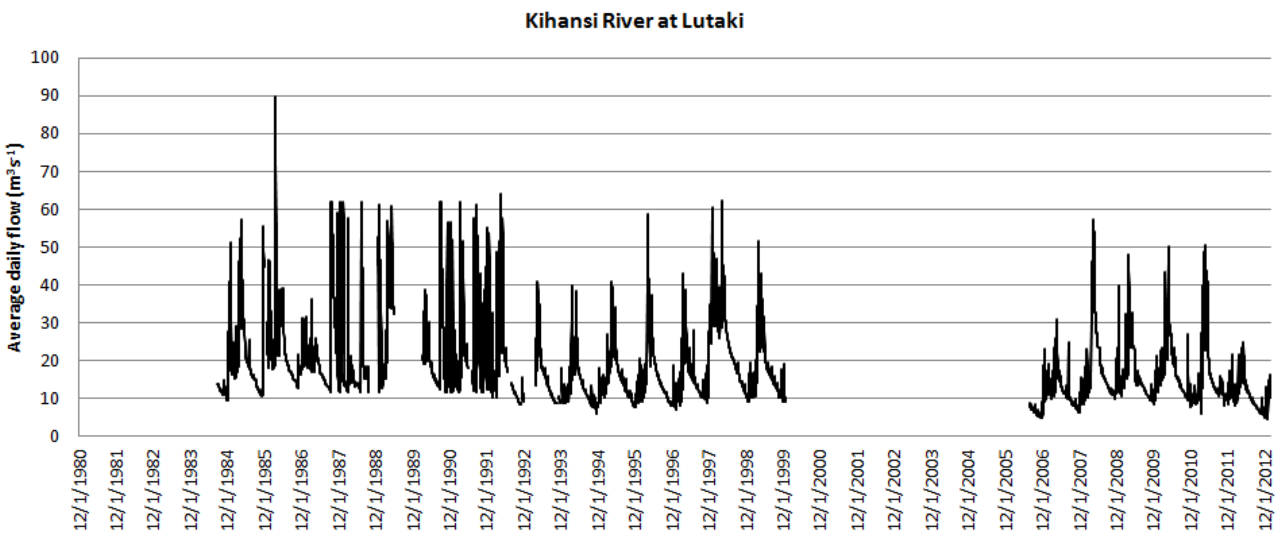


Figure 8: Time series of average daily discharge for Kihansi River (inflow) at Lutaki (1KB32)

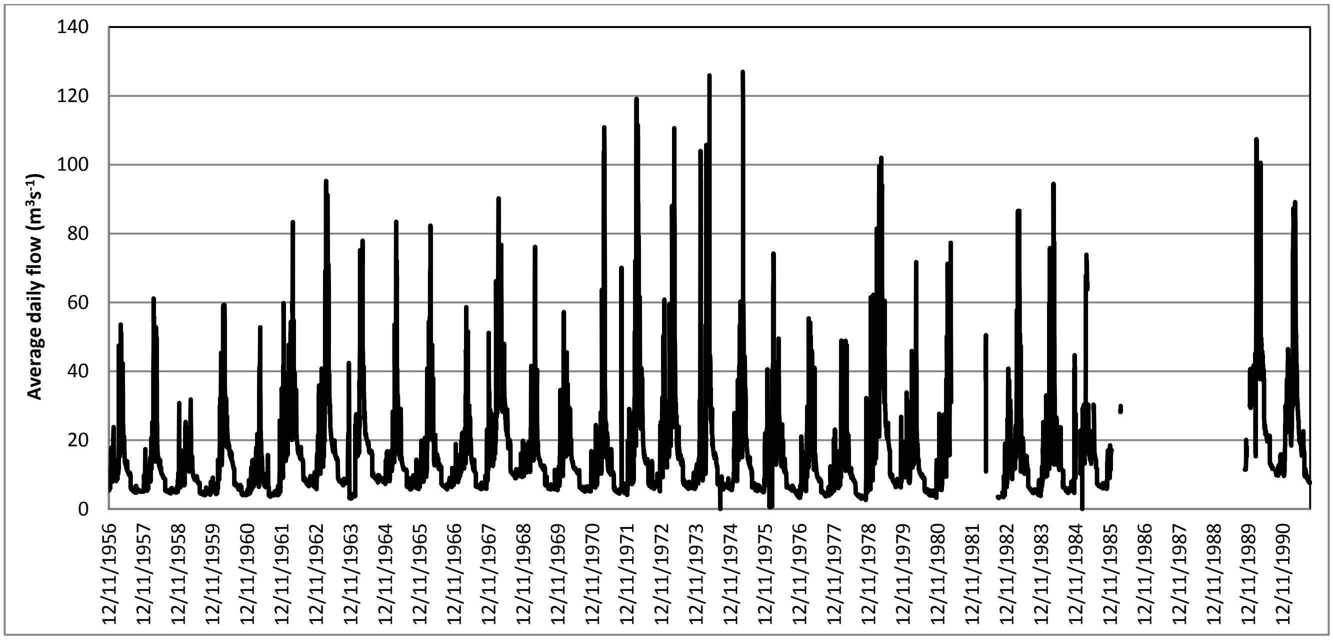
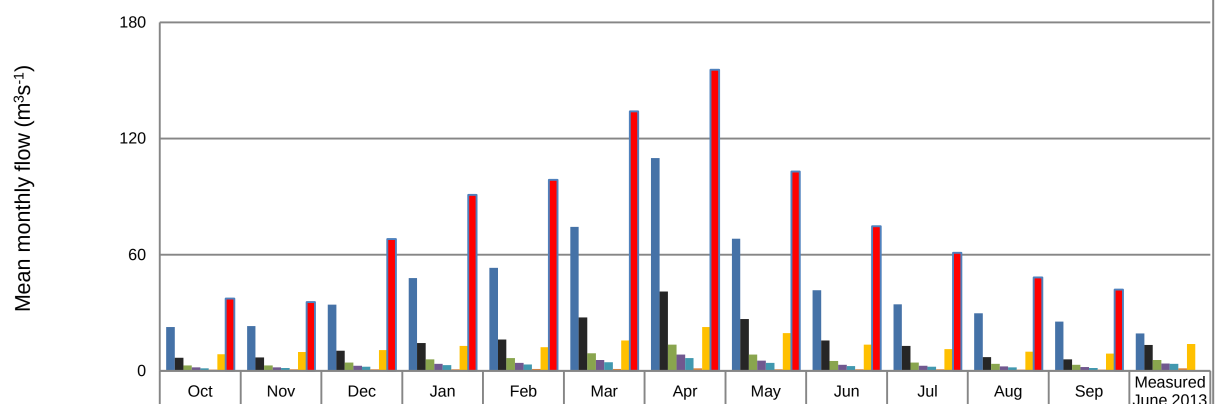


Figure 9: Time series of average daily discharge for Ruipa River at Mbingu



	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Measured June 2013
Mpanga River (1957-1991)	22.59	23.08	34.11	47.86	53.26	74.33	109.95	68.22	41.69	34.28	29.73	25.38	19.268
Ruipa River (1957-1991)	6.81	6.91	10.42	14.42	16.16	27.65	40.88	26.73	15.64	12.83	7.01	5.93	13.341
Chiwachiwa (1957-1991)	2.79	2.85	4.21	5.91	6.58	9.11	13.57	8.42	5.15	4.23	3.66	3.13	5.538
Londo River (1957-1991)	1.73	1.76	2.61	3.66	4.07	5.64	8.41	5.22	3.19	2.62	2.27	1.94	3.845
Mgugwe River (1957-1991)	1.36	1.39	2.06	2.89	3.21	4.45	6.63	4.11	2.51	2.07	1.79	1.53	3.535
Udagaji River (1957-1991)	0.62	0.72	0.72	0.88	0.90	0.90	1.23	0.83	0.76	0.76	0.67	0.72	1.283
Kihansi River (1985-2008)	8.54	9.79	10.75	12.84	12.13	15.71	22.67	19.45	13.56	11.24	9.94	8.95	13.901
Mnyera River (1956 - 1991)	37.29	35.46	68.10	90.82	98.56	133.99	155.53	102.94	74.67	60.95	48.30	41.97	

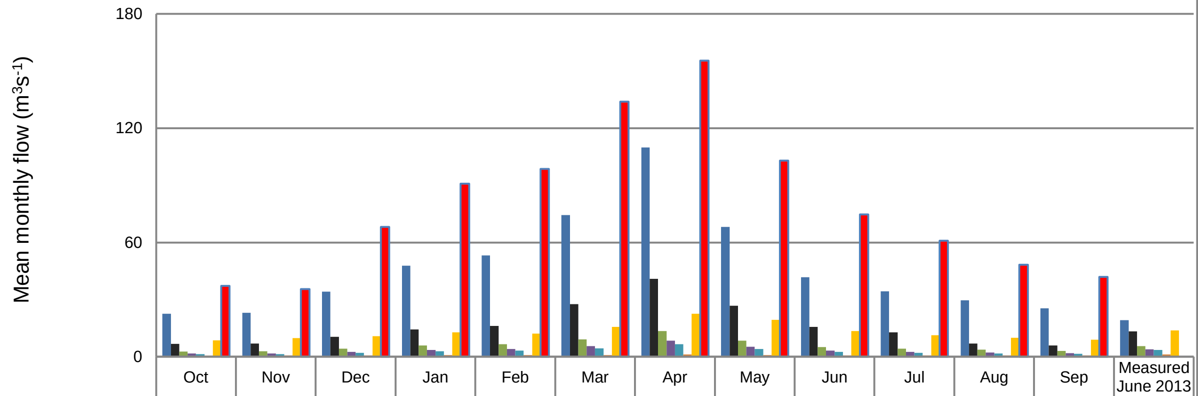


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Figure 10: Comparison of mean monthly flows between the periods and the measured discharges for the period 26th – 30th June 2013.

3.3 Land use and Land cover

The major land cover includes woodland, natural forest, cultivated land, water, bushland, grassland and urban (Figure 11). The major land use is agriculture being of rainfed agriculture, smallholder irrigation, residue moisture agriculture, homesteads and miombo wetlands (USAID, 2012). For example, agricultural potential area for Kisegese is (7298ha), Udagaji (1935ha), Mgugwe (2270ha) and Mpanga is 31,500ha (USAID, 2012). Thus from earlier, the region was considered as agricultural zone of high potential due to its fertile land (Deck, 1964). Agricultural expansion in the area goes simultaneously with changes in the river flow and thus Kashaigili (2008) and Yanda and Munishi (2007) advocate that land use change emerges a serious impact on hydrological regimes in Tanzania. Generally, the Kilombero valley is estimated to have potential areas for irrigation totaling to about 329,600 ha for surface water irrigation. Table 2 presents additional information on irrigation potential in the Kilombero Catchment.

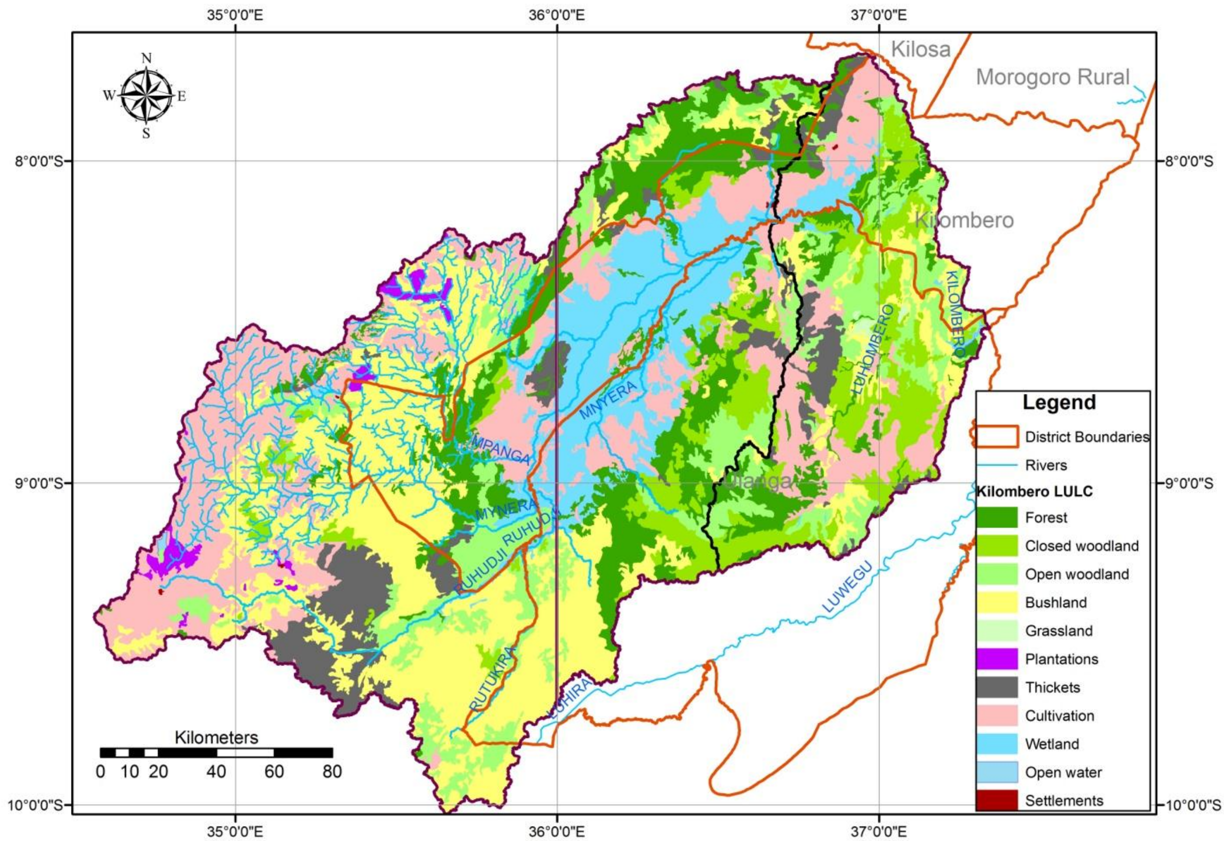


Figure 11: Land use land cover of the Kilombero Catchment
Source: FAO-Africover, 1997

Table 2: Irrigation potential in the Kilombero River Catchment

No.	Scheme	Owner	Capacity (ha)	Developed capacity (ha)	Use/ Product/ Crop
1.	Mngeta Farm	Commonwealth Development Corporation	5,780	5,780	Paddy
2.	Kihansi Farm		5,100		Paddy
3.	Ngalimira		5,000		
4.	Ngohelanga		5,000		Paddy
5.	Kilombero Valley Teak Company		28,000	11,500 (aim to develop at-least 13,000)	Teak
6.	Kilombero Sugar Company	Illovo Sugar (South African Company)	7,000	7,000	Sugarcane
7.	Escarpment Forest Company		15,000	15,000	Pine, Eucalyptus
8.	Kilombero Holdings Ltd	Kilombero Holdings Ltd	5,000	5,000	
9.	Idete & Kiberege Prison Farms		6,000	6,000	Paddy
10.	Mofu Farm	Canadian	500		Paddy
11.	Mbingu Farm	Mbingu Sisters	3,000	3,000	Paddy, maize, bananas & sunflower

Source: MNRT (2004) and RUBADA (2011)

The other important land use in the catchment is fishing. Fishing has traditionally been the primary resource use, though agriculture (especially rice farming) is rapidly expanding, as is cattle grazing due to immigrant pastoralists. There is also organized hunting in the dry season, which communities feel brings few local economic benefits.

3.5 Ecological aspects

Both aquatic fauna and flora are available in the Kilombero valley and in high diverse of species due to its various fluvial environments. However, numerous groups of aquatic birds are found such as *Varanus niloticus*, *Crocodylus niloticus*, and *Hippopotamus amphibious*. The area also consists of endemic birds which are two species of Cisitcola warblers and species of Kilombero weaver. Furthermore, there are 21 biome-restricted species and biogeographically populations of three water birds species and high density of raptors (Starkey *et al.*, 2002). It has regarded as 'Conservation Dependent' (IUCN, 1997) due to massive of large mammals such as *Loxodonta africana, Syncerus caffer* and *Kobus vardonii* that keep migrating and move seasonally to and from the Selous Game Reserve.

Fish an important aquatic fauna in the Kilombero River. It hosts a highly productive fishery (Bernacsek, 1981) with a potential yield of up to 25,000 tons per year. However, the catchment also supports industrial water uses (e.g., the Mufindi pulp mill), the effluent of which threatens its fishery and other environmental resources.

Most riverine fishes in the Kilombero River catchment, 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. Therefore, for the optimal functioning of a floodplain, seasons of low and high flow, are required. It is therefore essential to maintain 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 conditions to avoid reproductive failure (Norconsult, 2008).

The Kilombero River Catchment is also rich in the aspect of animal species. Animals that are kept include poultry, cattle, goats and pigs. According to WREM International (2012), other species are fish, crocodiles, monkeys and toads found in Kihansi River. There are Puku antelope (East, 1998), elephant, buffalo and other species of antelope. However, predator species found involve lion, leopard, spotted hyena and African wild dog. The catchment also has animals migrating to and from the valley (Wetlands International, 2007 and Starkey *et al.*, 2007). The valley is an Endemic Bird Area (EBA), species being the Kilombero weaver, Kilombero *cisticola* and the white tailed *cisticola* (Stevenson and Fanshaume, 2002). Furthermore, there is Udzungwa red colobus monkey.

The classification of vegetation types in the Kilombero River catchment (descriptive rather than quantitative) Starkey *et al*. (2002) identified eight different plant communities namely riverside grass, low-lying valley grassland, tall grass, marginal grassland, combretaceous wooded grassland and miombo woodland. The vegetation are both natural and planted (Munishi *et al.*, 2011). The natural vegetation types include valley-bottom wetlands, natural grasslands, wooded grasslands, and miombo woodlands whereas planted are Eucalyptus and Pine Plantation. Vegetation in the catchment serves not only conservation but also make a dwelling place for wild animals and birds, supports the fisheries industry, bee keeping, rearing of domestic animals and maintains the stability and fertility of the valley floodplains.

There have been some ecological concerns following the construction of Kihansi dam in the Kihansi River. During the construction phase of the Lower Kihansi project, the ecological quality and importance of the gorge below the dam was compromised. Since then, extensive measures have been taken to protect the gorge, but the damage (including the loss of habitat of a rare toad species) appears to be irreversible (TANESCO, 2006). The lower portion of the Kilombero River is located in the Selous Game Reserve.

3.6 Catchment Water Abstractions and Uses

3.6.1 Registered water use permits

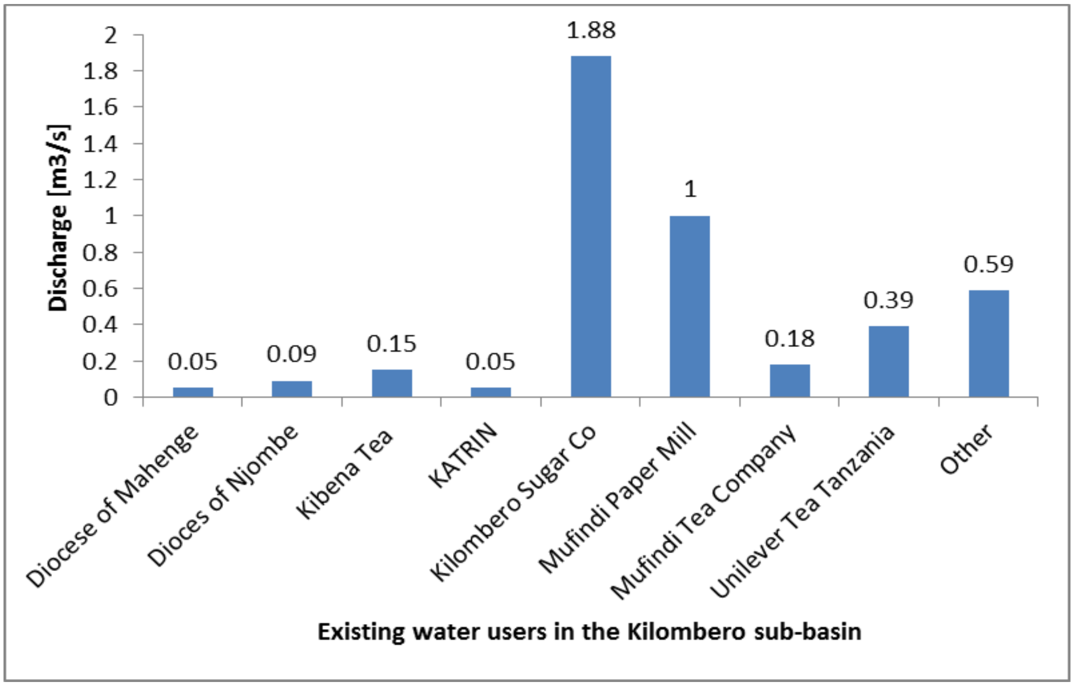
Kilombero River Catchment has various abstractions for irrigation, domestic and hydropower systems. Registered abstractions (Table by the Rufiji Basin Water Office indicate that the type of water sources range from shallow wells, boreholes, springs and river water. Types of main abstractors in the Kilombero catchment fall under hydropower, industrial, irrigation and domestic needs. The major current water abstractions in the Kilombero sub basin consist of irrigation for the Kilombero Sugar Company, the Mufindi Paper Mill, and Unilever Tea Tanzania Limited in Njombe, and for domestic consumption. It is however noted that hydropower is a non-consumptive use as normally water is returned back to the river. Figure 12 indicate the types of abstractors and amounts approved by Rufiji Basin Water Office (RBWO).

Table 3: Summary of registered and provisional water use permits/ abstractions in the Kilombero Catchment

Water source	**No. of registered water use permits**	**Total amount allocated (m^3d^{-1})**
Rivers	68	435.281
Boreholes and wells	5	0.005
Springs/ stream	26	0.204
Reservoirs	1	0.0003
Swamp	1	0.153
Total	**101**	**435.643**
	No. of provisional water use permits	-
Rivers	37	24.432
Boreholes and wells	13	0.166
Springs/ stream	31	1.991
Reservoirs	0	-
Swamp	0	-
Total	**81**	**26.588**
Grand Total	***182***	***462.231***

Source: RBWO Water User Database, 2013

Note: These are historical and documented information on abstractions from RBWO Water permit database, but according to the basin management, there a lot of abstractions that are not yet documented. A recent water point abstractions survey in Ulanga District which was conducted in May 2013 revealed existence of at-least 790 boreholes and wells. A major deficiency of this survey is lack consistency in documenting dates and quantities of abstractions.



Source: WREM International (2012).

Figure 12: Existing water users in the Kilombero River Catchment

3.6.2 Domestic water needs in the project beneficiary villages

According to DFID (2003), domestic water use is referred to as the water required fulfilling basic water supply and sanitation needs. Basic water supply needs reflect water used for drinking, food preparation, bathing, laundry, dishwashing and cleaning while basic sanitation needs implies water used for waste disposal. In Kilombero River Catchment, there are various domestic water uses with reference to study villages surrounding the Mpanga, Udagaji, Mgugwe, Chuwachuwa and Ruipa rivers. The studied villages include Kisegese, Udagaji, Mgugwe and Mpanga. Domestic water uses in these villages include water for cooking, watering flowers, watering gardens, flushing the toilets, mopping, washing utensils, washing clothes, constructing houses, brick making, pottery, cooling the milling engine, washing motorcycle/bicycles, local wine making (*Komoni*), watering animals (cows, goats, poultry, pigs), construction of brick kilns, bathing and drinking. In the studied villages, however, there are various institutions such as dispensaries, churches, mosques, schools, guest houses, canteens that use water at a different rate as compared to household level. The major source of water in these study villages are rivers and minor ones are wells, hand pumps (*midundiko*), dams and seasonal streams. The rise and fall of water level in the rivers and wells was reported to go simultaneously. Table 4 presents a summary of annual total domestic water needs in the study area. As shown on Table 4, the annual total domestic water need of river dependent villages is estimated at 348,380,024 liters/annum for Ruipa River, 144,163,722 liters/annum for Mgugwe River, 363,192,621 liters/ annum for Mpanga River and 93,544,720 liters/annum from Udagaji River.

Table 4: Estimated domestic water needs in the study area

	Annual volume (lts) villagewise			
	Kisegese	**Mgugwe**	**Mpanga**	**Udagaji**
Number of Households	**870**	**492**	**854**	**425**
Average Household size	**5**	**4**	**4**	**4**
Estimated population	**4350**	**1968**	**3416**	**1700**
Name of dependant river	**Ruipa River**	**Mgugwe River**	**Mpanga River**	**Udagaji River**
Water uses				
Cooking	12,702,000	7,183,200	12,468,400	4,653,750
Watering flowers	197,100	202,150	134,125	117,150
Watering gardens	9,526,500	8,097,800	23,400,000	9,307,500
Flush toilets	13,337,100	10,774,800	10,130,575	5,739,625
Mopping	15,877,500	6,734,250	15,585,500	4,653,750
Washing utensils	6,351,000	7,183,200	14,026,950	6,205,000
Washing clothes	16,286,400	15,578,000	15,585,500	3,536,000
Canteen services	459,900	175,200	1,460,000	175,200
Constructing houses	569,400	480,800	654,850	60,000
Brick making	57,600	54,830	900,000	115,200
Local wine making (*Komoni)*	700,800	438,000	456,250	112,320
Watering animals	1,428,975	102,200	22,582,185	2,545,875
Bathing	31,755,000	17,958,000	24,936,800	18,615,000
Making brick kilns	73,000,000	64,084,000	38,132,000	33,404,800
Drinking	3,796,000	2,693,700	4,052,230	2,171,750
Washing bicycles and motorbike	7,499,183	2,423,592	6,648,646	2,131,800
Total water needed	**193,544,458**	**144,163,722**	**191,154,011**	**93,544,720**
Other villages depending on the river	**Mbingu and Mofu**	**None**	**Kitengule, Ngalimila & Matema**	**None**
Percentange water use by other villages depending on the same river source	80%		90%	
Grand total domestic water needed	***348,380,024***	***144,163,722***	***363,192,621***	***93,544,720***

4.0 ENVIRONMENTAL FLOWS ASSESSMENT

4.1 The EFA methods

Various methodologies have been developed to assist in addressing EF (e.g. Arthington *et al*., 2010; Tharme, 2003). According to Dyson *et al*., (2003) these can be broadly classified into four categories (Table 5).

Table 5: 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; v. Long time series of data required.
3	Functional analysis or Holistic Methods	i. Build an understanding of the functional links between all aspects of the hydrology and ecology of the river system;

S/N	Environmental Flow Assessment Method	Characteristics of Each Environmental Flow Assessment Method
	(e.g. Building Blocks Method (BBM), Expert Panel Assessment Method, Scientific Panel Approach, Benchmarking Methodology, DRIFT)	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.

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 (Kashaigili, 2011). 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 6). Depending on the management target, it is possible to define threshold flows.

Table 6: 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
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.

EMC	Ecological description	Management perspective
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, Mozambique (Hughes and Hannart, 2003), and of recent in Great Ruaha River Catchment and Ruvu Catchment in Tanzania (Kashaigili, 2011). 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 in Kilombero River catchment Rivers

The rivers draining the project area, namely Mpanga, Mgugwe, Kihansi, Udagaji, Chiwa Chiwa, Londo and Ruipa Rivers were assessed for EF using a desktop reserve model. 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 stakeholders a wider possible range of required flows to maintain the river in different ecological 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 flow from the seven rivers (i.e. Mpanga, Mgugwe, Kihansi, Udagaji, Chiwa Chiwa, Londo and Ruipa) spanning the periods 1957 to 1984 for all the rivers with the exception of Kihansi, were used as inputs after filling some data gaps. The period 1957 to 1984 was considered to be a period with very minimal anthropogenic effects on river flows and thus represented nearly a natural flow condition. For Kihansi River, the pre- Kihansi dam river flow regulations spanning the period 1987 to 1999 was used.

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

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

- Equation 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±1, σ_{Qk} and $\sigma_{Qk\pm1}$ are standard deviations of daily flows in months k and k±1 respectively and $r_{Qk, Qk\pm1}$ is the cross correlation coefficient between daily flows in months k and k±1.

Flow seasonality and rainfall-runoff relationships determined whether month-to-month flow correlation modelling was the appropriate filling option. The procedure using correlation model involved several repetitive runs to fill the gaps with the lower correlation limit of 0.67. Use of the model is limited to recession flow and low flow months with data gaps less than or equal to a month. The model is not valid for high flows months and for data gaps exceeding a month. In the event that there were data gaps greater than a month in the recession and low flow months or for gaps occurring in high flow months, flow scaling from neighbouring stations was applied.

For ungauged river catchments (e.g. Mgugwe, Udagaji, Chiwa Chiwa and Londo) and gauged river catchments but with insufficient flow records (i.e. Ruipa), the rainfall and drainage area ratio approach was used for flow extrapolations. This approach is recommended for use in areas with minor variation in or similar catchments characteristics as is the case for the study catchments. Therefore, the Mpanga River flows were used to extrapolate flows for Mgugwe, Udagaji, Chiwa Chiwa and Londo rivers for the periods 1957 to 1984.

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.

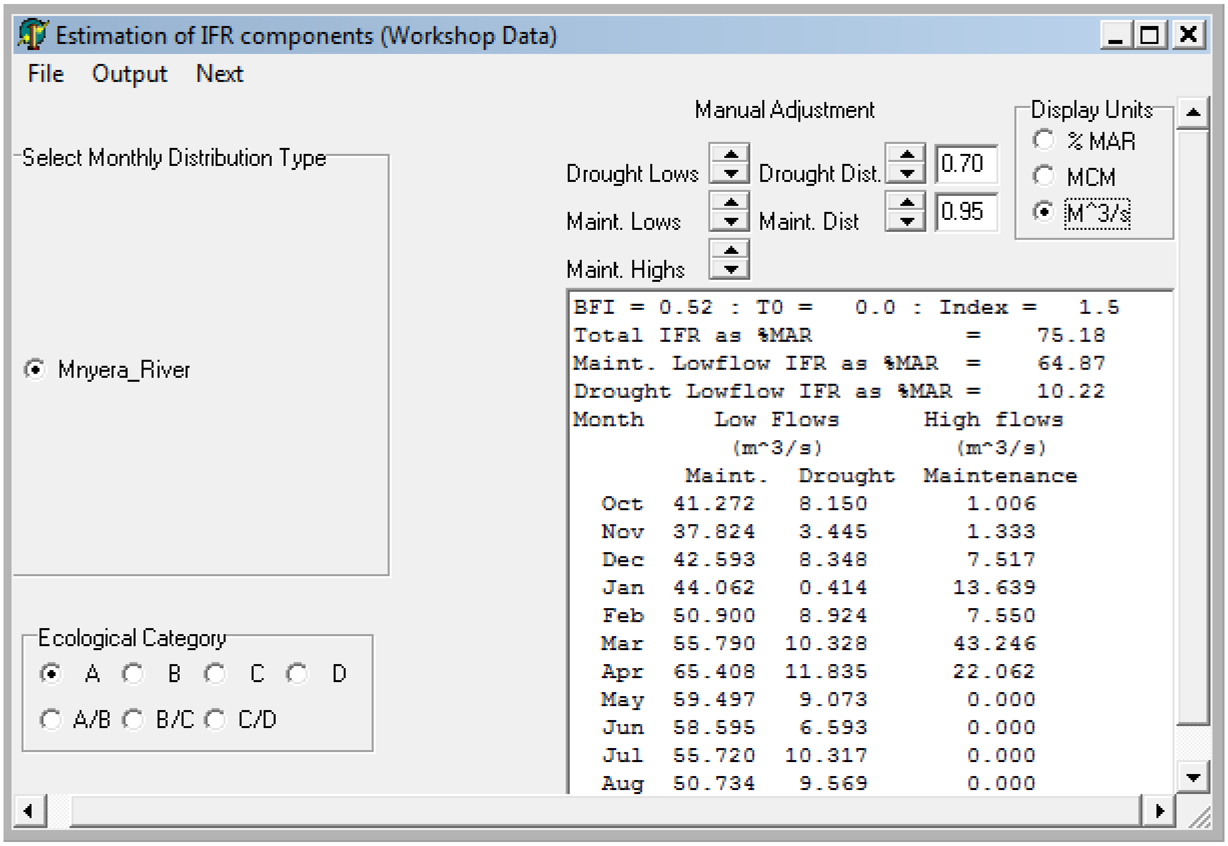


Figure 13: Ecological category for estimation of instream flow requirements

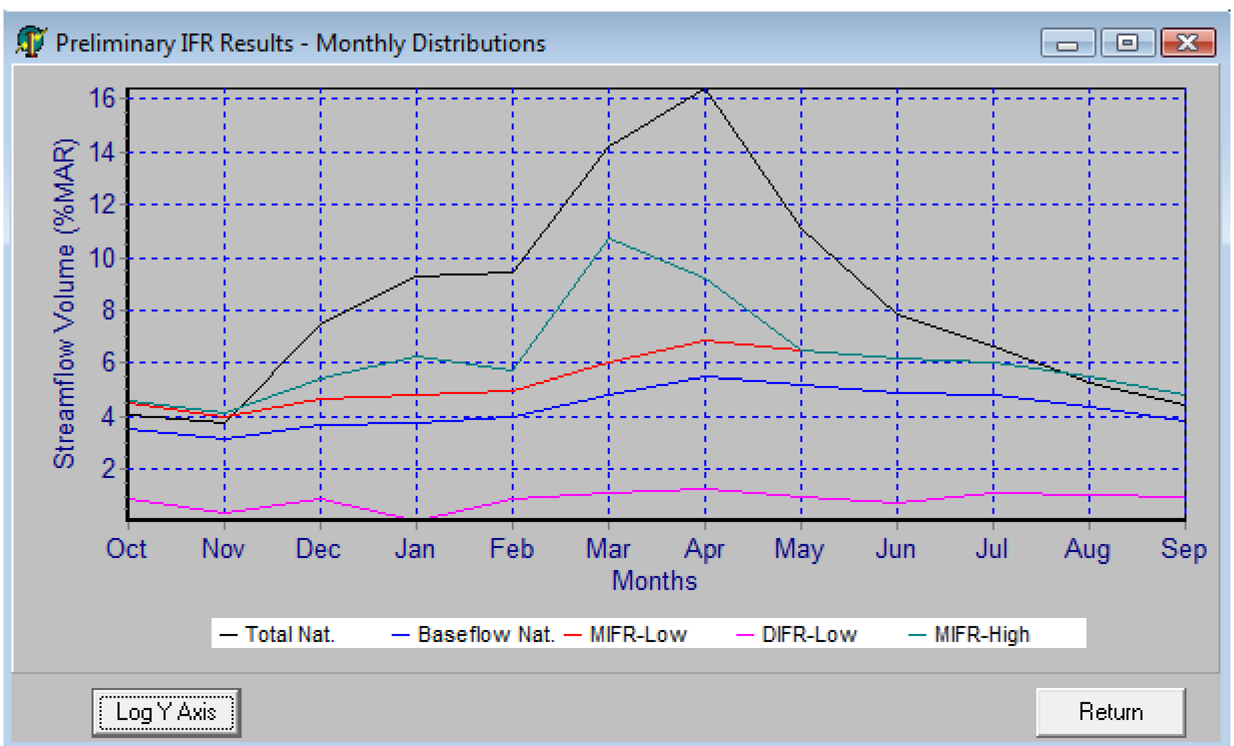


Figure 14: In-stream flow monthly distributions for Mnyera River (EMC = A)

4.2.2 Result of the Desktop Reserve Model for Study Rivers

The DRM has enabled estimation of the water requirements in the study rivers in consideration of the four Ecological Management Classes (A, B, C and D). Tables 6 through 9 present the model results for Mnyera River using ecological management classes A to D. Since the interpretation of the findings is generally similar, for all the four classes, one class result (EMC=A) for Mnyera River has been detailed discussed while others are implied.

The results (Table 7) indicate that, to maintain the river at class A, requires an average annual environmental flow allocation of 1616.16 Mm^3 (equivalent to 65.58% of MAR). This is the average annual "maintenance flow"; the sum of the maintenance low flows (i.e., 54.87 % MAR; 1352.21 Mm^3) and the maintenance high flows (i.e., 10.71% of MAR; 263.95 Mm^3). The drought-low-flows correspond to 10.17% of MAR (i.e., 250.58 Mm^3). These flows are distributed appropriately across the year and take into consideration the high and low flow months provisioning (e.g. Figure 19). Figures 15 through 18, present comparisons of the observed time series and the desktop reserve model derived environmental flow series for ecological management class A to D for Mnyera River, while Figure 20 presents the monthly available discharge after EF allocation for different EMC considerations.

For other rivers, a comparison between observed flow and simulated/estimated total maintenance flows for different ecological management classes (A-D) in the study rivers is provided in Figures 21, 23, 25, 27, 29 and 31 for Mpanga, Kihansi, Udagaji, Ruipa, Chiwachiwa, Rondo and Mgugwe Rivers respectively, while the monthly available discharge after EF allocation for different EMC considerations is presented in Figures 22, 24, 26, 28, 30 and 32 for Mpanga, Kihansi, Udagaji, Ruipa, Chiwachiwa, Rondo and Mgugwe Rivers respectively. It is important noting that these comparisons provide wide range of choices for the stakeholder to decide on the desired river condition in consideration of other development options. As it can be noted, if stakeholders decide to go for EMC=A, it means, more water will have to be left flowing in the rivers. In other words, it does not entertain river abstractions/ or development for other uses such as irrigation. Going for EMC=D, means you will have more water available for other uses, such as irrigation but with a beat of a compromise with the ecological conditions of the river. Therefore, a tradeoff is required between river development and environmental provisioning. As such, this can be achieved by making use of the generated information on monthly available discharge in relation to desired EMC.

Table 7: Summary of input and output from the desktop reserve model applied to the Mnyera River at Taveta Mission for EMC = A, based on 1957–1984 monthly flow series

Annual flows (Mm^3 or index values)							
MAR	=	2464.56		Total Environmental flow	= 1616.16	(65.58 %MAR)	
S.D.	=	544.61		Maintenance Low flow	= 1352.21	(54.87 %MAR)	
CV	=	0.22		Drought Low flow	= 250.58	(10.17 %MAR)	
Q_{75}	=	111.84		Maintenance High flow	= 263.95	(10.71 %MAR)	
Q_{75}/MMF	=	0.55					
BFI	=	0.52					
CV(JJA+JFM)	=	0.75					

Month	Observed flow (Mm^3)			Environmental flow requirement (Mm^3)			
				Low-flows		High-flows	Total-flows
	Mean	SD	CV	Maintenance	Drought	Maintenance	Maintenance
Oct	99.88	36.38	0.36	93.50	21.58	2.80	96.30
Nov	93.14	44.28	0.48	82.93	8.93	3.59	86.52
Dec	184.69	93.21	0.51	96.49	22.11	20.92	117.41
Jan	229.66	119.92	0.52	99.82	1.11	37.95	137.77
Feb	232.56	90.96	0.39	104.15	21.59	18.97	123.13
Mar	351.13	121.23	0.35	126.39	27.49	120.33	246.72
Apr	404.43	104.48	0.26	143.40	30.55	59.40	202.80
May	274.12	82.75	0.30	134.79	24.30	0	134.79
Jun	193.55	63.52	0.33	128.46	17.09	0	128.46
Jul	163.25	48.16	0.30	126.23	27.46	0	126.23
Aug	129.37	47.14	0.36	114.94	25.43	0	114.94
Sep	108.78	40.78	0.38	101.09	22.94	0	101.09

Table 8: Summary of input and output from the desktop reserve model applied to the Mnyera River at Taveta Mission for EMC = B, based on 1957–1984 monthly flow series

Annual flows (Mm^3 or index values)					
MAR	=	2464.56	Total Environmental flow	= 1135.73	(46.08 %MAR)
S.D.	=	544.61	Maintenance Low flow	= 948.03	(38.47 %MAR)
CV	=	0.22	Drought Low flow	= 251.99	(10.22 %MAR)
Q_{75}	=	111.84	Maintenance High flow	= 187.70	(7.62 %MAR)
Q_{75}/MMF	=	0.55			
BFI	=	0.52			
CV(JJA+JFM)	=	0.75			

Month	Observed flow (Mm^3)			Environmental flow requirement (Mm^3)			
				Low-flows		High-flows	Total-flows
	Mean	SD	CV	Maintenance	Drought	Maintenance	Maintenance
Oct	99.88	36.38	0.36	66.41	21.83	1.99	68.40
Nov	93.14	44.28	0.48	59.46	8.93	2.55	62.01
Dec	184.69	93.21	0.51	68.37	22.36	14.87	83.24
Jan	229.66	119.92	0.52	70.56	1.11	26.99	97.54
Feb	232.56	90.96	0.39	73.40	21.59	13.49	86.89
Mar	351.13	121.23	0.35	88.00	27.66	85.57	173.57
Apr	404.43	104.48	0.26	99.17	30.68	42.24	141.42
May	274.12	82.75	0.30	93.52	24.30	0	93.52
Jun	193.55	63.52	0.33	89.36	17.09	0	89.36
Jul	163.25	48.16	0.30	87.90	27.63	0	87.90
Aug	129.37	47.14	0.36	80.48	25.63	0	80.48
Sep	108.78	40.78	0.38	71.39	23.18	0	71.39

Table 9: Summary of input and output from the desktop reserve model applied to the Mnyera River at Taveta Mission for EMC = C, based on 1957–1984 monthly flow series

Annual flows (Mm³ or index values)					
MAR	=	2464.56	Total Environmental flow	= 688.90	(27.95 %MAR)
S.D.	=	544.61	Maintenance Low flow	= 540.55	(21.93 %MAR)
CV	=	0.22	Drought Low flow	= 251.99	(10.22 %MAR)
Q_{75}	=	111.84	Maintenance High flow	= 148.35	(6.02 %MAR)
Q_{75}/MMF	=	0.55			
BFI	=	0.52			
CV(JJA+JFM)	=	0.75			

Month	Observed flow (Mm³)			Environmental flow requirement (Mm³)			
				Low-flows		High-flows	Total-flows
	Mean	SD	CV	Maintenance	Drought	Maintenance	Maintenance
Oct	99.88	36.38	0.36	38.44	21.83	1.57	40.01
Nov	93.14	44.28	0.48	34.79	8.93	2.02	36.81
Dec	184.69	93.21	0.51	39.47	22.36	11.76	51.22
Jan	229.66	119.92	0.52	40.62	1.11	21.33	61.94
Feb	232.56	90.96	0.39	42.11	21.59	10.66	52.77
Mar	351.13	121.23	0.35	49.77	27.66	67.63	117.40
Apr	404.43	104.48	0.26	55.63	30.68	33.39	89.01
May	274.12	82.75	0.30	52.66	24.30	0	52.66
Jun	193.55	63.52	0.33	50.48	17.09	0	50.48
Jul	163.25	48.16	0.30	49.71	27.63	0	49.71
Aug	129.37	47.14	0.36	45.82	25.63	0	45.82
Sep	108.78	40.78	0.38	41.05	23.18	0	41.05

Table 10: Summary of input and output from the desktop reserve model applied to the Mnyera River at Taveta Mission for EMC = D, based on 1957–1984 monthly flow series

Annual flows (Mm³ or index values)							
MAR	=	2464.56		Total Environmental flow		= 428.09	(17.37 %MAR)
S.D.	=	544.61		Maintenance Low flow		= 302.77	(12.29 %MAR)
CV	=	0.22		Drought Low flow		= 251.99	(10.22 %MAR)
Q_{75}	=	111.84		Maintenance High flow		= 125.32	(5.08 %MAR)
Q_{75}/MMF	=	0.55					
BFI	=	0.52					
CV(JJA+JFM)	=	0.75					

Month	Observed flow (Mm³)			Environmental flow requirement (Mm³)			
				Low-flows		High-flows	Total-flows
	Mean	SD	CV	Maintenance	Drought	Maintenance	Maintenance
Oct	99.88	36.38	0.36	21.83	21.83	1.33	23.16
Nov	93.14	44.28	0.48	19.96	8.93	1.71	21.66
Dec	184.69	93.21	0.51	22.36	22.36	9.93	32.29
Jan	229.66	119.92	0.52	22.95	1.11	18.02	40.97
Feb	232.56	90.96	0.39	23.72	21.59	9.01	32.73
Mar	351.13	121.23	0.35	27.66	27.66	57.13	84.79
Apr	404.43	104.48	0.26	30.68	30.68	28.20	58.88
May	274.12	82.75	0.30	29.15	24.30	0	29.15
Jun	193.55	63.52	0.33	28.03	17.09	0	28.03
Jul	163.25	48.16	0.30	27.63	27.63	0	27.63
Aug	129.37	47.14	0.36	25.63	25.63	0	25.63
Sep	108.78	40.78	0.38	23.18	23.18	0	23.18

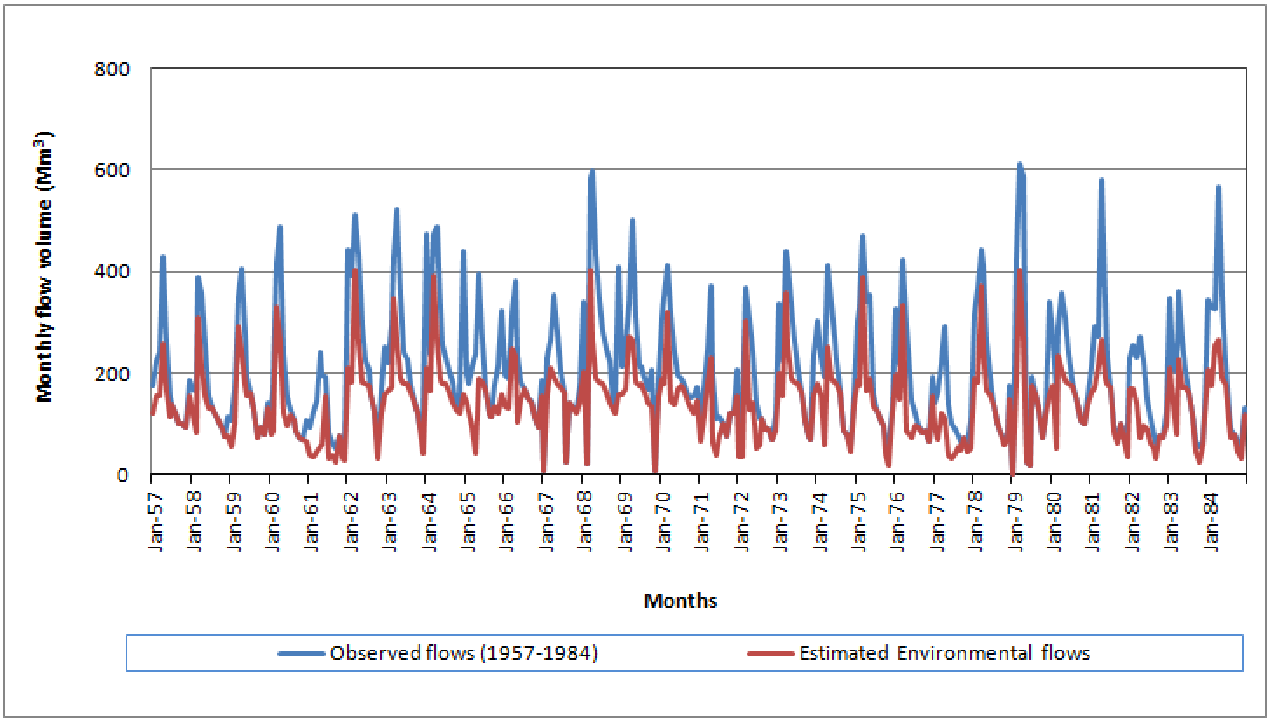


Figure 15: Estimated environmental flows and observed flows for the period (1957-1984) for Mnyera River at Taveta Mission (EMC = A)

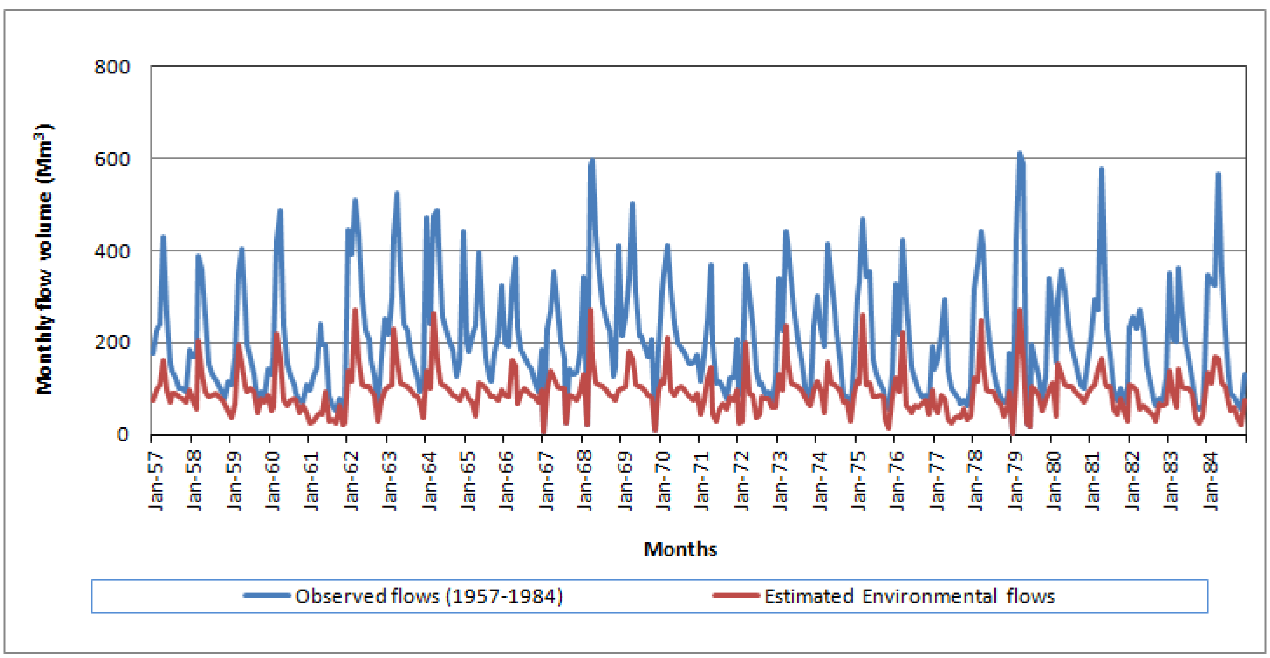


Figure 16: Estimated environmental flows and observed flows for the period (1957-1984) for Mnyera River at Taveta Mission (EMC = B)

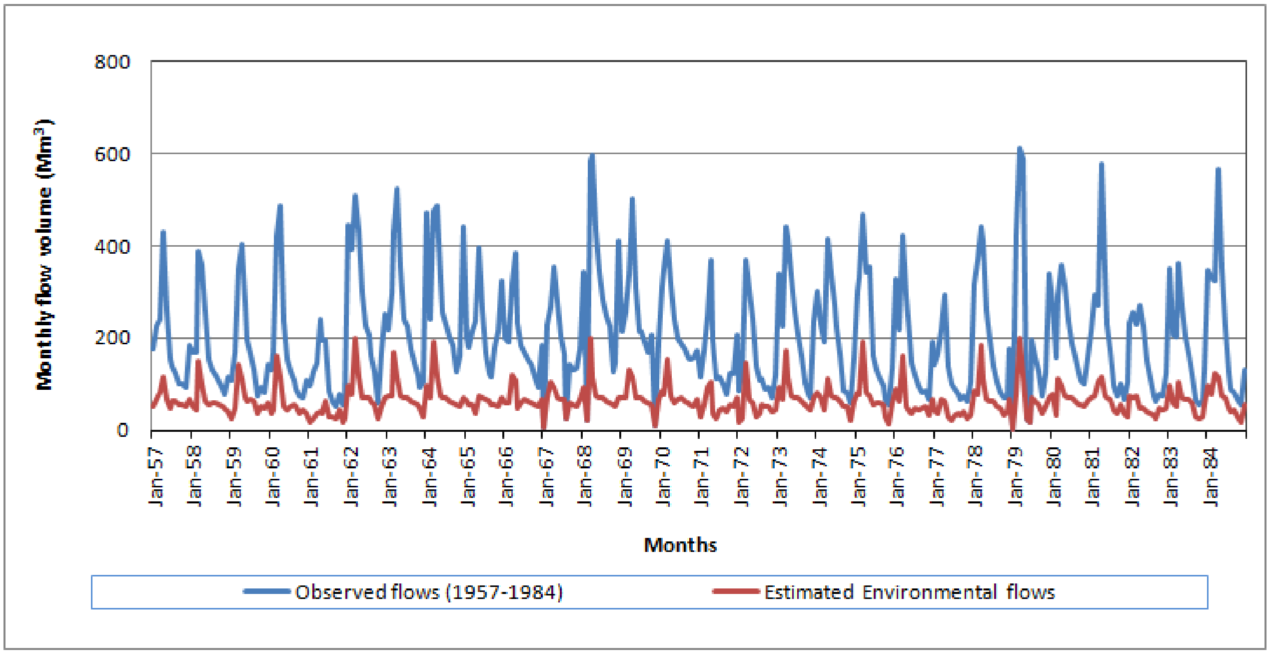


Figure 17: Estimated environmental flows and observed flows for the period (1957-1984) for Mnyera River at Taveta Mission (EMC = C)

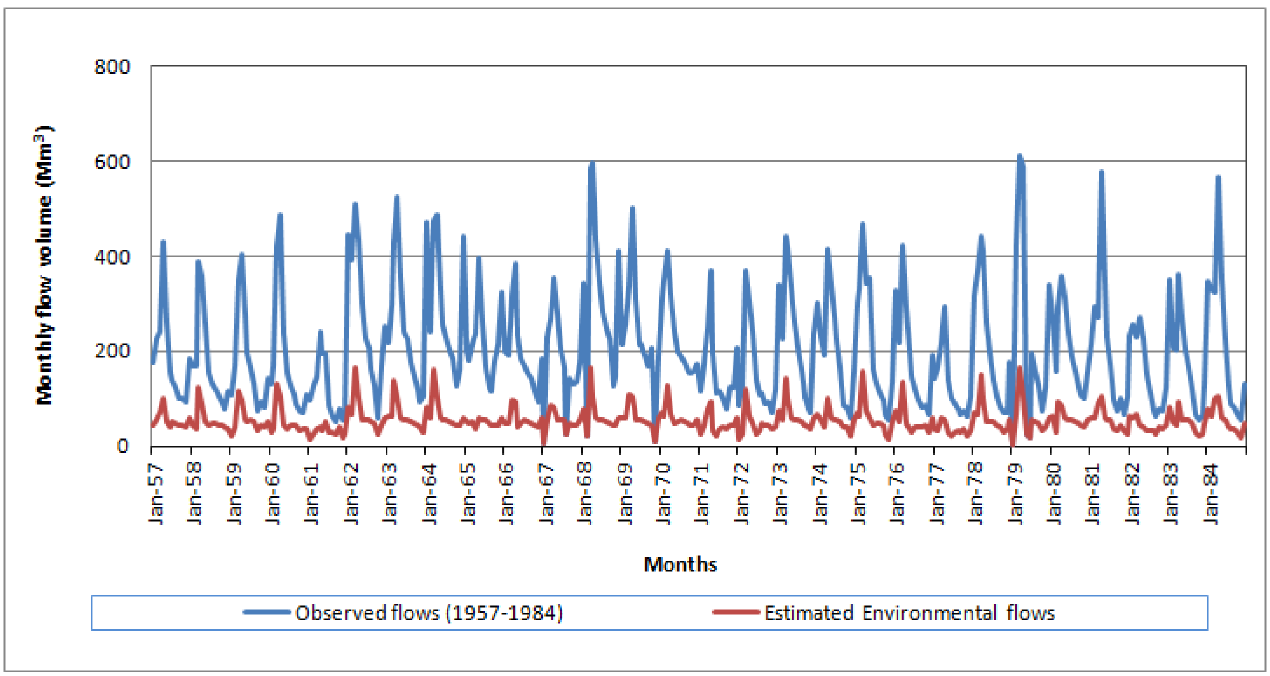


Figure 18: Estimated environmental flows and observed flows for the period (1957-1984) for Mnyera River at Taveta Mission (EMC = D)

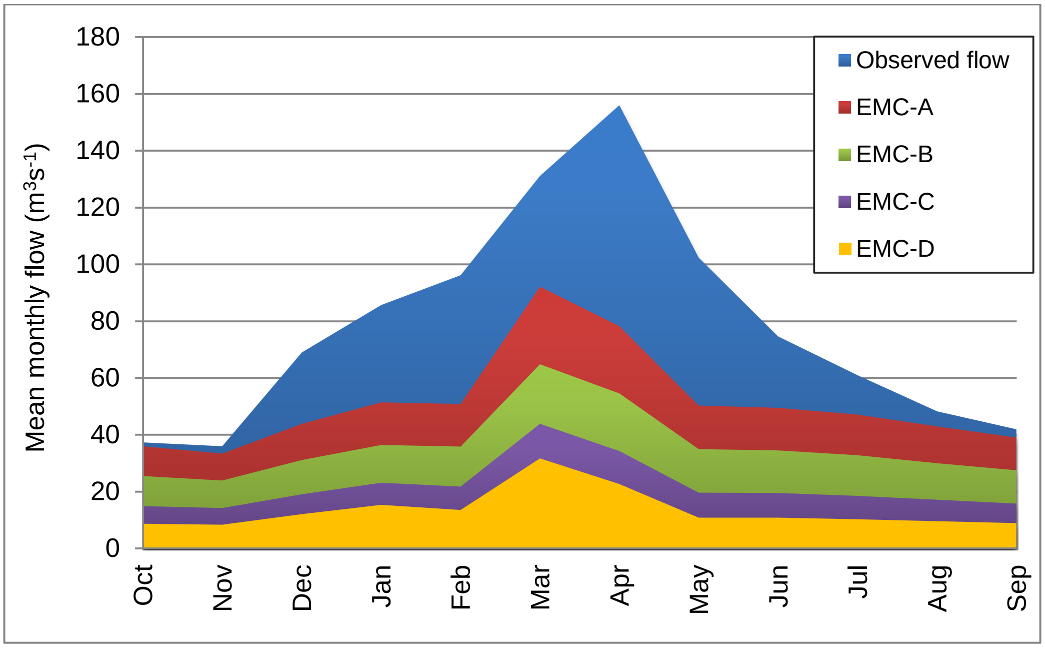
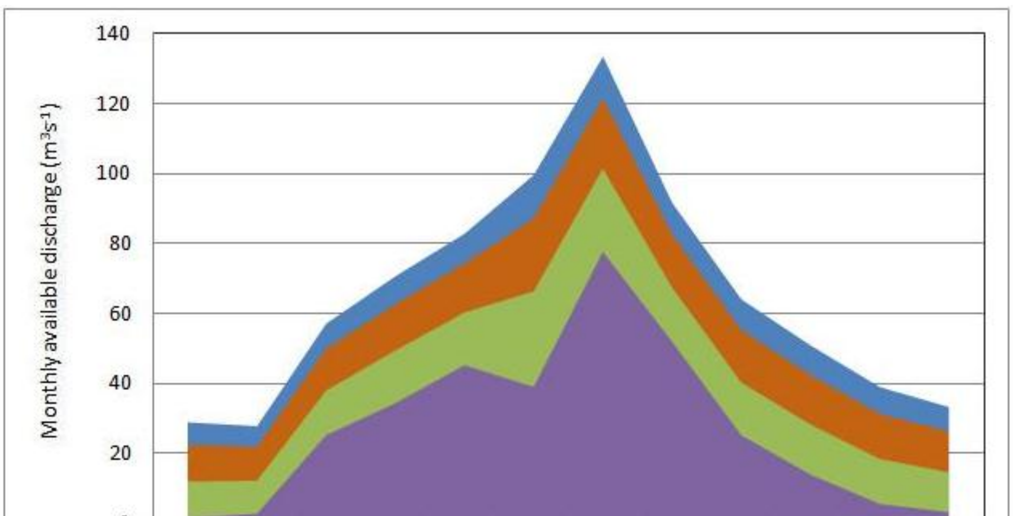


Figure 19: Comparison between observed and estimated total maintenance flows for different ecological management classes for the Mnyera River at Taveta Mission



	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep
EMC-D	28.65	27.58	56.90	70.45	82.60	99.44	133.3	91.46	63.86	50.63	38.73	33.03
EMC-C	22.35	21.73	49.83	62.62	74.32	87.27	121.6	82.68	55.19	42.39	31.19	26.13
EMC-B	11.76	12.01	37.88	49.33	60.21	66.29	101.4	67.43	40.19	28.13	18.25	14.43
EMC-A	1.34	2.56	25.12	34.31	45.24	38.98	77.79	52.02	25.11	13.82	5.39	2.97

Figure 20: Monthly available discharge after EF allocation for different EMC considerations for the Mnyera River at Taveta Mission

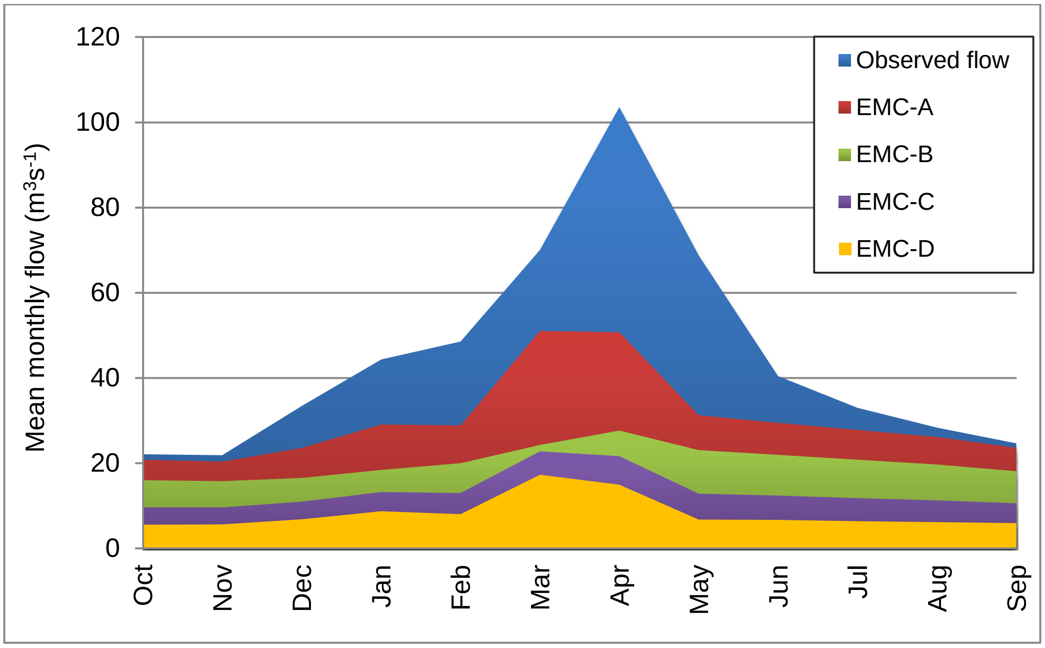
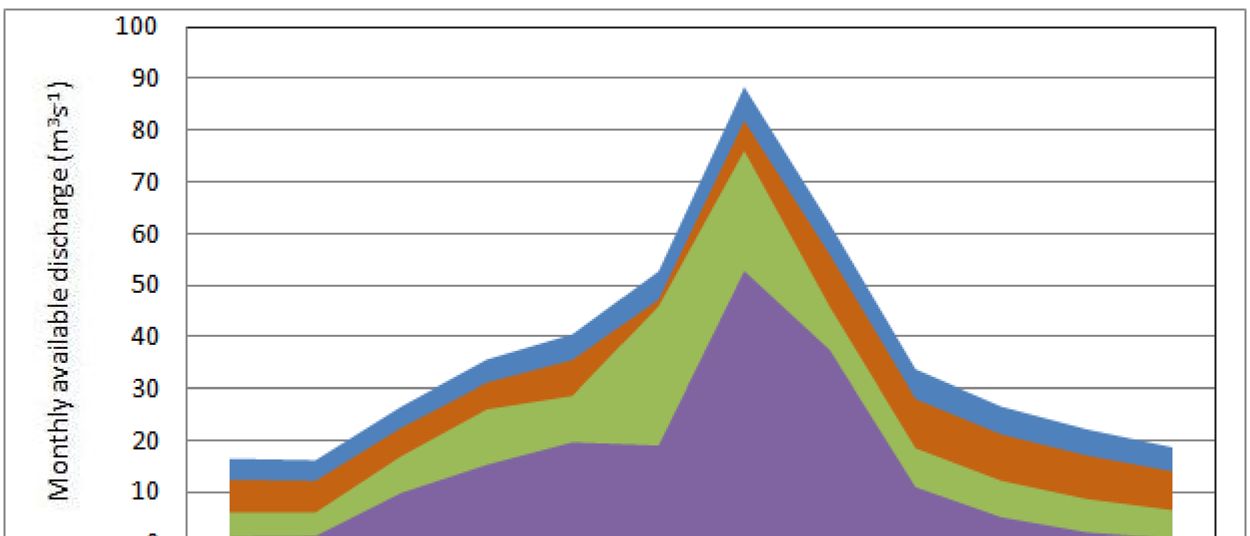


Figure 21: Comparison between observed and estimated total maintenance flows for different ecological management classes for the Mpanga River at Mpanga Mission



	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep
EMC-D	16.53	16.21	26.61	35.67	40.57	52.78	88.60	61.98	33.79	26.63	22.22	18.71
EMC-C	12.44	12.21	22.49	31.16	35.55	47.28	81.91	55.93	28.06	21.21	17.11	14.05
EMC-B	6.06	6.03	16.92	25.99	28.60	45.83	75.91	45.70	18.49	12.19	8.66	6.50
EMC-A	1.32	1.50	9.87	15.33	19.71	19.08	52.83	37.49	10.99	5.17	2.22	1.02

Figure 22: Monthly available discharge after EF allocation for different EMC considerations for for the Mpanga River at Mpanga Mission

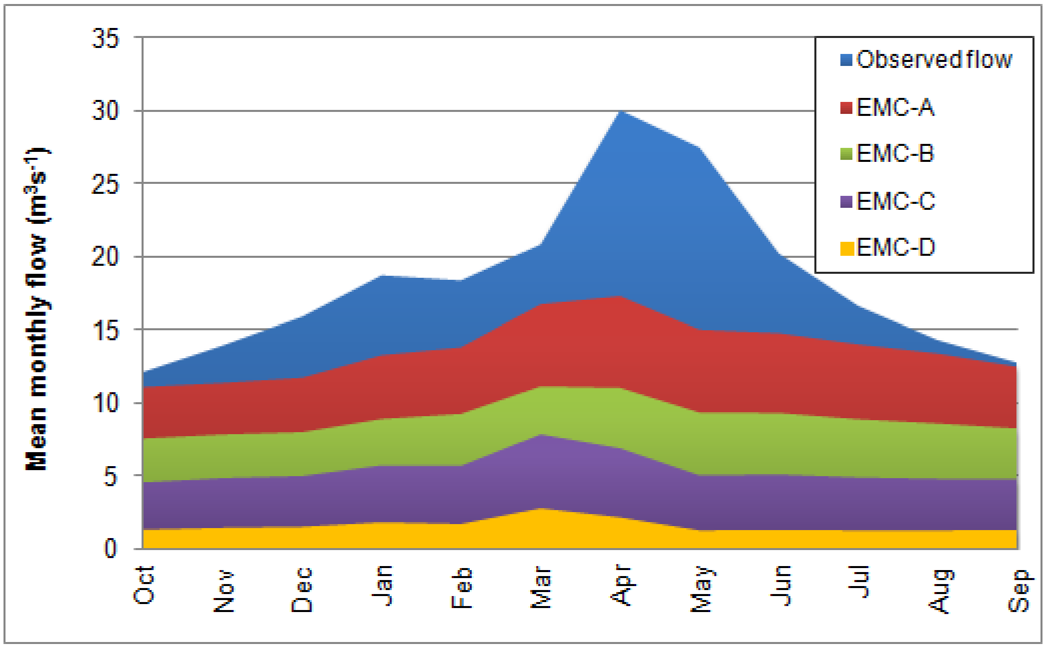
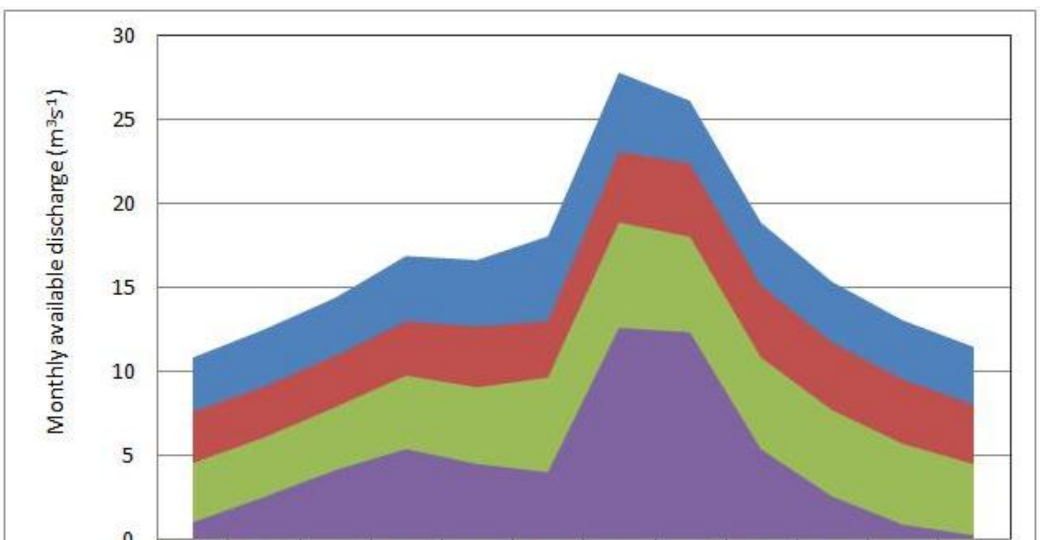


Figure 23: Comparison between observed and estimated total maintenance flows for different ecological management classes for the Kihansi River at Lugoda



	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep
EMC-D	10.83	12.50	14.39	16.90	16.67	18.08	27.87	26.19	18.91	15.36	13.05	11.47
EMC-C	7.59	9.09	10.92	12.99	12.68	13.00	23.13	22.42	15.12	11.74	9.51	8.00
EMC-B	4.52	6.05	7.85	9.76	9.06	9.63	18.91	18.05	10.84	7.69	5.66	4.45
EMC-A	0.98	2.49	4.09	5.36	4.47	3.98	12.61	12.35	5.35	2.53	0.84	0.20

Figure 24: Monthly available discharge after EF allocation for different EMC considerations for Kihansi River at Lugoda

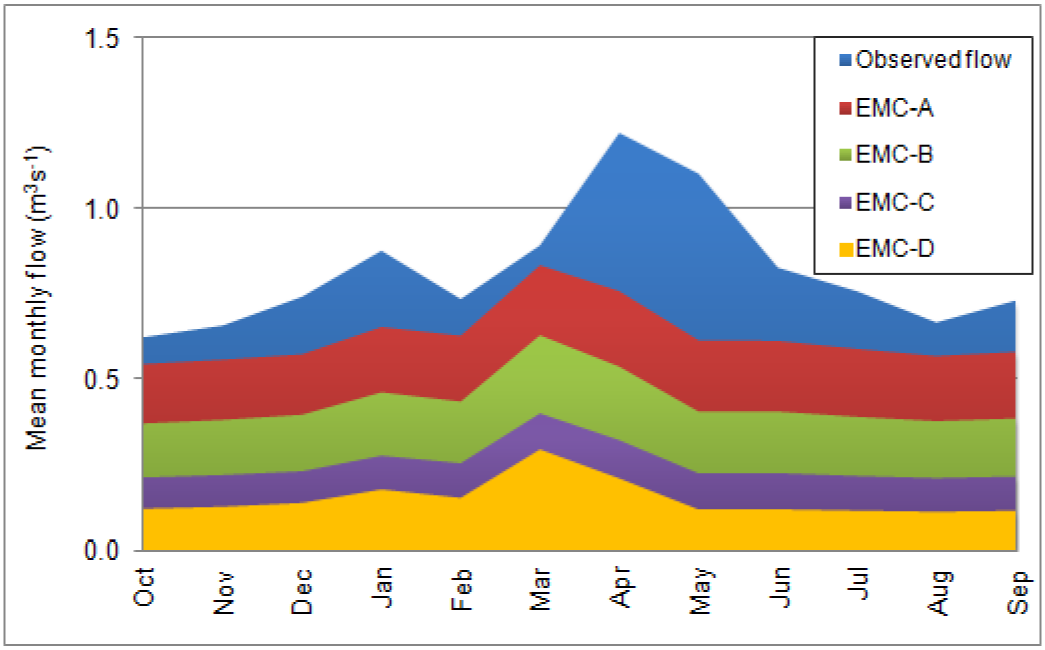
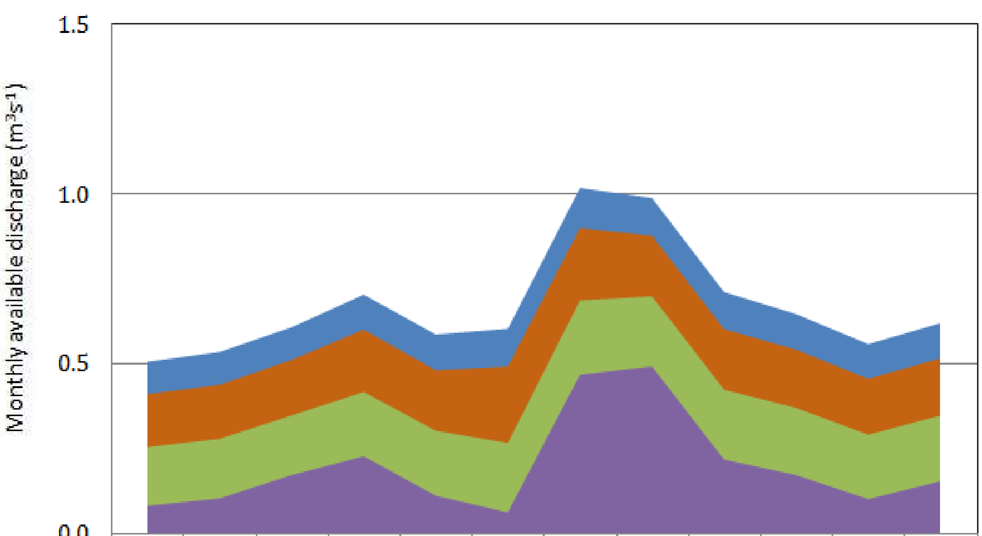


Figure 25: Comparison between observed and estimated total maintenance flows for different ecological management classes for Udagaji River at Udagaji



	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep
EMC-D	0.51	0.53	0.61	0.70	0.59	0.60	1.02	0.99	0.71	0.65	0.56	0.62
EMC-C	0.41	0.44	0.51	0.60	0.48	0.49	0.90	0.88	0.60	0.54	0.46	0.52
EMC-B	0.26	0.28	0.35	0.42	0.30	0.27	0.69	0.70	0.42	0.37	0.29	0.35
EMC-A	0.08	0.10	0.17	0.23	0.11	0.06	0.47	0.49	0.22	0.17	0.10	0.15

Figure 26: Monthly available discharge after EF allocation for different EMC considerations for Udagaji River at Udagaji

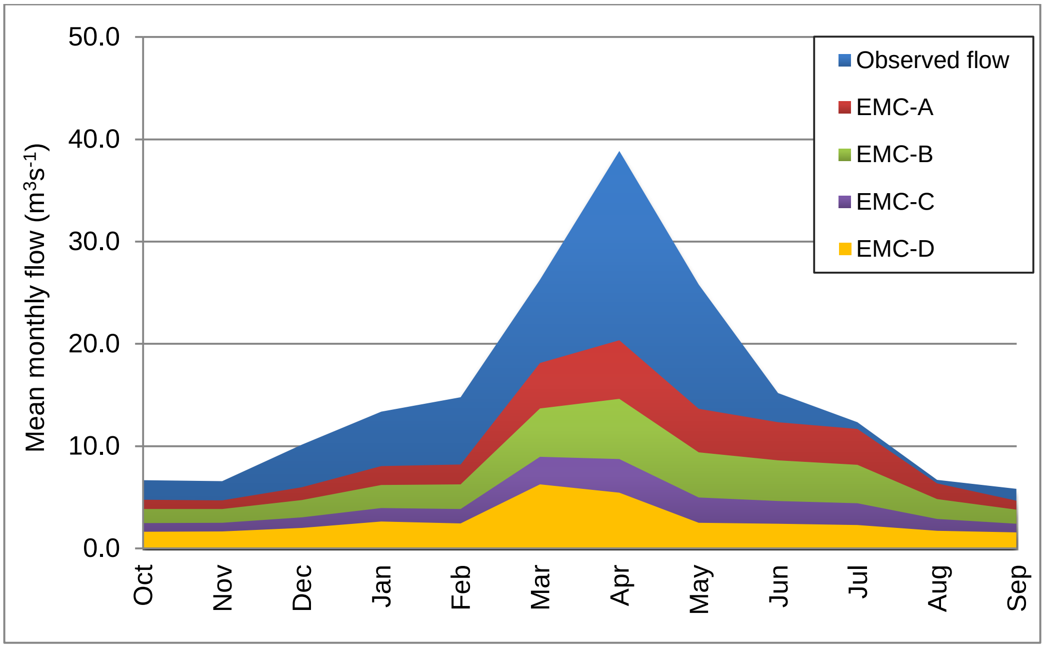
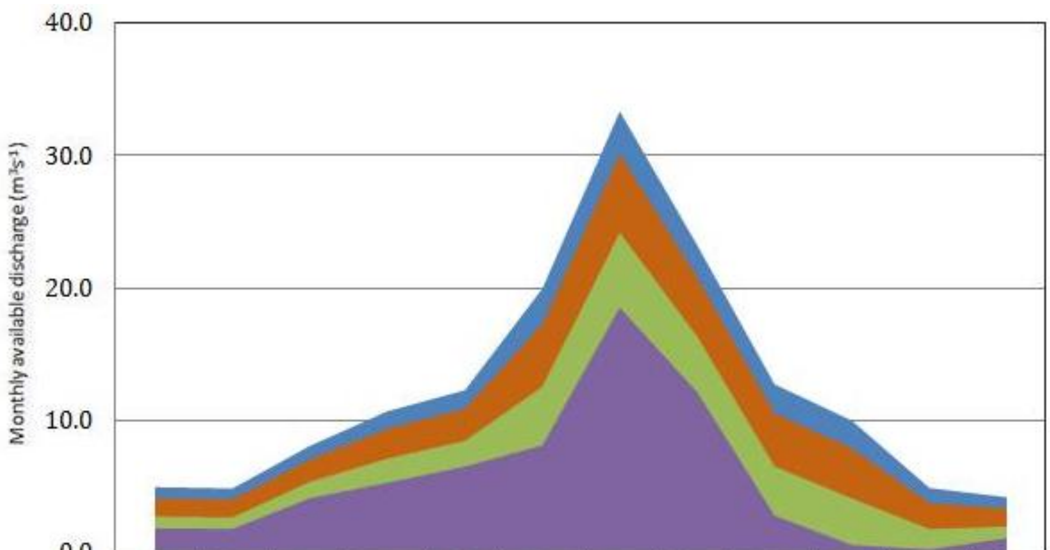


Figure 27: Comparison between observed and estimated total maintenance flows for different ecological management classes for Ruipa River at Mbingu



	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep
EMC-D	5.03	4.93	8.14	10.75	12.34	20.01	33.40	23.29	12.79	10.04	4.96	4.26
EMC-C	4.18	4.09	7.12	9.42	10.93	17.32	30.13	20.84	10.58	7.94	3.81	3.41
EMC-B	2.81	2.74	5.42	7.18	8.52	12.60	24.23	16.40	6.60	4.17	1.86	2.05
EMC-A	1.90	1.87	4.17	5.34	6.56	8.15	18.50	12.14	2.87	0.65	0.32	1.17

Figure 28: Monthly available discharge after EF allocation for different EMC considerations for Ruipa River at Mbingu

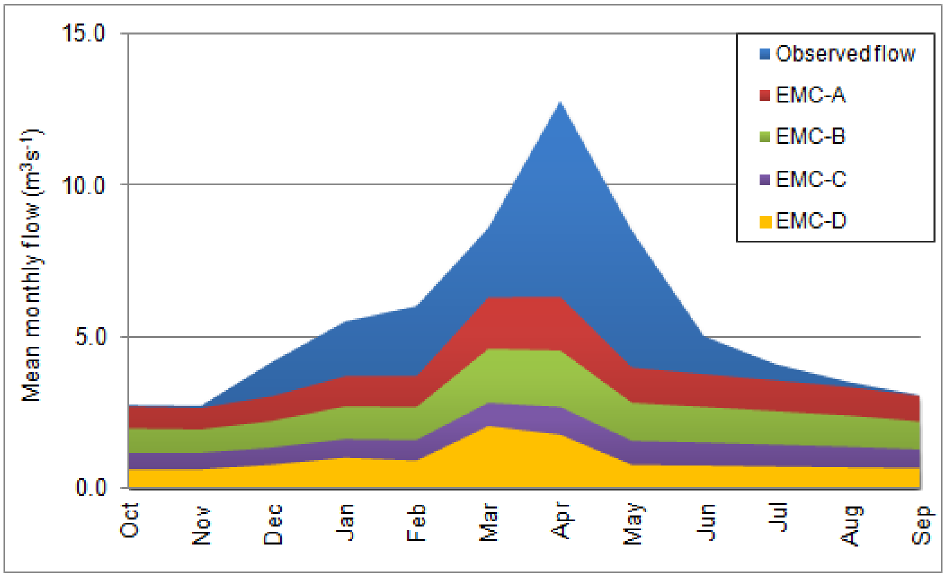
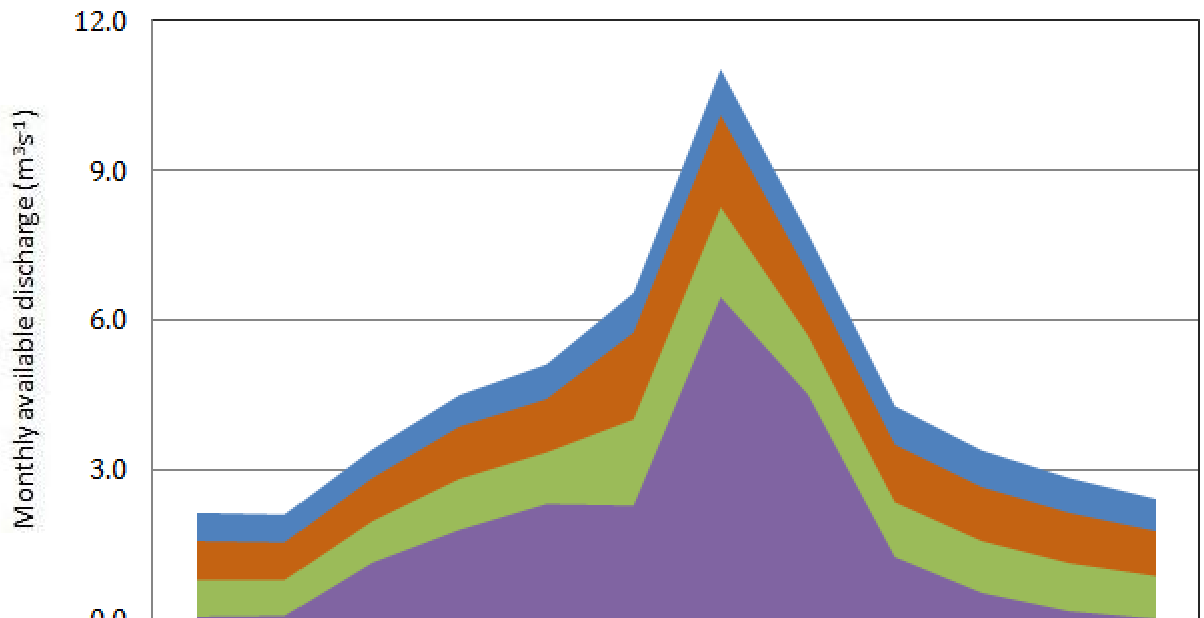


Figure 29: Comparison between observed and estimated total maintenance flows for different ecological management classes for Chiwachiwa River



	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep
EMC-D	2.14	2.10	3.41	4.50	5.12	6.55	11.04	7.75	4.28	3.39	2.83	2.41
EMC-C	1.57	1.54	2.83	3.86	4.41	5.75	10.10	6.93	3.50	2.65	2.13	1.76
EMC-B	0.79	0.79	1.97	2.82	3.35	4.01	8.27	5.70	2.35	1.57	1.13	0.87
EMC-A	0.05	0.07	1.14	1.80	2.32	2.29	6.47	4.52	1.25	0.53	0.16	0.01

Figure 30: Monthly available discharge after EF allocation for different EMC considerations for Chiwachiwa River

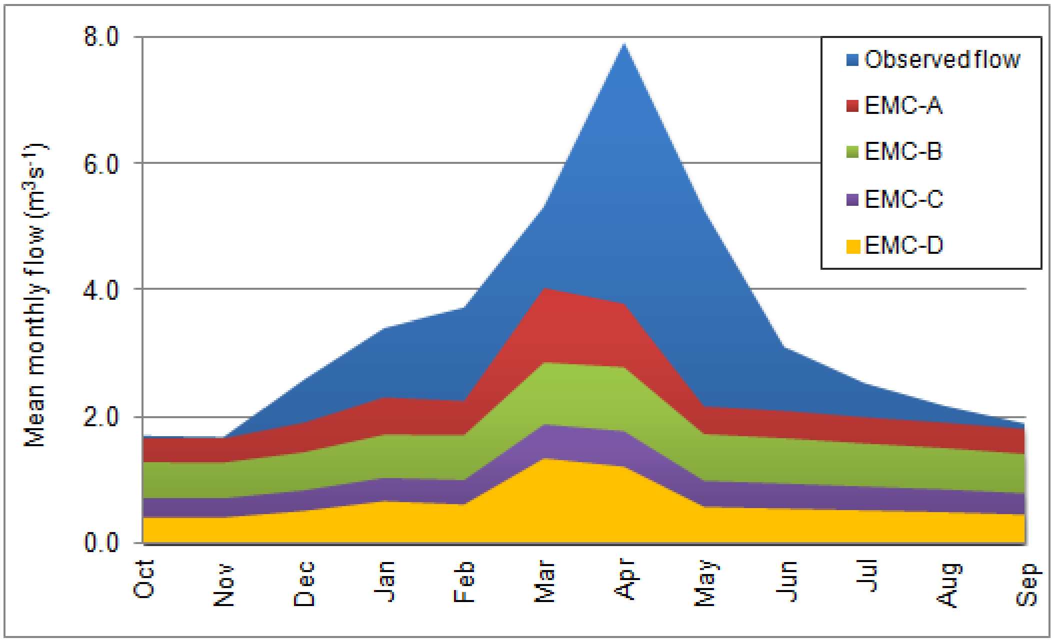
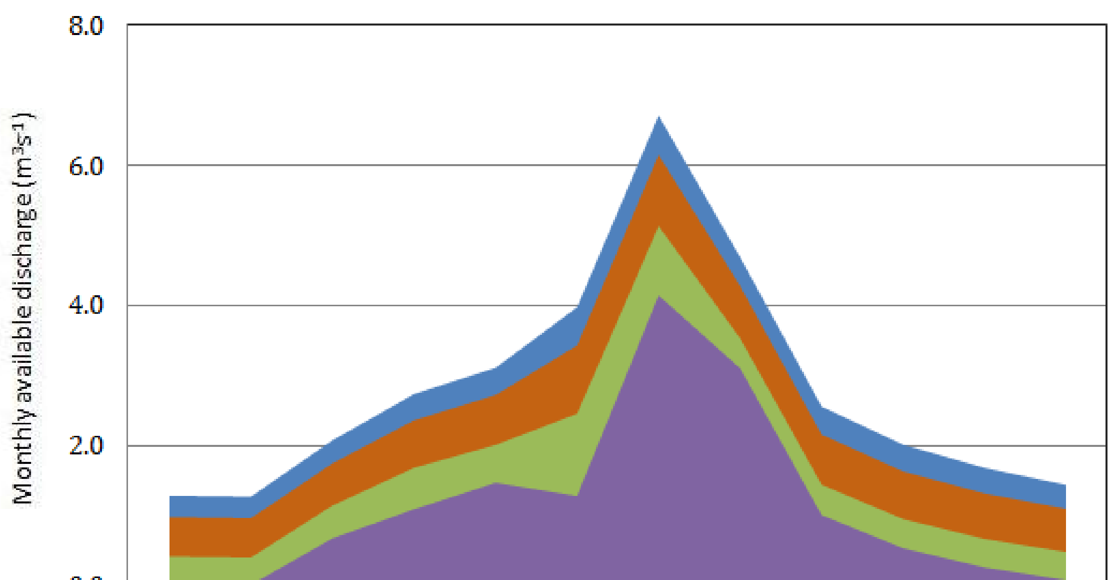


Figure 31: Comparison between observed and estimated total maintenance flows for different ecological management classes for Rondo River at Mbingu



	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep
EMC-D	1.29	1.28	2.08	2.74	3.12	3.98	6.72	4.69	2.56	2.02	1.69	1.44
EMC-C	0.98	0.97	1.75	2.36	2.72	3.43	6.14	4.27	2.16	1.63	1.32	1.10
EMC-B	0.42	0.41	1.15	1.69	2.02	2.46	5.15	3.54	1.45	0.96	0.67	0.48
EMC-A	0.04	0.02	0.68	1.09	1.47	1.28	4.14	3.10	1.01	0.54	0.26	0.08

Figure 32: Monthly available discharge after EF allocation for different EMC considerations for Rondo River at Mbingu

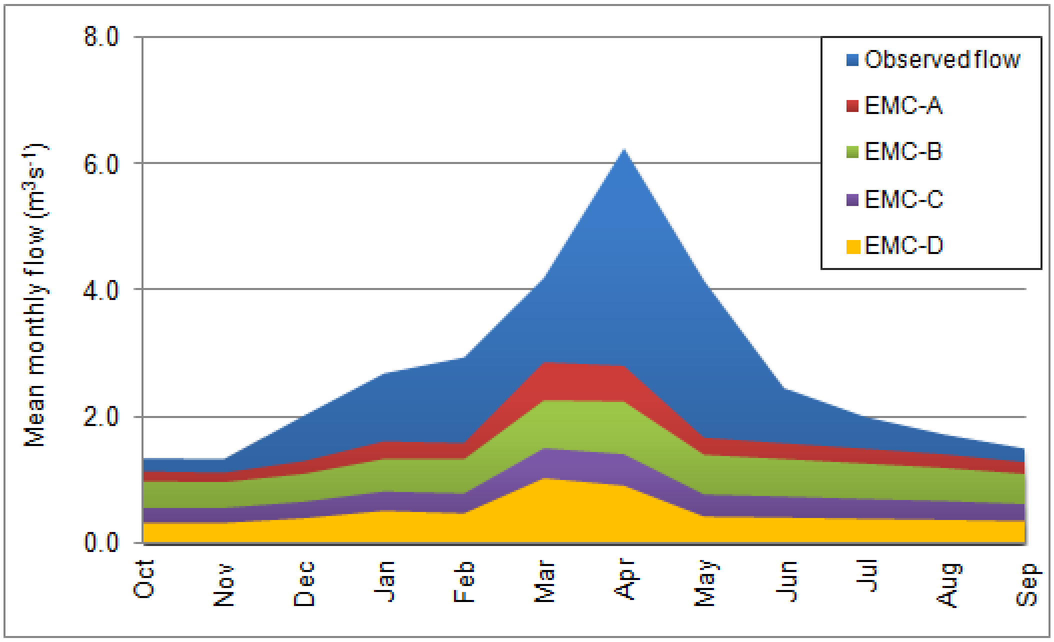
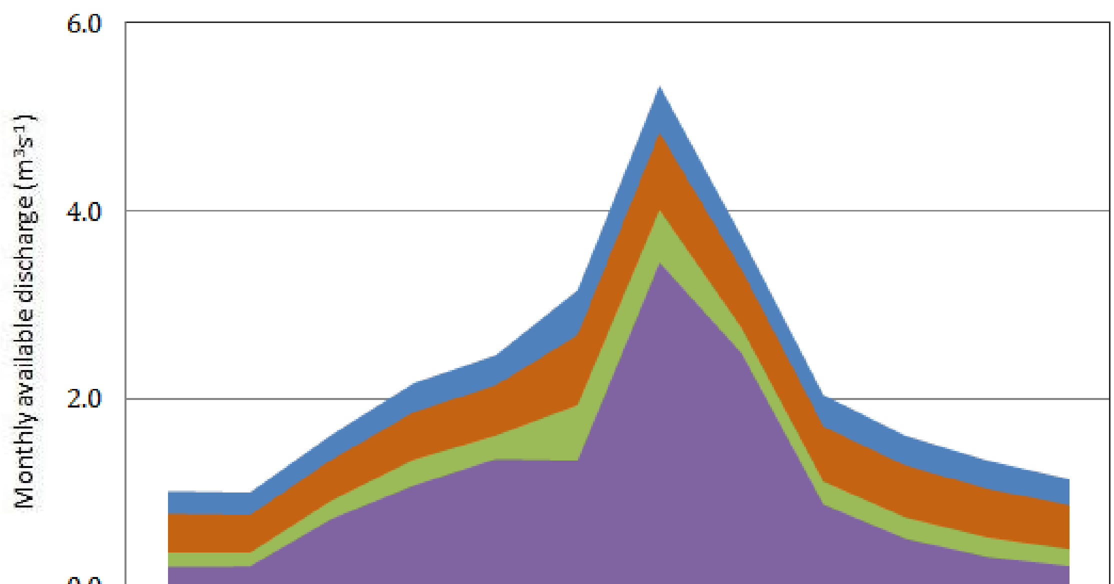


Figure 33: Comparison between observed and estimated total maintenance flows for different ecological management classes for Mgugwe River at Mgugwe



	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep
EMC-D	1.02	1.00	1.62	2.17	2.47	3.16	5.33	3.73	2.04	1.61	1.35	1.15
EMC-C	0.78	0.77	1.36	1.86	2.15	2.68	4.83	3.38	1.71	1.29	1.05	0.87
EMC-B	0.36	0.36	0.92	1.35	1.61	1.93	4.01	2.75	1.12	0.74	0.52	0.40
EMC-A	0.21	0.22	0.73	1.08	1.36	1.35	3.46	2.49	0.88	0.51	0.32	0.22

Figure 34: Monthly available discharge after EF allocation for different EMC considerations for Mgugwe River at Mgugwe

4.2.3 Limitation and accuracy of the DRM estimates

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 (Kashaigili, 2011). The extrapolation to other areas, like Tanzania (Kilombero River catchment), 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 time constraint, the model has been recommended to provide the initial EF estimates which are important for river development planning. It is however important noting that this study was an initial attempt to estimate the environmental flow for all the rivers under IRRIP2 project area. A more comprehensive study is necessary to account for ecology and socio-economic aspects that were not thoroughly considered in this initial assessment. Another important aspect is on the resolution of the used data. 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 daily data aggregation.

5.0 CONCLUSIONS

The main objective of the study was to conduct a rapid domestic water needs and environmental flow assessment that will inform the ongoing feasibility studies for the development of the four IRRIP2 irrigation areas and the associated ongoing environmental impact assessment work covering the same areas in the Kilombero sub-basin. The work utilizes the historical river flow data from the available gauging stations in the sub-basin and the information on water uses from beneficiary villages.

The findings have revealed domestic water need to comprise of water for cooking, watering flowers and home gardens, flushing the toilets, mopping, washing utensils, washing clothes, constructing houses, brick making, pottery, cooling the milling engine, washing motorcycle/bicycles, local wine making (*Komoni*), watering animals (cows, goats, poultry, pigs), construction of brick kilns, bathing and drinking. In annual terms, the annual total domestic water need was estimated at 348,380,024 liters/annum for Ruipa River, 144,163,722 liters/annum for Mgugwe River, 363,192,621 liters/ annum for Mpanga River and 93,544,720 liters/annum from Udagaji River.

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This study has applied a Desktop Reserve Model (DRM) to provide initial estimates of environmental flows for all rivers in IRRIP2 project area based solely on hydrological data. Detailed presentation of the findings is provided for Mnyera River for the Ecological Management Classes A to D, and the same implied too for other rivers. For Mnyera River, in order to maintain the river at class A, an average annual environmental flow allocation of 1616.16 Mm^3 (equivalent to 65.58% of MAR) is required. This is the average annual "maintenance flow"; the sum of the maintenance low flows (i.e., 54.87 % MAR; 1352.21 Mm^3) and the maintenance high flows (i.e., 10.71% of MAR; 263.95 Mm^3). The drought-low-flows correspond to 10.17% of MAR (i.e., 250.58 Mm^3). These flows are distributed appropriately across the year and take into consideration the high and low flow months provisioning. For lower class, EMC = D, the total annual maintenance flow is estimated at 17.37% MAR; 428.09 Mm^3. Such a wide range in environmental water provisioning provides the stakeholders, managers and decision makers a better idea of the possible range of required flows to maintain the river in different desired river flow conditions. Therefore, if stakeholders decide to go for EMC=A, it means, more water will have to be left flowing in the rivers. In other words, it does not entertain river abstractions/ or development for other uses such as irrigation. Going for EMC=D, means you will have more water available for other uses, such as to meet irrigation water needs but with a bit of a compromise with the ecological conditions of the river. Therefore, a tradeoff is required between river development and environmental provisioning. As such, this can be achieved by making use of the generated information on monthly available discharge in relation to desired EMC.

More importantly is a realization of the fact that where water withdrawals are essential for livelihoods, there is a need to consider trade-offs in water provision to different ecosystems. It is also 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 carry out detailed analysis of possible irrigable area based on available water after accounting for EF allocation for different EMCs and domestic water needs.

REFERENCES

Bunn, S.E. and Arthington, A.H. (2002). Basic principles and ecological consequences of altered flow regimes for aquatic biodiversity. Environmental Management 30: 492-507.

Darwall, W. R. T., Smith, K. G., Allen, D. J., Holland, R. A., Harrison, I. J. & Brooks, E. G. E. (Eds.). (2011). The diversity of life in African freshwaters: Under water, under threat. An analysis of the status and distribution of freshwater species throughout mainland Africa. Gland: IUCN.

Deck, A. D. (1964). The Kilombero Valley of South-Central Tanganyika. E.Afr. Geogr. Rev. No 2 (37 – 43).

DFID (Department For International Development). (2003). Handbook for the Assessment of Catchment Water Demand and Use, OX10 8BA, UK.

DWAF (Department of Water Affairs and Forestry), (1999). Resource Directed Measures for Protection of Water Resources, vol. 8, Classification System for Water Resources, DWAF, Pretoria, South Africa.

Dyson, M., Bergkamp, G. and Scanlon, J. (Eds.) (2003). Flow. The Essentials of Environmental Flows. IUCN, Gland, Switzerland and Cambridge, UK. xiv + 118pp.

Halcrow, W. and Partners, (1992). Infrastructure operation and maintenance manual. National Agricultural and Food Cooperation, Kapunga rice project, Mbeya, Tanzania, pp 3.5 - 5.7.

HR Wallingford (2003). Handbook for the Assessment of Catchment Water Demand and Use 248pp.

Hughes, D.A. (2001). Providing Hydrological Information and Data Analysis Tools for the Determination of the Ecological In-stream Flow Requirements for South African Rivers. Journal of Hydrology , 241 (1-2), 140-151.

Hughes, D.A., and Münster, F., (2000). Hydrological Information and Techniques to Support the Determination of the Water Quantity Component of the Ecological Reserve for Rivers. Report to the Water Research Commission by the Institute for Water Research, Rhodes University, WRC Report No. 867/3/2000, Pretoria, South Africa.

Hughes, D.A., Hannart, P., 2003. A desktop model used to provide an initial estimate of the ecological in-stream flow requirements of rivers in South Africa. Journal of Hydrology 270 (3-4), 167–181.

IUCN Eastern and Southern Africa Programme, (2010). The Ruvu Basin: A Situation Analysis., xvi + 96 pp.

IWMI, (2002). Agricultural water use and improving rural livelihoods in Sub-Saharan Africa: current status, future directions and the role of the international programme for technology and research in irrigation and drainage (IPTRID), International Congress for Irrigation and Drainage. South Africa Office of the International Water Management Office (IWMI-SA) Pretoria, Montreal, pp. 38.

JICA, (1994). Study on Water Resources Development in the Ruvu River Basin.

Kadigi, R. M. J., Kashaigili, J. J. and Mdoe N. S. (2003). The Economics of Irrigated Paddy in Usangu Basin in Tanzania: Water Utilization, Productivity, Income and Livelihood Implications. Paper to be presented at the 4th WARFSA/WATERNET Symposium. Gaborone Botswana, 15-17 October 2003. 8pp.

Kashaigili, J.J. (2011). Rapid Environmental Flow Assessment for Ruvu River. Consultancy Report submitted to iWASH.

Kashaigili, J.J. (2008). Impacts of land-use and land-cover changes on flow regimes of the Usangu wetland and the Great Ruaha River, Tanzania. Elsevier Journal, Physics and Chemistry of the Earth 33:640-647

Kashaigili, J.J., McCartney, M. and Mahoo, H.F. (2007). Estimation of environmental flows in the Great Ruaha River Catchment, Tanzania. Journal of Physics and Chemistry of the Earth 32 (2007) 1007–1014.

Kihila, J. (2005). A study on sedimentation rate for Mindu Dam and its implications on capacity of water supply for Morogoro Municipality. Master of Science in Environmental Technology and Management at the University of Dar es Salaam. University College of Lands and Architectural Studies (UCLAS), Dar es Salaam.

Kilombero farm (2004). A Brief Overview of the Kilombero District. [http://kilombero-valleyfarms.org/kilombero%20brief%20report.htm] site visited on 3rd September, 2013.

King, J.M., Tharme, R.E. and de Villiers, M.S. (Eds) (2002). Environmental flow assessments for rivers: Manual for the building block methodology. Water Research Commission Technology Transfer Report No. TT131/00. Pretoria, SA, Water Research Commission. 340 pp.

Knights, P. (2002). Environmental flows, lessons from an Australian experience. Proceeding of International Conference: Dialogue on Water, Food and Environment. Hanoi, Vietnam,18 pp.

Michael E. McClain, Japhet J. Kashaigili and Preksedis Ndomba (2013) Environmental Flow Assessment as a Tool for Achieving Environmental Objectives of African Water Policy, with Examples from East Africa, International Journal of Water Resources Development, 1-16. http://dx.doi.org/10.1080/07900627.2013.781913

Norconsult. (2008). Environmental Impact Assessment (EIA) Statement for Kidunda Dam. Dar es Salaam Water and Sewerage Authority. Final Report

Munishi, P.K.T., Wilfred, N.N. Nshare, J.S., Moe, S.R., Shirima, D.D. and Kilungu, H.H. (2011). Valley Bottom Wetlands Can Serve for Both Biodiversity Conservation and Local Livelihoods Improvements, Ecosystems Biodiversity, Oscar Grillo (Ed.), ISBN: 978-953-307-417-7.

Smakhtin, V.Y. (2001). Low flow hydrology: a review. Journal of Hydrology, 240: 147-186.

Starkey, M., Birnie, N., Cameron, A., Daffa, R.A., Haddelsey, L., Hood, L., Johnson, N., Kapapa, L., Makoti, J., Mwangomo, E., Rainey, H. & Robinson, W. (2002). The Kilombero Valley wildlife Project: an ecological and social survey in the Kilombero Valley, Tanzania. Kilombero Valley Wildlife Project, Edinburgh.

Stevenson, T. and Fanshawe, J. (2002). Field Guide to the Birds of East Africa: Kenya, Tanzania, Uganda, Rwanda and Burundi T. & A.D. Poyser. London.

Tharme, R.E. (2003). A global perspective on environmental flow assessment: merging trends in the development and application of environmental flow methodologies for rivers. River Research and Application 19: 397-442.

Tharme, R.E. and King, J.M. (1998). Development of the building block methodology for instream flow assessments and supporting research on the effects of different magnitude flows on riverine ecosystems. Pretoria, SA, Water Research Commission Report No. 576/1/98. 452 pp.

United Republic of Tanzania URT, (2006). A Study to Establishing Mechanism for Payments for Water Environmental Services for the Rufiji River Basin in Tanzania for Ministry of Ministry of Natural Resources and Tourism Forest and Beekeeping Division

United Republic of Tanzania URT, (2011a). ASDP Performance review (draft 3). March 2011.

United Republic of Tanzania URT, (2011b). Evaluation of the performance and achievement of the agricultural sector development programme (ASDP)

United Republic of Tanzania, URT, (2002a). National Irrigation Master Plan Main Report

URT (Ministry of Water) (2012) Rufiji IWRMD Plan Interim Report, Volume I, Rufiji River Basin Physical, Socio-economic, and Management Profile, developed by WREM International Inc., Atlanta, Georgia, USA, 119 p.

URT (United Republic of Tanzania) (2002). National Water Policy (NAWAPO) of 2002, 88pp.

URT, (Ministry of Water) (2012) Rufiji IWRMD Plan Interim Report Volume II, Water Resources Availability Assessment, WREM International, Atlanta, Georgia, USA, 143p.

USAID ( ). Irrigation & Rural Roads Infrastructure Project (IRRIP2): Project Overview. Retrieved from http://crsps.net/wp-content/uploads/2013/03/Tues-M-6-Hall-CDM-Irrigation-project.pdf] site visited on 06/04/2013.

USAID. (2012). Location of IRRIP 2 Irrigation Projects. Morogoro, Tanzania.

Wami/Ruvu Basin Water Office (WRBWO). (2008). Business Plan. WRBWO, Morogoro.

WSSR, (2010). Water Sector Status Report (2010): Ministry of Water and Irrigation, United Republic of Tanzania

Yanda, P. Z and Munishi, P. K. T. (2007). Hydrologic and Land Use/Cover Change Analysis for the Ruvu River (Uluguru) and Sigi River (East Usambara) Watersheds. WWF/CARE Dar es Salaam, Tanzania

APPENDICES

Appendix 1: Inventory of water use registered and provisional water use permits

Source Name	Source type	Water use	Grant type	District	Amount allocated (m^3d^{-1})
Ngalawa River	River	DOMESTIC	Final	Mufindi	4.5
A Well	Boreholes and wells	DOMESTIC	Final	Ulanga	14.2
Bore Hole at Namawala	Boreholes and wells	DOMESTIC	Final	Kilombero	136.4
Chambinga Stream	Springs/ stream	IRRIGATION	Final	Mufindi	2,223.5
Chita River	River	DOMESTIC	Final	Kilombero	33,415,105.7 **
Dam on Un-named	Reservoirs	DOMESTIC	Final	Mufindi	22.5
Fikiri River	River	IRRIGATION	Final	Mufindi	4,345.1
Furua River	River	DOMESTIC	Final	Ulanga	92.7
Gideoni Spring	Springs/ stream	IRRIGATION	Final	Ulanga	225.0
Hagafiro River	River	HYDROPOWER	Final	Njombe	362,813.9
	River	IRRIGATION	Final	Njombe	102.7
Holianga Stream	Springs/ stream	DOMESTIC	Final	Mufindi	1.8
Homani River	River	DOMESTIC	Final	Mufindi	200.0
	River	INDUSTRIAL	Final	Mufindi	109.1
	River	IRRIGATION	Final	Mufindi	2,223.5
Ichonde Stream	Springs/ stream	DOMESTIC	Final	Kilombero	90.9
Idete River	River	DOMESTIC	Final	Kilombero	566.8
Idetero River	River	DOMESTIC & IRRIGATION	Final	Mufindi	2,454.9
	River	IRRIGATION	Final	Mufindi	2,450.0
Ifugiko Stream	Springs/ stream	IRRIGATION & FISH FARMING	Final	Mufindi	1,136.5
Igeri Stream	Springs/ stream	DOMESTIC	Final	Njombe	4,893.8
Ihambo Stream	Springs/ stream	FISH FARMING	Final	Mufindi	1,136.5
Kidofi River	River	IRRIGATION	Final	Mufindi	978.8
Kidogo Stream	Springs/ stream	DOMESTIC	Final	Njombe	50.4
Kiduma Stream	Springs/ stream	DOMESTIC	Final	Kilombero	133.2
Kigogo Ruaha River	River	DOMESTIC	Final	Mufindi	1,803.6
	River	INDUSTRIAL	Final	Mufindi	84,520.0
	River	IRRIGATION	Final	Mufindi	2,223.5
Kihansi River	River	HYDROPOWER	Final	Mufindi	3,585,600.0
Kilimatembo Stream	Springs/ stream	IRRIGATION	Final	Mufindi	133.3
Kinoga River	River	IRRIGATION	Final	Mufindi	587.2
Lihogosa Swamp	swamps	DOMESTIC	Final	Njombe	252.3
	swamps	DOMESTIC & INDUSTRIAL	Final	Njombe	445.9
	swamps	DOMESTIC & IRRIGATION	Final	Njombe	5,753.4
	swamps	DOMESTIC & IRRIGATION & INDUSTRIAL	Final	Njombe	1,753.4
	swamps	IRRIGATION	Final	Njombe	5,049.6

Lugoda "A" Stream	Springs/ stream	DOMESTIC	Final	Mufindi	9.1
	Springs/ stream	IRRIGATION	Final	Mufindi	1,223.5
Lugoda "D" Stream	Springs/ stream	IRRIGATION	Final	Mufindi	1,223.4
Luhanga River	River	DOMESTIC	Final	Mufindi	10.0
	River	IRRIGATION	Final	Mufindi	440.4
Luiga River	River	DOMESTIC	Final	Mufindi	136.4
	River	IRRIGATION	Final	Mufindi	1,992.8
Luisenga River	River	DOMESTIC	Final	Mufindi	27.3
	River	IRRIGATION	Final	Mufindi	2,202.2
Luisenga Stream	Springs/ stream	IRRIGATION	Final	Mufindi	1,468.1
Lumemo River	River	DOMESTIC	Final	Kilombero	190.9
	River	DOMESTIC & IRRIGATION	Final	Kilombero	2,709.4
	River	IRRIGATION	Final	Kilombero	1,000.0
Malata River	River	DOMESTIC	Final	Kilombero	54.6
Matugutu Stream	Springs/ stream	IRRIGATION	Final	Mufindi	1,712.8
Mbalu River	River	DOMESTIC & IRRIGATION	Final	Ulanga	22.7
Mlimba River	River	DOMESTIC & INDUSTRIAL	Final	Kilombero	550.0
Msolwa River	River	IRRIGATION	Final	Kilombero	103,993.2
Mzanza River	River	IRRIGATION	Final	Mufindi	489.4
Nanganje Stream	Springs/ stream	DOMESTIC	Final	Kilombero	611.7
Navabungu River	River	DOMESTIC & IRRIGATION & INDUSTRIAL	Final	Ulanga	2,446.8
Nyakimunga River	River	IRRIGATION	Final	Mufindi	734.1
Nyamalala River	River	DOMESTIC	Final	Mufindi	13.6
	River	IRRIGATION	Final	Mufindi	1,000.0
Nyamanyuki River	River	DOMESTIC	Final	Mufindi	13.6
Nyarabusi River	River	DOMESTIC	Final	Mufindi	-
Nyaupele and Ngegemi Springs	Springs/ stream	DOMESTIC	Final	Mufindi	432.0
Sebele Spring	Springs/ stream	DOMESTIC	Final	Njombe	6.0
Sofi River	River	IRRIGATION	Final	Ulanga	1,957.5
Spring	Springs/ stream	DOMESTIC	Final	Ulanga	9.5
Springs	Springs/ stream	DOMESTIC	Final	Njombe	24.5
Tasanga River	River	IRRIGATION	Final	Mufindi	1,666.7
Timbwi River	River	IRRIGATION	Final	Mufindi	489.4
Tri.butary of Mumilandope River	River	IRRIGATION	Final	Mufindi	500.0
Tribuatry of Ihanya River	River	DOMESTIC	Final	Mufindi	13.6
Tribuatry of Ngalawa R.	River	DOMESTIC	Final	Mufindi	4.6
Tributary Kigogo River	River	DOMESTIC	Final	Mufindi	9.1
Tributary Luisenga	Springs/ stream	DOMESTIC	Final	Mufindi	11.8
Tributary Nyakigunga River	River	IRRIGATION	Final	Mufindi	489.4
Tributary of Fuagi	River	DOMESTIC	Final	Mufindi	9.1

River					
Tributary of Homani River	River	DOMESTIC & IRRIGATION	Final	Mufindi	9.1
Tributary of Idetero river	River	IRRIGATION	Final	Mufindi	1,225.0
Tributary of Ifupira River	River	DOMESTIC	Final	Mufindi	9.1
Tributary of Ihanya River	River	DOMESTIC	Final	Mufindi	13.6
Tributary of Ikogolo	River	DOMESTIC	Final	Mufindi	23.6
Tributary of Ilolo River	River	IRRIGATION	Final	Mufindi	1,000.0
Tributary of Kigogo River	River	IRRIGATION	Final	Mufindi	1,225.5
Tributary of Kigogo Ruaha River	River	DOMESTIC	Final	Mufindi	4.5
Tributary of Kitabango stream	Springs/ stream	IRRIGATION	Final	Njombe	734.1
Tributary of Lasanga River	River	DOMESTIC & IRRIGATION	Final	Mufindi	27.3
Tributary of Luiga River	River	IRRIGATION	Final	Mufindi	9,000.0
Tributary of Lyakinyaga	River	DOMESTIC & IRRIGATION	Final	Mufindi	6.8
Tributary of Mumilandope River	River	IRRIGATION	Final	Mufindi	500.0
Tributary of Nyamalongole	River	DOMESTIC & IRRIGATION	Final	Mufindi	172.8
Tributary of Sabila River	River	DOMESTIC	Final	Mufindi	4.5
	River	IRRIGATION	Final	Mufindi	833.3
Tributary Tamba Guyi River	River	DOMESTIC	Final	Mufindi	13.6
Triibutary of Nyakingunga River	River	IRRIGATION	Final	Mufindi	833.3
Unnamed Spring	Springs/ stream	DOMESTIC	Final	Ulanga	45.5
Unnamed Stream	Springs/ stream	DOMESTIC	Final	Njombe	27.3
Unnamed Trb.Kimera	Springs/ stream	DOMESTIC	Final	Mufindi	1.8
Unnamed Trib Kinji	Springs/ stream	DOMESTIC	Final	Mufindi	23.6
Vengu River	River	IRRIGATION	Final	Mufindi	735.3
Wazo River	River	DOMESTIC	Final	Mufindi	-
	River	IRRIGATION	Final	Mufindi	3,280.2
Well	Boreholes and wells	DOMESTIC	Final	Ulanga	3.6
Well at Hulala River	Boreholes and wells	DOMESTIC	Final	Ulanga	149.8
Well at Luli	Boreholes and wells	DOMESTIC	Final	Ulanga	90.9
West Ruaha River	River	DOMESTIC	Final	Njombe	45.5
Bernadeta spring	Springs/ stream	COMMERCIAL	Provisional	Njombe	14.4
Bokera Stream	Springs/ stream	DOMESTIC	Provisional	Kilombero	7.0
Bore Hole BH No. MG 55/92	Boreholes and wells	DOMESTIC	Provisional	Kilombero	150.0
Borehole	Boreholes and wells	COMMERCIAL	Provisional	Morogoro	14.0
	Boreholes and wells	DOMESTIC	Provisional	Kilombero	356.2

	Boreholes and wells	INDUSTRIAL	Provisional	Kilombero	3.0
BoreHole (Na.MG.112/92)	Boreholes and wells	DOMESTIC	Provisional	Kilombero	10.0
Chamange Stream	Boreholes and wells	DOMESTIC	Provisional	Ulanga	129.0
Chirundu River	River	DOMESTIC	Provisional	Ulanga	629.0
Filambo River	River	DOMESTIC & IRRIGATION	Provisional	Njombe	150.0
Fukulwa River	River	DOMESTIC	Provisional	Njombe	3,024.0
Habata River	River	HYDROPOWER	Provisional	Njombe	432.0
	River		Provisional	Njombe	518.4
	River		Provisional	Mufindi	136.4
Ichonde River	River	DOMESTIC	Provisional	Kilombero	347.0
	River	DOMESTIC & IRRIGATION	Provisional	Mufindi	12.7
Igubike River	River	DOMESTIC	Provisional	Njombe	172.8
Iheng'u and Ihalali Streams	Springs/ stream	DOMESTIC	Provisional	Njombe	50.0
Isimani stream	Springs/ stream	DOMESTIC & IRRIGATION	Provisional	Kilombero	24.7
Iyanjo spring	Springs/ stream	COMMERCIAL	Provisional	Njombe	23.8
Kibaoni Borehole	Boreholes and wells	DOMESTIC	Provisional	Kilombero	4.0
	Boreholes and wells		Provisional	Mufindi	4,904.9
Kidugalo Borehole	Boreholes and wells	DOMESTIC	Provisional	Ulanga	1.0
	Boreholes and wells		Provisional	Mufindi	8,640.0
Kimbwi river	River	DOMESTIC & IRRIGATION	Provisional	Mufindi	26.4
Kinyangedzi Stream	Springs/ stream	DOMESTIC	Provisional	Njombe	51.8
Kisanambaga Spring	Springs/ stream	DOMESTIC	Provisional	Kilombero	2.0
Kyepa Stream	Springs/ stream	HYDROPOWER	Provisional	Njombe	129,680.0
Lufilyo Springs	Springs/ stream	DOMESTIC	Provisional	Njombe	280.8
Lufuo Stream	Springs/ stream	DOMESTIC	Provisional	Njombe	0.5
	Springs/ stream	HYDROPOWER	Provisional	Mufindi	3,888.0
	Springs/ stream		Provisional	Mufindi	136.4
	Springs/ stream		Provisional	Kilombero	200.0
	Springs/ stream		Provisional	Kilombero	18.2
	Springs/ stream		Provisional	Kilombero	100.0
Luvande Springs	Springs/ stream	DOMESTIC	Provisional	Njombe	7,340.7
Lwanginga River	River	DOMESTIC & LIVESTOCK & FISH FARMING	Provisional	Njombe	21.6
Mfumbi River	River	HYDROPOWER	Provisional	Kilombero	60,480.0
Mhulu stream	River	DOMESTIC	Provisional	Ulanga	90.0
Mkelema River	River	DOMESTIC	Provisional	Njombe	1.2
Mkungwe river	River	IRRIGATION	Provisional	Mufindi	33.5
Mngeta River	River	IRRIGATION	Provisional	Kilombero	432,000.0
Molimba River	River	DOMESTIC	Provisional	Mufindi	324.0
Mpando River	River	DOMESTIC	Provisional	Njombe	725.8
Mpanga river	River	DOMESTIC	Provisional	Kilombero	1,200.0
	River	FISH FARMING	Provisional	Ulanga	129.6
	River	IRRIGATION	Provisional	Kilombero	3,456.0
Msiwasi River	River	IRRIGATION	Provisional	Mufindi	700.0

Msuguliko river	River	IRRIGATION	Provisional	Iringa	200.0
Mtimbira River	River	DOMESTIC	Provisional	Ulanga	827.0
Mtoya River	River	IRRIGATION	Provisional	Njombe	2,450.0
Muhangavya Stream	Springs/ stream	INDUSTRIAL	Provisional	Kilolo	50.0
Ngalanga Stream	Springs/ stream	IRRIGATION	Provisional	Njombe	259.2
Nine Tube Wells	Springs/ stream	DOMESTIC	Provisional	Mufindi	13.0
Njokomoni Stream	Springs/ stream	DOMESTIC & INDUSTRIAL	Provisional	Kilombero	7.0
Nole River	River	HYDROPOWER	Provisional	Njombe	15,984.0
Nyakagede Stream	Springs/ stream	DOMESTIC & FISH FARMING	Provisional	Njombe	0.3
Nyalumang'ala River	River	DOMESTIC	Provisional	Kilombero	153.2
Nyamalonga Stream	Springs/ stream	DOMESTIC	Provisional	Njombe	2,592.0
Nyamalongolo River	River	IRRIGATION	Provisional	Mufindi	700.0
Nyamangala-Kilindi Stream	Springs/ stream	IRRIGATION	Provisional	Njombe	259.2
Ruhudji River	River	HYDROPOWER	Provisional	Njombe	1,341,884.3
Ruipa River	River	IRRIGATION	Provisional	Kilombero	6,912.0
Sanje River	River	IRRIGATION	Provisional	Kilombero	84,672.0
Shallow well	Boreholes and wells	DOMESTIC	Provisional	Kilombero	8.0
Sonjo River	River	DOMESTIC	Provisional	Kilombero	76.0
Springs at Kibena	Springs/ stream	DOMESTIC	Provisional	Njombe	21.6
Ten Tube Wells	Boreholes and wells	DOMESTIC	Provisional	Mufindi	42.0
Tributary of Kidofi River	River	IRRIGATION	Provisional	Mufindi	1,225.0
Tundu River	River	DOMESTIC	Provisional	Kilombero	4,159.7
Two Boreholes	Boreholes and wells	DOMESTIC	Provisional	Kilombero	90.0
Udeka River	River	HYDROPOWER	Provisional	Njombe	146,880.0
	River	IRRIGATION	Provisional	Mufindi	133.3
	River	DOMESTIC & INDUSTRIAL	Provisional	Njombe	18.2
Unnamed Stream Distributary of Ruhudji river	Springs/ stream	IRRIGATION	Provisional	Njombe	30.0
Unnammed Stream	Springs/ stream	DOMESTIC	Provisional	Njombe	113.7
Uwemba Schemes	Springs/ stream	COMMERCIAL	Provisional	Njombe	10.0
Uwepele stream	Springs/ stream	DOMESTIC	Provisional	Njombe	84.0
Vigoi spring	Springs/ stream	DOMESTIC	Provisional	Ulanga	454.6
Wana Stream	Springs/ stream	DOMESTIC	Provisional	Njombe	156.5
Wangama Spring	Springs/ stream	IRRIGATION	Provisional	Njombe	25,920.0
	Springs/ stream	DOMESTIC & INDUSTRIAL	Provisional	Kilombero	191.0
	Springs/ stream	DOMESTIC & INDUSTRIAL	Provisional	Mufindi	3.6
Grand Total					**39,936,794.9**

Note:
**the values are on the higher side. This could be a typing error.