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Environmental Flow Assessment of Great Ruaha River in Southwestern Part of Tanzania

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Abstract: Environmental Flow Assessments (EFAs) are becoming the global standard for determining the amount of water required to sustain aquatic ecosystems and sustain socio-economic development. EFAs comprise structured, science-based approaches to determine how much water must be left in the river to protect the aquatic ecosystems and achieve the desired ecological state. The building block methodology (BBM) that was used in this study is designed to identify a series of important flows (the building blocks) which will together provide the essential aspects of the natural hydrological regime that ensure the persistence of as much of the biodiversity as possible. The results show that a total inflow into eastern wetland of 5.52-6.81 m^3/s is required in order to sustain an outflow of 1-2 m^3/s past Ng'iriama and hence meet the "minimum" recommended flow rates further downstream at BBM1 and BBM2 during the drought low flow conditions. The rationale being that a satisfactory flow during drought low flow conditions will guarantee sufficient flows during low flow periods in normal and wet years. The low flows of 2.5 m^3/s and 19 m^3/s are recommended for the driest and wettest months, respectively.

Key words: Environmental flow, Great Ruaha River, building block methodology.

1. Introduction

The Great Ruaha River (GRR) arises in the highlands of the Usangu catchment, which is located in the rift valley in south-west Tanzania (Fig. 1). Water drains off the highlands into the Ruaha National Park (RNP)—through the Usangu Plains, into the Usangu Wetland, emptying at the north-eastern extreme of the catchment at Ng'iriama, into the Middle GRR (MGRR) to the reservoir and power plants at Mtera and Kidatu, before joining the Rufiji River and emptying into the Indian Ocean.

The GRR catchment is of major importance to the economy of Tanzania. For example:

- The RNP hosts a high diversity of flora and fauna including, notably, large mammals which help to attract a thriving and potentially growing tourist industry, thus earning foreign income for Tanzania. The Usangu wetland and GRR are the only sources of water in the park which flows constantly, in natural conditions;
- The Ruaha catchment is important for supporting the local and national economy. It is known locally as the "bread basket" of Tanzania. It provides water supplies to meet the agricultural needs of 90% of the people living in the catchment who are almost entirely dependant on natural resources. Agricultural produce from the area contributes to the national economy as well as to food security [1];
- Mtera and Kidatu hydropower dams on the Great Ruaha River generate about 50% of the electricity in Tanzania, contributing to the countries energy security;
- The river and its associated ecosystems offer numerous wider socio-economic benefits including water purification and filtration of pollutants; aesthetic, cultural and spiritual values; conservation

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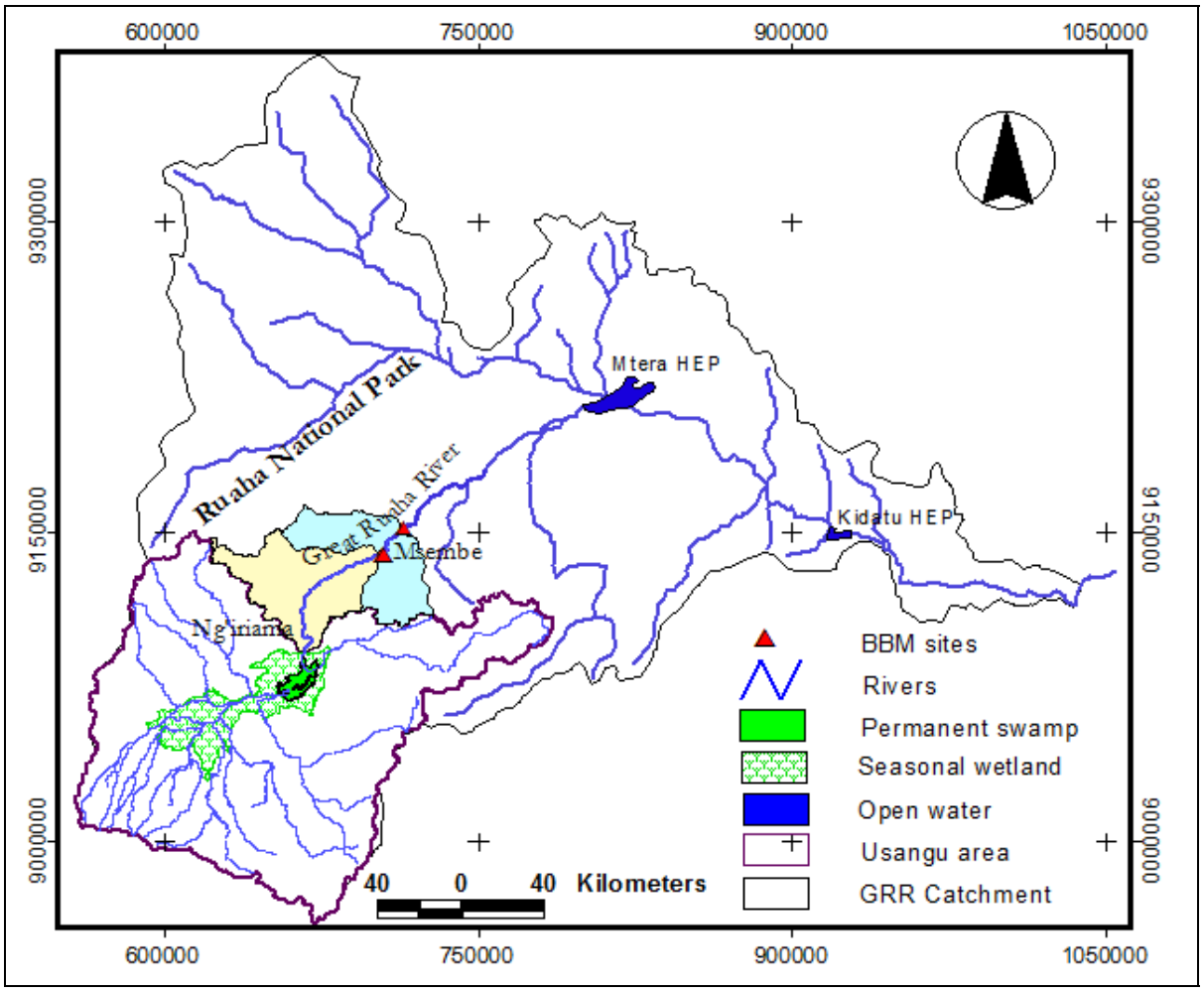


Fig. 1 The GRR catchment and the location of BBM stations.

of biodiversity which preserves resilience and options for the future, especially in the face of climate change.

In recognition of the crucial role that Great Ruaha River flows play to national economy of Tanzania, the WWF Tanzania Country Office through the coordination of Petro Masolwa and Shadrack Mwakalila conducted an Environmental Flow Assessment (EFA) study from 2008 to 2010. The objectives of the EFAs were to recommend flow rates, for different seasonal scenarios, required to restore dry season flows to the middle section of Great Ruaha River (GRR) and Usangu wetland in the Ruaha National Park (RNP).

The Brisbane Declaration [2] provides a useful description of environmental flows: "Environmental flows describe the quantity, quality and timing of water flows required to sustain freshwater and estuarine ecosystems and the human livelihoods and well-being that depend on these ecosystems". This definition acknowledges the linked variables of quantity, quality, and timing that together constitute an environmental flow regime of sufficient quality to meet management goals.

2. Methodology

EFAs comprised structured, science-based approaches to determine how much water must be left in the river to protect the aquatic ecosystems and achieve the desired ecological state. The objective of the EFA was to determine the flows necessary to maintain or restore riverine conditions in the Middle GRR (MGRR) in the RNP, between Ng'iriama and

the Mtera Dam, so that the water resource management of the upper catchment could take these requirements into account. The reason for focusing the study on the MGRR was that this is the section of the river which lies within the RNP, in which the low season flows have ceased since 1993, because of over abstractions and catchment modifications upstream.

The combination of methods was used for data collection and analysis. The following literatures provided information that was relevant to situation analysis:

- The original & present state of the Great Ruaha river systems [2-5];
- The importance and sensitivity of the Great Ruaha river systems [6];
- The relationship between river flow and the ecosystem [7, 8].

The building block methodology (BBM) was used to determine the required flows for the GRR (Fig. 2). The BBM is ideally suited for assessing flows for rivers where there is no single species (such as salmon or trout) of overriding importance—in other words, systems in which the aim is to ensure a healthy, functioning ecosystem. The methodology is designed

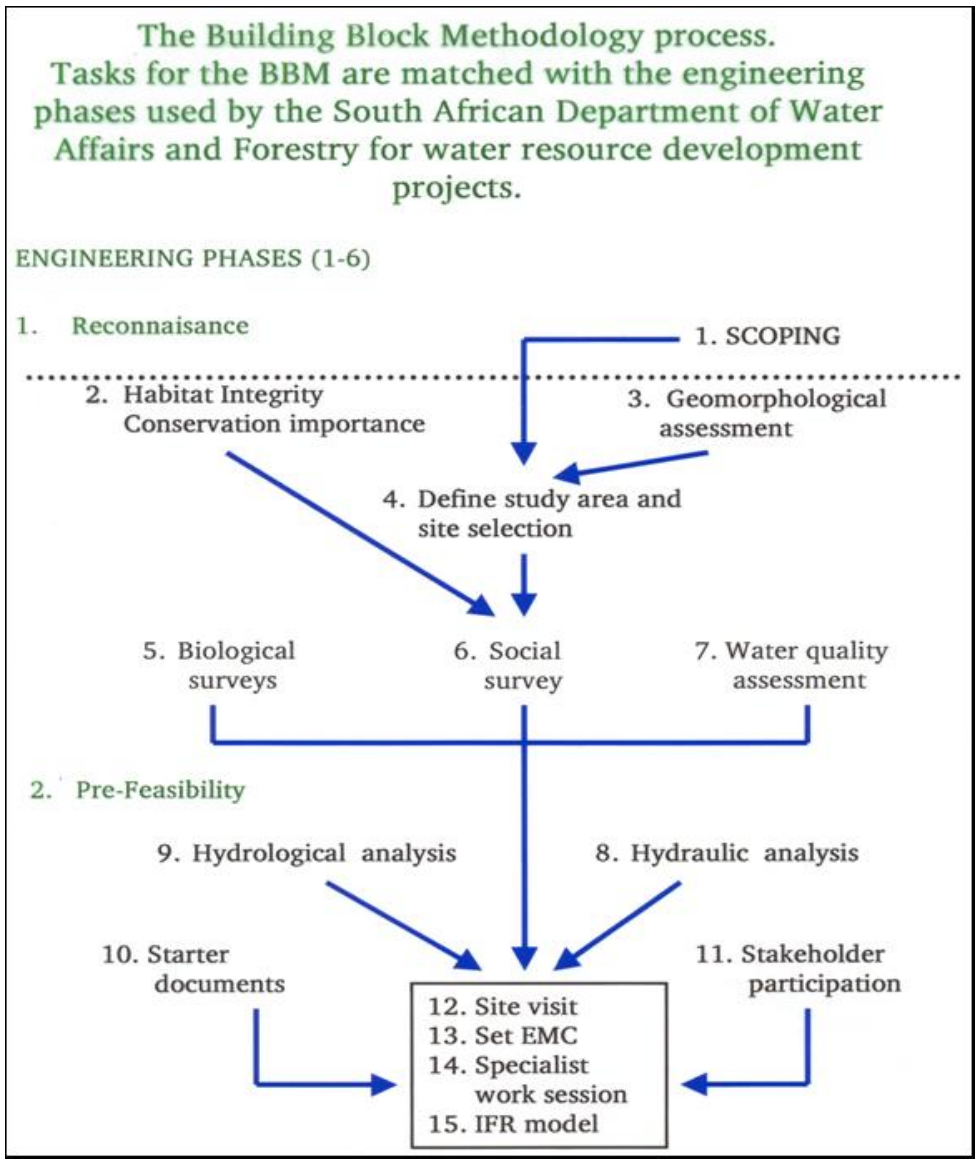


Fig. 2 Initial steps in the BBM process.

to identify a series of important flows (the building blocks) which will together provide the essential aspects of the natural hydrological regime that ensure the persistence of as much of the biodiversity as possible. Therefore, a river field study was conducted at the two BBM sites to:

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

The following flows were considered:

- Dry season low flows for maintenance years;
- Wet season low flows for maintenance years;
- Wet season high flows for maintenance years;
- Dry season low flows for drought years;
- Wet season low flows for drought years;
- Wet season high flows for drought years.

Fig. 2 illustrates the process of initial assessment of flows necessary to maintain or achieve a predetermined environmental state.

Two field visits were conducted in December 2009 and February-March 2010, for reconnaissance survey and detailed fieldwork, respectively. The first visit corresponds to the dry season, while the second visit corresponds to the wet season. Fig. 3 shows the BBM sites and the catchment in more detail.

3. Results and Discussion

Flows in the Usangu wetland and river are the major driver of conditions in the RNP. The riparian and floodplain vegetation depend on the flows and water levels, providing critical habitat for large mammal populations during the dry season. This vegetation also plays a critical role in stabilising the river banks, particularly during floods. If the riparian vegetation disappears, erosion will destroy the characteristic channel forms and habitats—a condition which cannot be rehabilitated in less than decades or centuries.

The loss of low flows during the dry season results

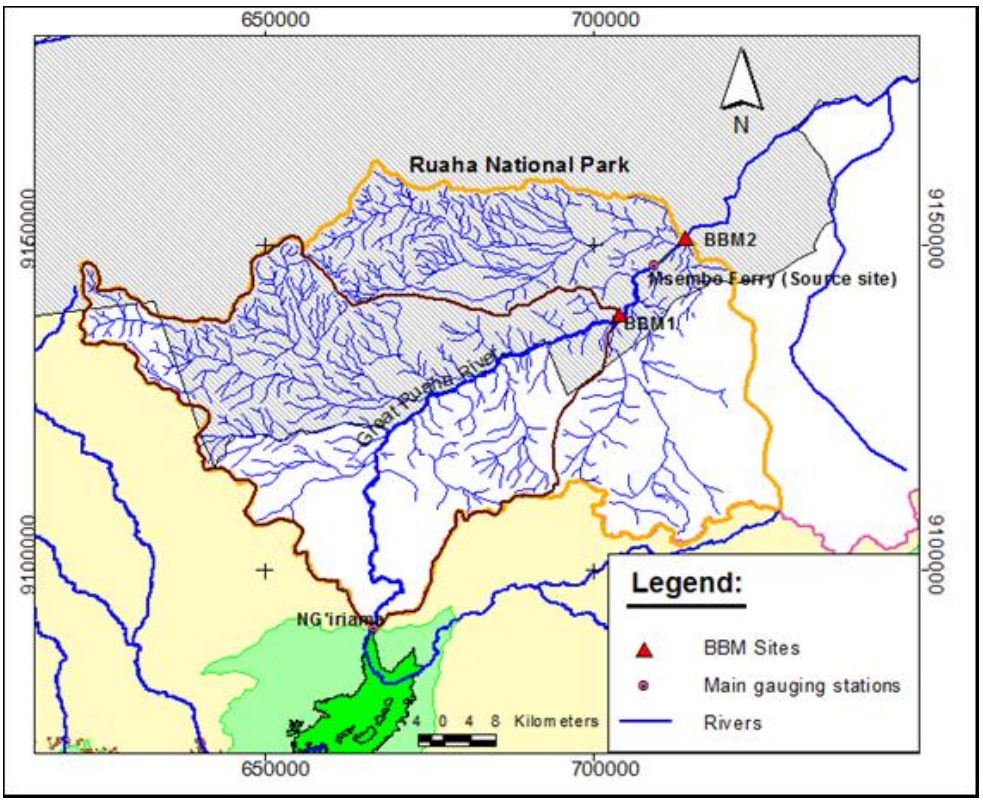


Fig. 3 Detailed map showing location of BBM sites and their contributing catchment.

in a shrinking of the permanent wetland, causing cessation of flows further downstream, past Ng'iriama, into the river, leading to a series of disconnected, isolated pools, concentrated in the upper middle section of the river. These pools become crowded with hippos, crocodiles and fish. Terrestrial mammals also concentrate around the remaining water, resulting in local overgrazing, especially of riparian vegetation. This concentration of terrestrial and aquatic game degrades habitat, encourages erosion, and increases aggression and the incidence of parasites and disease (e.g. anthrax outbreak in 2003).

At present, the riverine ecosystem may still be in the early stages of this sequence, with the possibility of halting or even reversing the progression of degradation if flows can be restored. In the shortterm, a restoration of a minimum continuous flow during the dry season will go a long way to halting the cycle of degradation.

However, if the present flow situation persists, particularly the increasing periods of no-flow during the dry season, then the major changes in the riparian and channel zones and the lack of open water areas will result in the loss of much of the riverine biodiversity, the breakdown of the channel morphology, the loss of dry season refuge feeding areas for terrestrial animals, and increased social disruption and disease.

Ultimately, unless the functions of the GRR are conserved, the entire RNP will lose the biodiversity for which it was founded. The national and international heritage value of the area will disappear, with the concurrent loss of tourist revenues.

3.1 Recommended Environmental Flows at BBM1

Figs. 4 and 5 illustrate the recommended flows for BBM1.

It should be noted that floods do not run continuously from February to June (they are discrete high flow events).

3.2 Recommended Environmental Flows at BBM2

Figs. 6 and 7 illustrate the recommended flows for BBM2.

3.3 Dry and Wet Season Environmental Flows

Recommended flows at BBM1 and BBM2 are summarized in Tables 1 and 2, respectively. Recommended dry and wet season flows are summarized in Table 3.

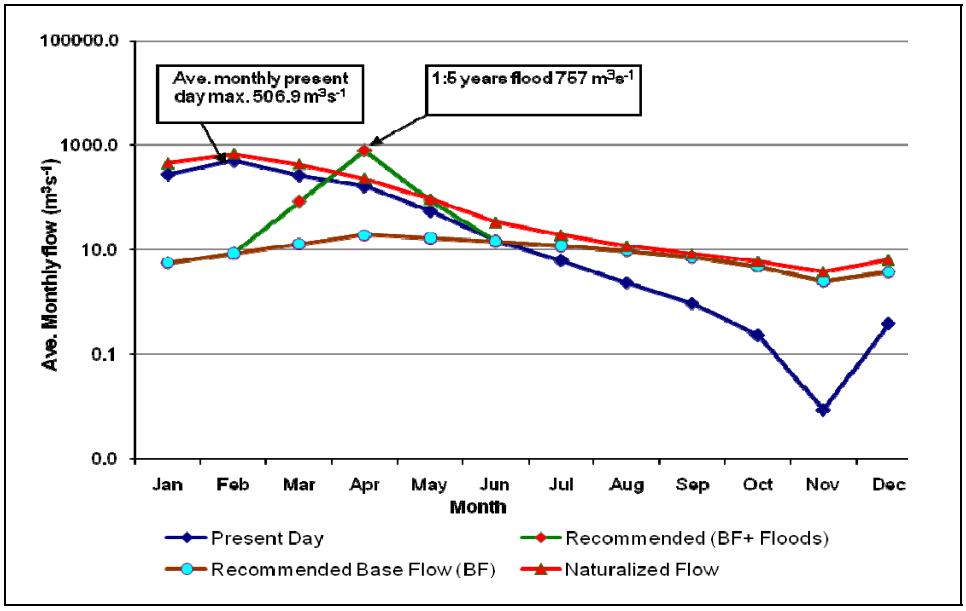


Fig. 4 Recommended maintenance flow against present day and naturalised flow for BBM1.

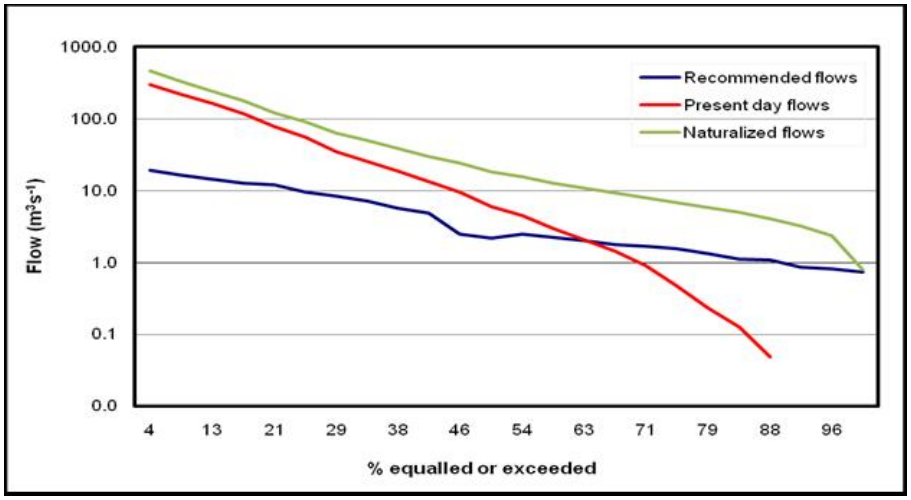


Fig. 5 Flow duration curve for recommended maintenance and drought flow for BBM1.

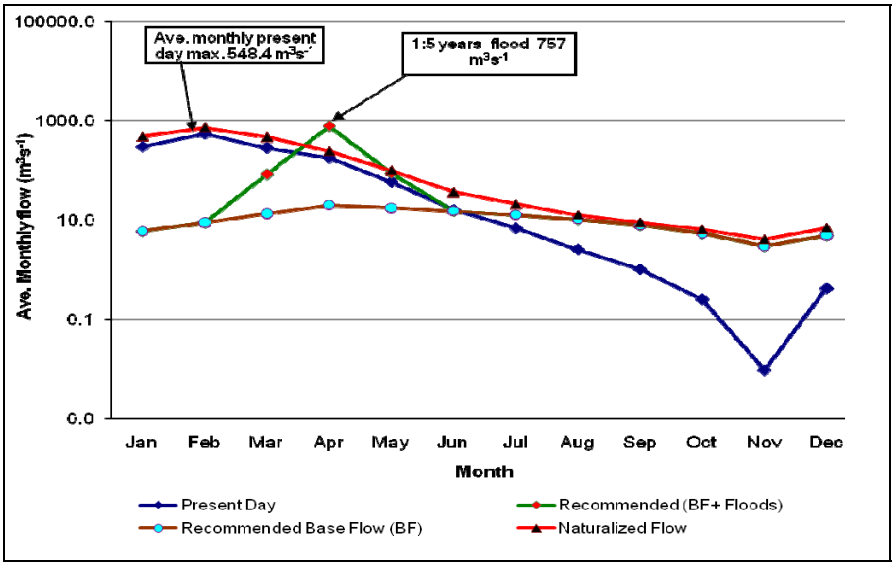


Fig. 6 Recommended maintenance flow against present day and naturalised flow for BBM2.

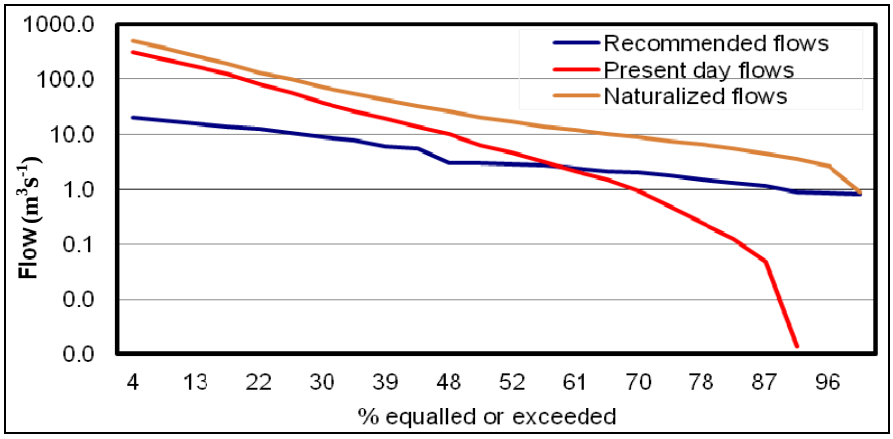


Fig. 7 Flow duration curve for recommended maintenance and drought flow for BBM2.

Table 1 Summary of recommended flows for BBM1.

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

Table 2 Summary of recommended flows for BBM2.

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

Table 3 Summary of recommended flows for dry and wet season.

Dry and wet season flows	Recommended flows ($m^3 \cdot s^{-1}$)	
	BBM1	BBM2
Dry season low flows for maintenance years	2.5	3
Wet season low flows for maintenance years	19	20
Wet season high flows for maintenance years	70	70
Dry season low flows for drought years	0.85	0.85
Wet season low flows for drought years	2.5	3
Wet season high flows for drought years	50	50

The low flows (2 $m^3 \cdot s^{-1}$) during the driest month of a maintenance year are required to:

- Inundate more riffle sections to increase habitat diversity and therefore fish species diversity;
- Maintain active channel flows to inundate benches and sustain emergent vegetation that fish need for shelter/cover;
- Permit more fish passage over obstacles;
- Flush out pools to improve water quality (more favourable habitats for fish).

The primary motivation for maintaining low flow flows in a dry season of the maintenance year would be to inundate the main channel (especially vast area of riffles and benches) to provide a variety of habitats for resident fish species. The recommended discharge results in an average hydraulic depth which is enough to cover appreciable portion of mid-channel riffles. The resultant maximum velocity is also suitable for *Chiloglanis* and juveniles of other species which need appreciable inundated vegetation for cover/shelter and feeding.

For Riparian vegetation, this flow will support population expansion of the permanent flow dependent riparian species *Leersia hexandra* and *Pennisetum purpreum* and the survival of woody species at the bank such as *A. albida, T. indica, C. apiculata* and *Diospyros fischeri*. This flow will allow the riparian woody species at the bank to get enough water for survival. The permanent flow dependent species can regenerate in the channels, and the roots of woody species in the bank can continue getting water for physiological functions and hence survival. Even though the flow is on only one side of the channel, the water below the sands can still be available for flow dependent species, since they have average root length of 30 cm which can still source water.

The low flows (19 m^3/s) during the wettest month of a maintenance year are required to:

- Provide cue for migration and spawning in fishes;
- Inundate macrophytes and emergent vegetation along banks (some fish and invertebrates need

vegetation to deposit their eggs);

• Displace dominant competitors (e.g. oligochaetes for invertebrates) and allow drift of species into new habitats.

The primary motivation for having low flows in a wet season of the maintenance year would be to inundate the vast area of the channel (including lower bank aquatic vegetation-sedges) and increase habitat diversity. Increased habitat diversity would provide ample resources (shelter, food, hiding from predators, etc.) enabling fish to attain good body condition index, fast growth rates and accumulate enough energy for successful spawning in the coming season. For riparian vegetation, this flow will:

• Help to supply nutrients to the riparian vegetation to enable it to perform best in this season and to supply sufficient forage for the aquatic life;

• Inundate roots of woody riparian plant species in the bank to provide sufficient water and nutrients for the development of reproductive structures;

• Wash plant debris into the stream as a nutrient source for invertebrates and fish.

This flow is above the requirement for the survival and regeneration of all the riparian vegetation (e.g. permanent flow dependent species including *Leersia hexandra*, *Schoenoplectus corymbosus* and *Phragmites mauritianum* as well as the regenerants of *A. albida*, *T. indica*, *C. apiculata* are likely to perform well at this flow and expand their populations.

4. Conclusion

Based on the key findings of this study, a total inflow into eastern wetland of 5.52-6.81 m^3/s is required in order to sustain an outflow of 1-2 m^3/s past Ng'iriama and hence meet the "minimum" recommended flow rates further downstream at BBM1 and BBM2 during drought low flow conditions. The low flows of 2.5 m^3/s is recommended for the driest month, while the low flows of 19 m^3/s is recommended for the wettest month.

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