Stakeholder enhanced environmental flow assessment: The Rufiji Basin case study in Tanzania

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Abstract:

Environmental flows (E flows) are now a standard part of sustainable water management globally but are only rarely implemented. One reason may be insufficient engagement of stakeholders and their priority outcomes in the E flow-setting process. A recent environmental flow assessment (EFA) in the Kilombero basin of the Rufiji River in Tanzania concentrated on a broad-based investigation of stakeholders' use and perceptions of the ecosystem services provided by the river.

The EFA process generally followed the Building Block Methodology but with an enhanced engagement of stakeholders. Engagement began with the involvement of institutional stakeholders to explain the purpose of the EFA and to elicit their priority outcomes. Extensive interactions with direct-use stakeholders followed to investigate their uses of and priorities for the rivers. Results were used by the EFA specialist team in choosing flow indicators and defining measurable environmental objectives. The specialists then met to reach a consensus of the flow requirements. The EFA results were lastly reported back to stakeholders.

During the Kilombero EFA we learned that stakeholders at all levels have a good awareness of the natural services provided by a healthy river and can contribute to the setting of environmental objectives for the rivers and floodplain. These can be factored into the biophysical assessments of river flows required to maintain habitats, processes, water quality and biodiversity. It is therefore important to allocate significant resources to stakeholder engagement. It now remains to be seen if enhanced stakeholder engagement, including the increased understanding and capacity built among all stakeholders, will increase support for the implementation of the recommended flows.

1. Introduction

Environmental flows (E flows) are designed to provide a flow regime that will support a range of ecosystem services that otherwise would be reduced or lost due to modified river flows. E flows may limit the extent to which water can be allocated to consumptive water users (Arthington , 2012; Arthington *et al.*, 2006). Environmental flows became part of the water allocation process in a number of countries during the 1980's and 90's (e.g. the USA, Australia and South Africa) and have since become a standard part of freshwater policy and management world-wide (Le Quesne *et al*, 2010). Many countries, including Tanzania, now have a requirement for environmental flows embedded in their water legislation. Although E flows are being assessed for numerous rivers, the implementation (i.e. actually providing the required flows in the river) has so far only been achieved in a handful of rivers (O'Keeffe, 2013). There are many reasons for this lack of implementation: rivers may already be over-allocated, and clawing back water from users is unpopular and difficult; perceptions of the relative importance of different water uses (domestic, agricultural and industrial) often result in a low priority for water that is left in the river for environmental purposes; current economic models underestimate the importance and value of ecosystem goods and services (Gilvear *et al*, in press). These perceptions are all underpinned by a widespread lack of understanding about environmental flows and their purpose at all levels from policy makers, managers and diverse stakeholders. There is a growing realisation of the importance of making sure that all the players in environmental processes understand the issues, the diversity of opinions and perceptions, and the advantages and costs (eg Hirst, 1989; Nel *et al*., 2007; Gelcich *et al*., 2014; Leleu *et al.*, 2012; Gelcich and O'Keeffe, 2016).

The process of environmental flow assessment (EFA) tries to provide consistent and objective ways of calculating the magnitude, frequency, duration and diversity of flows that are required to meet different environmental objectives. EFA methodologies have developed over time (Tharme, 2003). Originally, they consisted of hydrological models linked to some measures of hydraulic habitat availability, either for single target species (e.g. Instream Flow Incremental Method (IFIM), Milhous *et al*., 1989), or for general ecosystem health (e.g. Tennant, 1976). Many such methodologies are still in frequent use, but gradually socio-cultural and economic components have been added to the assessments (e.g. DRIFT, King *et al*., 2003). However, it is becoming clear that EFA should be undertaken not just with a social add-on but within a comprehensive long-term framework of stakeholder involvement and capacitation (Gilvear *et al*, in press). In this trajectory, stakeholders at different levels are educated as to the meaning and worth of E flows, and are engaged through interviews and meetings to provide information on the priority uses of a river, the most valued goods and services, and to participate in setting the environmental objectives that will guide the assessment of flow requirements for the river. Gilvear *et al* (in press) point out that, as yet, only a few studies have actually utilised ecosystem services concepts in assessing environmental flows, with exceptions (e.g. Notter *et al*., 2012).

A recent EFA for the Kilombero basin of the Rufiji River in Tanzania (McClain *et al*., 2016) concentrated on a broad-based investigation of stakeholders' use and perceptions of the priority goods and services provided by the river. This paper describes the methods used and results obtained from this assessment of the priority uses, ecosystem goods and services enjoyed by the riparian and floodplain communities, and the environmental priorities of the institutional stakeholders. It summarises the results of this process and relates these findings to the traditionally used biophysical flow indicators derived from ecology, geomorphology, and water quality. This more multidisciplinary approach identified a modified flow regime which satisfies the requirements and has the support of as many stakeholders as possible.

2. Kilombero EFA Case Study

A detailed description of the EFA process, methods and results for the Kilombero can be found in McClain *et al* (2016). For this paper, the aim is only to summarise the ways that the different specialists selected and used biophysical, social and cultural indicators to assess flow requirements to maintain or improve the environmental conditions of the rivers and floodplains, and then to discuss how the scientific recommendations relate to the priority needs and preferences of the stakeholders. The EFA focused on selected river reaches of the Rufiji Basin that are most vulnerable to the impacts of four planned rice irrigation schemes along the northern margin of the Kilombero River Valley. The specialists identified five sites for detailed studies (Figure 1). The number and locations of detailed study sites were selected based on a preliminary zonation of the rivers proximal to the planned irrigation schemes, and available time and financial resources. Study sites reflected three river zones with distinct flow-related social-ecological characteristics. The methodology used was the Building Block Methodology (BBM) (King *et al*, 2008) modified to add greater emphasis on discovering the needs and priorities of stakeholders and matching the flow recommendations to them (this paper).

Broadly, the EFA process followed the following steps:

- Recruitment of a team of specialists (hydrologist, hydraulics engineer, fish, invertebrate and riparian vegetation ecologists, geomorphologist, water chemist, and sociologists) to undertake the investigations of flow-related issues and interests. Also included were representatives from the government agencies most closely involved in the development of the water resources of the Kilombero sub-basin (see a. below).
- The involvement of institutional stakeholders (see b. below) to explain the purpose of the EFA and to elicit their interests and priorities for the outcomes.
- Extensive interactions with the direct-use stakeholders (see c. below) to gather information on the uses of the river basin and the priorities for maintaining or improving riverine and floodplain condition.
- The above three steps fed into the preparations of the biophysical specialists, in terms of their choice of flow indicator species, components, processes and uses, and the definition of detailed environmental objectives for the EFA (see d. below).
- Following these preparations, the specialists gathered for a 5 day workshop to reach a consensus on the flows required to meet the environmental flow objectives and preferences of the stakeholders, using the BBM process (see e. below).
- A report of the EFA results was presented to stakeholders at a feedback meeting which related these results to a feasibility study of the proposed rice-growing projects. The stakeholders were then asked to respond to the recommendations (see f. below).

The following sections summarise the approach to engage with stakeholders, identify their needs and objectives, and ultimately incorporate these into the flow indicators used by the various specialists to set the E flow recommendations.

a. Government and the Rufiji Basin Water Board

Since the overall project for the Kilombero sub-basin (including the proposed rice irrigation schemes) was intimately associated with a number of government ministries, these received reports and updates on the EFA as it progressed. There was a particular requirement that the EFA process should ultimately be owned by the Rufiji Basin Water Board, since they are tasked with the decisions and implementation of E flows. The Ministry of Agriculture also has major responsibilities which might be influenced by the results of the EFA. So staff from these two organisations were seconded to the EFA team and participated in all the meetings, results and report writing.

b. Institutional stakeholders

Environmental flows is a relatively new water management concept in Tanzania, even though it is already entrenched in the water legislation. An aim of the Kilombero EFA was therefore to explain to as many Tanzanian institutions (government and private) as possible what E flows are, how they are assessed, and why they are important. An institutional stakeholder meeting was held on February 10th 2014, to inform stakeholders about the environmental flow assessment, to explain the methodology applied, and to introduce the team undertaking it. A second objective was to answer stakeholder questions about the environmental flow assessment and discuss how it fits into larger plans to promote sustainable development in the Kilombero sub-basin. A final objective was to receive input from stakeholders on the level of ecological health and ecosystem services they desire for the Kilombero river, its riparian areas and floodplains.

A total of 31 participants attended the workshop. These were drawn from central government ministries, local government authorities, the Rufiji Basin Water Board, universities and research institutes, development partners, Southern Agricultural Corridor of Tanzania (SAGCOT) and various other projects.

A checklist of 23 information, production and regulation ecosystem services that are supported by environmental flows (developed from De Groot *et al* 2005 (as cited in Krchnak *et al*., 2009) was provided to workshop participants, and every participant was asked to select five priority services. Biodiversity conservation scored highest, followed by fertile land for flood-recession agriculture and grazing, fish/shrimp/crabs and water for people. Services such as health and pest control, cultural activities, medicinal plants and materials for building and/or firewood were not identified as the highest priorities. Table 1 lists the 5 services rated most important by the delegates. The identified preferences were used by the team of specialists in their formulation of environmental flow objectives.

c. Direct-use stakeholders

To describe the resources and services used by communities and their relationship with river flows in the Rufiji EFA, a checklist for ecosystem services developed from deGroot *et.al*, 2002 was used . Further refinement was made in some of the services to allow for a better linkage to the flow-dependent and -independent services and to distinguish between cultivated and non-cultivated resource uses (Table 2).

A two-pronged approach was used to assess the direct-use of riverine resources by local communities:

- Participatory Rural Appraisal (PRA) technique to elicit and capture qualitative information on the use of riverine resources for socio-economic needs. Information gathered included resource mapping (location and extent).
- Questionnaire survey in order to quantify and triangulate the information collected through PRA technique

The PRA was done in 16 villages close to the five study sites (Figure 1). Key informants included village executive officers, traditional healers, school children and fishermen. For the quantitative survey, a structured questionnaire was conducted face to face in all villages. In the two surveys a total of 736 households were consulted.

The assessment did not include an economic valuation of the goods and services, due to the continuing level of uncertainty in available methods and the tendency to undervalue their benefits (Gilvear *et al.*, in press).

In general, the communities seem to attach a high value to ecosystem services that enhance their livelihoods rather than to the services that enhance ecosystem health such as regulatory and information services (Table 2). The highest preference (97% of the respondents) was attached to moist and fertile soils for flood recession agriculture (crop cultivation). Water for domestic uses followed second. Health control (ranked fourth) is also considered very important (malaria, bilharzia and urinary tract infection control). Services that received little preference include aquatic animals, recreation and tourism, and sites for cultural and ritual activities. Although the institutional stakeholders ranked biodiversity conservation as the most important service, the direct use stakeholders gave it a low preference (ranked 13 out of 17).

Economic activities influenced communities' preferences strongly. The most important economic activity at all survey sites was crop cultivation, followed by fishing and livestock, but proportions differed according to sites (Table 3). Fishing was more important at sites 1, 4, and 5, while livestock keeping was more important at sites 2 and 3 (Figure 1). Site 3 had the largest proportion of "other" economic activities, including brick making and small businesses

The relative contribution of the different activities to the annual household income is presented in table 4. For the villages of sites 1, 2 and 3 crop farming is their main source of income, out of which rice is the most important cash crop. At site 4 fishing becomes almost as important as crop farming, while at site 5 fishing is the main source of income.

d. Summary of the use of biophysical indicators to identify required flow conditions

A series of hydraulic cross-sections was surveyed at each of the 5 sites (Figure 1), and these provided the basis for hydraulic modelling which related water depths at different flows to current speeds, wetted perimeters and discharges in m^3sec^{-1}. The various specialists sampled fish, riverine invertebrates, riparian and floodplain vegetation, use of river and floodplain resources by local communities, water quality, channel morphology and sediment types at each site in order to identify flow-sensitive species, components and processes. They then investigated habitat preferences, ecosystem services used, water quality conditions, and sediment transport conditions in terms of depths, current velocities and wetted perimeter. These conditions were then converted to flow discharges (supported by the hydraulic model) required to achieve the pre-defined environmental objectives.

Throughout the study area, the hydrological record indicated that flow conditions have changed very little from natural, as there are presently few upstream flow-regulating structures or large-scale water abstractions. The observed changes in catchment condition, and the resultant impacts on present ecological state (PES) in terms of geomorphology and water quality appear in large part related to increased settlement, and widespread, rapid conversion of land to agriculture (including the destruction of natural forest and wetland habitats).

The biophysical specialists were tasked to take the results of the stakeholder preferences and use them to set biodiversity and physical process objectives. For example, the fish specialists checked which species were felt to be of most importance for livelihoods, and made sure that their flow recommendations would provide for the habitat maintenance of these species. At the same time, the use of the most flow-sensitive fish and invertebrate species as indicators for flow requirements aims to maintain the entire biodiversity, including those species on which the livelihood-important species depend. Similarly, maintaining the riparian vegetation provides direct benefits in terms of harvestable plants such as reeds and medicinal species, but also provides stability and erosion resistance for the river channel and banks. Maintaining the geomorphological processes, such as sediment entrainment and deposition, ensures that the habitat diversity on which biodiversity depends will also be maintained. Provision of sufficient flow will be irrelevant if the water quality deteriorates below sustainable levels. The social/cultural investigations also provide their own assessments of specific flows required at different sections of the river system. Checking that these match up with the biophysical flow requirements provides more motivation for providing the E flows. Summary information on the findings of each biophysical specialist are presented in the sections below.

Fish:

Fish communities were identified according to Table 5. The riffle and lotic guilds most sensitive to flow conditions were used as indicators, on the assumption that, if fast-flowing and deep hydraulic habitat conditions suitable for these species are maintained, less sensitive guilds will automatically be catered for in terms of pool and marginal habitats. Sampling using electro-fishing was used to characterise the depths, current velocities and substrate types where these sensitive species were found during different seasons. Flows required for the dry season are usually motivated in terms of maintaining some residual fast-flowing habitat at depths which will cater for these species and will maintain connectivity along the river. Wet season flows and floods were related to the breeding requirements of fish, floodplain and riparian zone inundation.

Invertebrates:

Invertebrates provide easily sampled communities with great diversity, and also respond very rapidly to changing conditions. Different families have well-known tolerances to both hydraulic and water quality conditions and were used similarly to the fish communities to assess depths, velocities, and wetted perimeter required to maintain flow-sensitive species.

Thirty two (32) families belonging to 9 orders of macroinvertebrates were encountered in the samples at all sites. The most sensitive taxa recorded in this study include Prosopistomatidae, Heptageniidae, Teloganodidae, Perlidae, Helodidae, Pyralidae, Psephenidae, Tricorythidae and Leptophlebiidae. The sensitive taxa were mostly found in samples collected from rapids and riffle habitats with velocities > 1.4 m/s.

The information from macroinvertebrate sensitivity scores indicate that Udagaji river (site 2) has good water quality with high habitat diversity. The Mpanga and Kilombero rivers (sites 3 and 4) were on the border-line between good and bad water quality while moderate pollution is likely already occurring in the Lwipa River (site 1) (Figure 1).

Geomorphology:

The fluvial geomorphology is initially used as a main designator of zonation in the rivers, since changes in gradient, associated channel morphology and sediment types will be major processes in structuring habitat types. Sediment type, channel structure and size will all change with flow changes, because mobilisation, transport and deposition will all be affected. Existing models of gradients, flow velocities and water depths, can predict how the channel and sediments (and therefore habitats) are likely to change as flows are modified.

Generally, the predictions were as follows: If water abstraction increases, the rivers Lwipa, Udagaji and Mpanga (sites 1 to 3) will be subject to bed aggradation, with their river-beds and water levels rising all along their courses. This will result in decreased conveyance in their channels and increased flood frequency. Aggradation might also result in the colonization of the sediment deposits that emerge during low flows by vegetation, resulting in river width reduction. The decrease of reference water depth will result in increased width-to-depth ratios, with the possibility that bars start to form on the river bed. These bars might then be colonized during low flows, resulting in bar stabilization leading to opposite bank erosion, creating new channel bends. The final configuration of the Kilombero (sites 4 and 5) will be characterized by increased longitudinal slope and reduced water depth.

Riparian Vegetation:

Riparian vegetation provides a number of important services for the river ecosystem, including maintenance of channel structure by reducing bank erosion during high flows. For example, the riparian woody plant species such as *Ficus sycomorus*, *Acacia xanthophloea* and *Voacanga africana* have networks of well-developed root systems that bind the soil structure of stream banks. Riparian and aquatic plant species are also important as food sources and breeding sites for fish and macroinvertebrates. Floodplain vegetation is very important to provide extra habitats for migratory fish and the supply of nutrients to the main channel during high flows. Floodplain inundation is also essential for flood recession agriculture.

Vegetation surveys included aquatic, riparian, floodplain and terrestrial vegetation zones at the five study sites (Figure 1). These revealed that all the sites were species-rich and dominated by native plant species. Some species were common in all sites, suggesting that their flow requirements are met in terms of velocity, depth and substrate. *Phragmites mauritianus* and *Penissetum purpureum* (Poacea), which occur along the channel and on lower river-banks, were common indicator plant species for all sites. These are highly water-dependent species, so that any extensive change in flows will have negative consequences to these species and their communities.

Six plant communities were identified based on flow requirements. The dominant species of each community are Pistia-Vossia aquatic community, Phragmites-Penissetum grasslands, Ficus spp.-Cyperus, Voacanga-Ficus-Acacia riparian community, Panicum-Kigelia floodplain community and Diplorhynchus-Combretum woodland. These groups are a result of geomorphologic and hydrological processes that have taken place in Kilombero catchment over time.

Water Quality:

Maintaining reasonable water quality is necessary, both for human health reasons, and so that the recommended flows can achieve the required environmental objectives. The water quality in the EFA process is used not so much to recommend flows, but rather to predict whether the flows recommended by the other specialists are likely to result in adequate water quality, especially during low-flow periods when dilution is reduced.

Water quality was assessed in terms of a wide range of parameters, from temperature and system variables such as pH, through to nutrients. Contaminants were indirectly evaluated (e.g. through questions to farmers about pesticide application). Present water quality conditions were scored independently for the wet and dry seasons, because most water quality parameters tend to be at their worst at very low flows (e.g. low oxygen, high ammonia). Wet season values for some parameters may be high (e.g. high turbidity, nitrates, and organic material) due to entrainment at high flows. Results indicated that at Sites 1, 2 and 3 water quality is still relatively natural, site 4 shows slightly modified water quality, and at site 5 water quality is relatively natural during the wet season, but slightly modified during the dry season.

It was concluded that the present water quality modifications are a consequence of land-use activities, domestic waste, pesticides, and the occasional use of poisons for fishing. They are unlikely to be affected by the environmental flows recommended, and should be addressed at source.

e. Flow setting workshop

At a week-long meeting in June, 2015, the specialists met to discuss and motivate consensus flows for dry season and wet season base-flows and floods, for normal and drought years, that would maintain or improve environmental conditions to the objectives identified by each specialist group. During the flow-setting workshop the flow motivations of the different specialists were integrated. For example a fish species that is essential for the diet of the communities may only be able to survive when other fish and invertebrate species are protected, when geomorphological processes and riparian vegetation ensure the maintenance of habitats, and when water quality is maintained within ecological requirements. All these indicators guide the flow recommendations that provide the river and floodplain biodiversity on which people depend. This process provided E flow recommendations based on interlinked information and analysis, including stakeholder information.

f. Feedback workshop following the EFA

Following the EFA study, the draft report was distributed to the institutional stakeholders, and a further stakeholder meeting was held in February 2016. The aims were to: portray information/results; to engage the participants in discussion about the meaning of the results in relation to the implementation of proposed irrigation schemes, and to inspire participants to identify additional utility for study results. The delegates were similar to those for the 2014 meeting (section b. above), but included many more agricultural representatives, such as members of local irrigation boards and projects, since the presentations were primarily aimed at assessing support for proposed irrigated rice-growing.

This was the final meeting involving the EFA specialist team, and, from their point of view, was an opportunity to inform more stakeholders about the EFA (particularly those with agricultural interests), and to demonstrate the links and consequences between the potential irrigation and the EFA.

3. Insights gained from the Case Study

Introducing the idea of environmental flows to stakeholders (who may have little or no experience of the issue) is often challenging. Globally, there is a basic view that rivers are a very valuable resource for human use and that the main product they provide is freshwater, the basis of life, livelihoods, food production, industry and sanitation. A consequence of this view is that water flowing out of the end of a river, if not a waste, may at least be perceived as a lost opportunity for improving human welfare. Accepting the premise of environmental flows, that water should be left in the river, and that a fairly high proportion of mean annual runoff may have to be left in the river if relatively good environmental conditions are to be maintained, requires a 180^{o} change of this mind-set. To convince people that this change is useful and desirable needs compelling reasons. The scientific process of assessing water requirements to maintain biophysical diversity and processes may seem convincing to specialist environmentalists but has to compete with the economic values of consumptive water uses, of which the majority of non-specialist stakeholders are well aware. To be able to demonstrate that the scientific indicators are connected to the maintenance of a whole suite of goods, services and livelihoods that are strongly valued by stakeholders is a major step up in the understanding and acceptance of E flows. Providing quantified hydraulic and hydrological flow requirements, motivated at a number of biophysical levels and disciplines, and linked directly to the ecosystem goods and services which are valued by the local direct-user stakeholders, and the broader societal institutions, makes the strongest possible case for maintaining or restoring the required environmental flows. Because the Rufiji EFA was the first introduction to the concept of environmental flows for most stakeholders, it was important to keep the messages and questions simple (minimising modelling, economics and statistics), allowing stakeholders to make common-sense connections between flow indicators and their own priorities.

The Kilombero project has shown that riparian and floodplain dwellers use and benefit from a wide range of ecosystem goods and services, and that they understand and value the natural river flows and floodplain inundation that drive them – although, understandably, they often value direct livelihood services highest. The institutional stakeholders also demonstrated that their priorities included a high valuation of biodiversity and natural processes provided by the river. The government agencies and basin water board showed their commitment to the environmental flows process by allocating staff to attend and contribute to all the activities of the Kilombero assessment.

The outcomes of the Rufiji EFA demonstrated the value of spending time and resources on the social and cultural aspects of E flows. Large numbers of people and institutional staff learned what E flows are and were able to express their preferences for the different services from the rivers. These preferences were factored into the environmental objectives of the EFA, triangulated with the results of the bio-physical specialists, and the results have been fed back to as many stakeholders as possible.

Of course, the assessment of flows required to maintain or improve conditions is only a first step. Implementing (in the case of the Kilombero, maintaining) the required flows would be the real outcome. Ultimately, providing environmental flows becomes a societal choice. The recommended flows can be as carefully assessed and motivated as possible, but if government, citizens and institutions decide that consumptive uses must have priority, and that rivers must only be seen as water conduits and waste disposal channels, then we can only do our best to define the consequences of such a plan as accurately and comprehensively as possible.

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Figure 1: The Kilombero sub-basin of the Rufiji River basin, Tanzania, showing the positions of the 5 detailed EFA study sites. The inset shows the position of the Kilombero sub-basin within the Rufiji basin. (Modified from McClain *et al*, 2016)

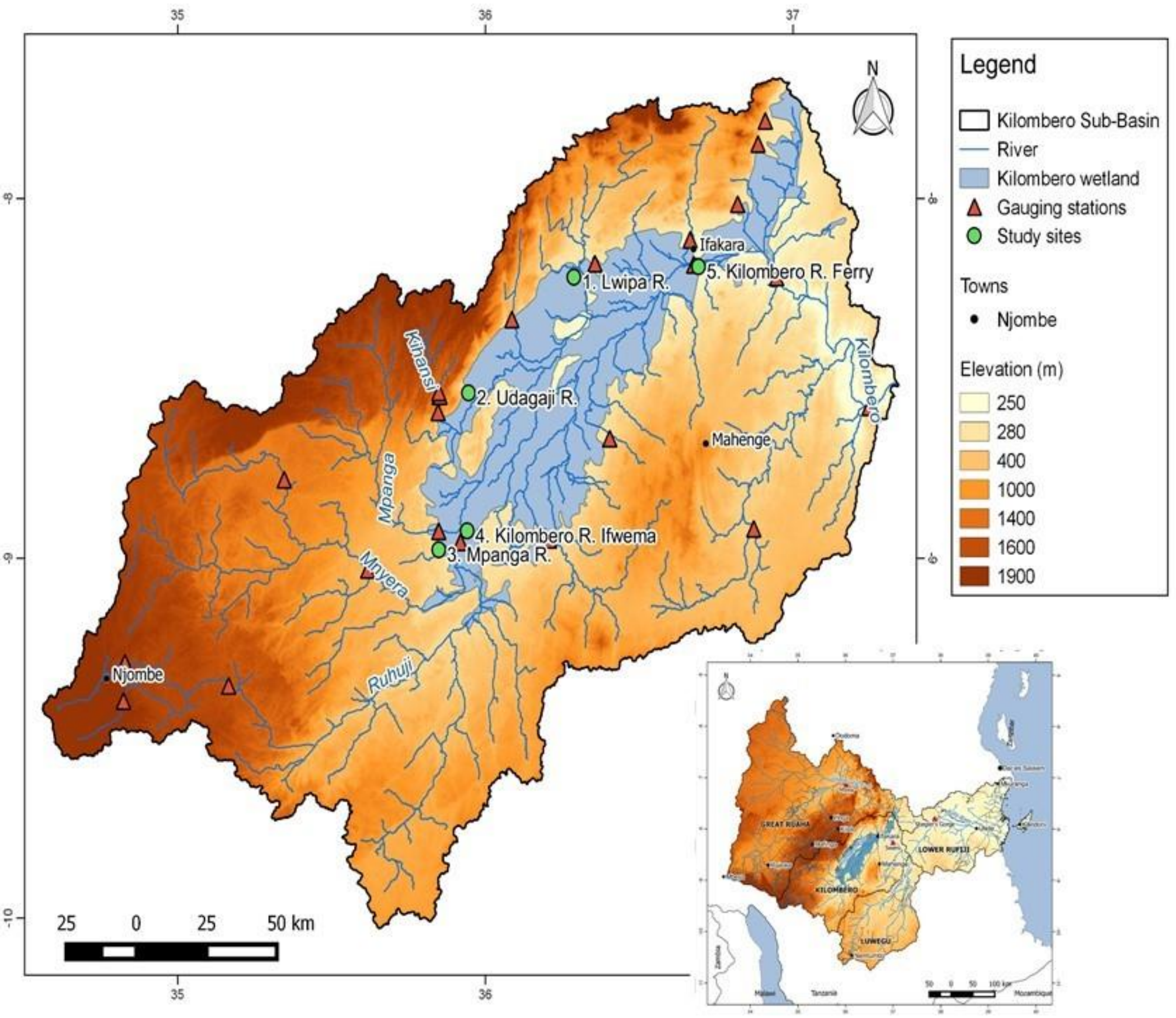

Table 1: Priority ecosystem services favoured by institutional stakeholders in Tanzania. (from McClain *et al*, 2016)

Service category	Service provided	Key flow-related function	Key environmental flow component	Scores	Ranking
Information	Biodiversity conservation	Sustaining ecosystem integrity (habitat diversity and connectivity)	Natural flow regime	**27**	**1**
Production	Fertile land for flood-recession agriculture and grazing	Supply of nutrients and organic matter, moisture conditions in soils	Floodplain inundation	**20**	**2**
Production	Fish/shrimp/crab s (non-recreational)	Habitat availability and connectivity, food supply	In-stream flow regime, flood-plain inundation, flows sustaining riparian vegetation	**17**	**3**
Production	Water for people-subsistence/ rural and piped/urban	Water supply	Floodplain inundation	**15**	**4**
Regulation	Groundwater replenishment (low-flow maintenance	Groundwater (aquifer) replenishment	Floodplain inundation	**13**	**5**

Table 2: Respondents preferences of ecosystem services supported by environmental flows at BBL sites 1-5. (from McClain *et al*, 2016)

Service provided	**Riverine resource service**	**BBM sites**					**Mean**
		1	**2**	**3**	**4**	**5**	**1-5**
Production							
Water for people-subsistence / rural and piped/urban *(Water for domestic uses)*	Domestic use	2	1	1	2	2	2
Fish/shrimp/crabs (nonrecreational) *(Fish and fishing grounds)*	Fishing	6	6	5	4	5	5
Fertile land for flood recession agriculture and grazing *(Moist and fertile soils for flood recession agriculture)*	Crop cultivation	1	2	2	1	1	1
Fertile valley plains for grazing	Livestock keeping	12	8	6	11	15	11
Wildlife for hunting (nonrecreational) *(Aquatic animals such as hippopotamus, crocodiles and snails)*	Animals, birds and insects	16	16	17	15	17	17
Vegetables and fruits	Natural vegetables and fruits	10	10	10	9	8	9

	Cultivated vegetables and fruits	3	3	3	3	3	3
Fiber/organic raw material for building/firewood/handicraft	Construction materials	5	4	7	6	6	6
	Weaving materials						
	Fuel						
Medicine plants	Traditional medicine						
Inorganic raw material for construction and industry (gravel, sand, clay) *(Soils for brick making)*		9	7	9	7	10	8
Water for navigation		13	14	13	14	12	14
Regulation							
Chemical water quality control (purification capacity)							
Physical water quality control		7	9	8	8	9	7
Flood mitigation	Flooding	8	11	14	10	7	10
Groundwater replenishment (low-flow maintenance)							
Health control *(Malaria, bilharzia and UTI control)*	Water associated problems	4	5	4	5	4	4
Pest control							
Erosion control (riverbank/bed and delta dynamics) *(Sedimentation and erosion control)*		11	12	11	12	14	12
Prevention of saltwater intrusion (salinity control)							
Prevention of acid sulphate soils development							
Carbon "trapping" (sequestration)							
Microclimate stabilization							
Recreation and tourism (incl. fishing and hunting)		17	15	16	17	16	16
Information							
Biodiversity conservation		14	13	12	13	13	13
Cultural/religious/historical/symbolic activities *(Sites for cultural and ritual activities)*	Traditional dancing	15	17	15	16	11	15
	Rituals						
	Unyago						
	Circumcision						
	Jando						
	Swimming						

Adapted from De Groot *et al* 2005 (as cited in Krchnak *et al*., 2009)

Table 3: Main economic activities at BBM site 1-5 (from McClain *et al*, 2016)

Percentage household engaged in economic activity	BBM sites				
	1 (%)	2 (%)	3 (%)	4 (%)	5 (%)
Crop farming	96	93	93	96	98
Livestock keeping	40	38	44	37	28
Fishing	48	30	33	42	43
Others	19	28	39	25	19

Table 4: Contribution to annual household income (from McClain et al, 2016)

Economic activities	BBM sites				
	1 (%)	2 (%)	3 (%)	4 (%)	5 (%)
Crop farming (Maize, Rice, Sunflower, Sesame and Banana)	69	80	72	47	14
Vegetable cultivation	6	6	10	0	0
Livestock keeping	5	6	7	14	4
Fishing	18	3	9	38	81
Weaving	0	0	1	0	0
Others	2	5	1	1	1
Total	100	100	100	100	100

Table 5: Representative fish species in major environmental guilds in the Kilombero Valley. (from McClain *et al*, 2016)

Fish community type	**Ecological guild**	**Representative fish genera/species in the Kilombero System**	**Sensitivity to flow**
Rhithronic communities	Riffle guild	*Chiloglanis, Amphilius, Parakneria,*	Critical
	Pool guild	Small Barbus species (e.g. B. paludinosus), Brycinus)	Moderate
Potamonic communities	Lotic guild	*Labeo, Barbus macrolepis, Alestes, Distichodus, Schilbe.*	High
	Eurytopic guild	Clarias, Tilapia, Oreochromis, Mormyrids (Petrocephalus, Marcusenius)	Low
	Catadromous guild	Eels (Anguilla)	High