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Assessing Reserve Flows for the Mara River

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Kenya and Tanzania

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- establish a trans-boundary agreement to ensure water flows to sustain the biodiversity of the Mara-Serengeti ecosystem
- encourage implementation of harmonized river basin management practices and policies.
- facilitate cross boundary management of natural resources in the Mara River basin.

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Acronyms

ASPT	Average Score Per Taxon
BBM	Building Block Methodology
CAC	Catchment Area Committee
CMS	Catchment Management Strategy
EFA	Environmental Flow Assessment
EFR	Environmental Flow Recommendation
EIS	Ecological Importance and Sensitivity
EMC	Ecological Management Category
FDC	Flow Duration Curve
GLOWS	Global Water for Sustainability
IUCN	International Union for Conservation of Nature
LVBC	Lake Victoria Basin Commission
LVBWO	Lake Victoria Basin Water Office
LVSCMA	Lake Victoria South Catchment Management Authority
MAR	Mean Annual Runoff
MCM	Million Cubic Meters
MDGs	Millennium Development Goals
MOWI	Ministry of Water and Irrigation
NGO	Non-Governmental Organization
PES	Present Ecological State
PHABSIM	Physical Habitat Simulation Model
RQO	Resource Quality Objective
SASS	South African Scoring System
USAID-EA	United States Agency for International Development – East Africa
WRMA	Water Resources Management Authority
WRUA	Water Resource User's Association
WSL	Water Surface Level
WWF-EARPO	WWF-Eastern Africa Regional Programme Office
WWF-ESARPO	WWF-Eastern and Southern Africa Regional Programme Office

Executive summary

The Kenya Ministry of Water and Irrigation (MOWI), formed in 2003, has as its fundamental goal conserving, managing and protecting water resources for socioeconomic development. In 2002, the Water Act was passed to provide for the management, conservation, use and control of water resources and for the acquisition and regulation of rights to use water. The Tanzania Ministry of Water and Irrigation was formed in 2005 to ensure that water resources are developed and managed sustainably in collaboration with all stakeholders and to facilitate participatory irrigation. In 2008, Tanzania passed the Water Resources Management Act to provide for a legal and institutional framework for sustainable management and development of water resources, to outline principles for water resources management, to make provisions for prevention and control of water pollution, and to provide for participation of stakeholders and the implementation of the National Water Policy. Within both the Kenya Water Act (2002) and the Tanzania Water Resources Management Act (2008), reserve flows were defined as that quantity and quality of water necessary to satisfy basic human need and to protect aquatic ecosystems, and they were given the first priority in water resource allocation.

Under these laws, the water authorities of Kenya and Tanzania are obligated to establish reserve flows for the Mara River in order to guarantee sufficient flows at all times to meet basic human water needs and protect ecosystems for their critical goods and services, which underpin sustainable development. Environmental Flow Assessments (EFAs) are becoming the global standard for determining the amount of water required to sustain aquatic ecosystems and satisfy basic human needs, accounting for both components of the reserve. The responsibility for establishing and maintaining the reserve in the Mara River lies with the Lake Victoria South Catchment Area of the Kenya Water Resource Management Authority and the Lake Victoria Basin Water Office of the Tanzania Ministry of Water and Irrigation. This study is a joint effort by the Kenyan and Tanzanian water authorities, under the auspices of the Lake Victoria Basin Commission of the East African Community and in cooperation with NGO and university partners, to establish the reserve flow for the Mara River in the section of the river extending from the Mau Forest to the protected areas of the Serengeti-Masai Mara ecosystem.

The reserve refers to both the quantity and quality of river flows, and it has highest priority in water allocation plans. Thus, allocations of water for agriculture, industry, and municipal supplies exceeding 25 litres per day per person should be made only from the portion of flow in excess of the reserve. Under severe low-flow conditions, allocations for these uses may need to be curtailed or temporarily halted in order to maintain the reserve flow. The immediate establishment and implementation of the reserve in the Mara River is critical due to increasing extractive demands, especially during droughts, and threats to basic water needs of Mara residents and to the basin's world-renowned biodiversity.

The human population in the Mara River Basin is estimated to be growing at an annual rate of more than 3%. This has been accompanied by a greater than 50% increase in agricultural lands in the last two decades at the expense of nearly a quarter of the basin's forests and grasslands. In addition to the associated effects of deforestation, water abstractions for livestock, agricultural irrigation and other industries are on the rise. The Mara is not a large river, and the ever increasing abstractions are certain to, at some point in the future, severely degrade the riverine ecosystem and even impinge upon the most basic water needs of people living along the river. The effects of such a dry down would be profound, both to people, livestock, wildlife, and the basin's economy. It could very likely, for example, cause a crash in the wildebeest population, leading to a breakdown in the entire migration cycle that sustains the Serengeti-Masai Mara ecosystem. The implications of a disruption to such a significant natural process are far-reaching.

The reserve flow was determined by a team of Kenyan, Tanzanian, and international scientists using a structured, science-based approach to determine how much water must be left in the river to protect the aquatic ecosystems and meet resource quality objectives. The Building Block Methodology was applied. This method was developed in South Africa during the 1990s and is among the most robust and widely applied holistic methods that address both the structure and function of all components of the river ecosystem.

The assessment of the reserve flow was launched during an initial workshop in 2006 convened to provide technical guidance on the methodology to a team of specialists recruited to carry out the analytical components of the assessment. Specialists included a geomorphologist, hydrologist, hydraulic engineer, aquatic ecologist, riparian ecologist, water quality specialist, and socio-economist. The team of specialists identified three appropriate study sites in distinct geomorphological reaches of the basin and conducted site assessments of physical, biological and social indicators during low and medium flows in 2007. Status of critical indicators was related to in stream flow levels using hydrological and hydraulic analysis. The findings of each specialist were used to determine a modified flow regime for the river that would serve as the reserve.

The assessment found that during years of normal rainfall the reserve is easily met and ample river water is available for extractive uses. At Site 3 on the border between Kenya–Tanzania and Masai Mara National Reserve–Serengeti National Park, the reserve accounts for, on average, 35% of the average monthly flow recorded over the 26 years of available flow data for the river near that site. At Site 1 on the Amala River, the recommended reserve flow levels account for 25% on average of recorded flows during maintenance years. It is important to note, however, that the percent of flow held in the reserve varies over the course of a year, mirroring the natural highs and lows of the system. The majority of water available for abstraction is therefore concentrated in a few months when flows are high. Far less water is available for abstraction during dry season months.

The situation during drought years is quite different, as the assessment found that, presently, the reserve is not being met during several months of the year at Sites 1 and 2. The observation that drought year reserve flows are not being met in the upper and middle reaches of the Mara may be the first clear evidence of a trend toward unacceptable alterations of the Mara River's flow regime. Upstream impacts are necessarily linked to downstream resources, and poorly managed water abstraction above the wildlife reserves will ultimately affect the downstream reaches as well.

The Mara River currently has no major dams acting to significantly modify its flow regime. Thus, reserve flow prescriptions must be achieved by improving management of the catchment and controlling permits for abstractions. The unequal distribution of flows throughout the year also poses the challenge of developing and implementing sustainable technologies for harvesting and storing wet season runoff for consumptive use during dry months. Monitoring of flows and abstraction levels will be critical to determine the current state of the reserve and the amount available for further consumptive use. Because the Mara is a trans-boundary river, these efforts must be closely coordinated between responsible institutions in the two countries.

The reserve estimates in this assessment have not taken into account the environmental flow requirements of the Mara Swamp, which may be different. The reserve also does not include flow volumes necessary to meet the extractive water needs of Tanzanian communities and industries between Serengeti National Park and the Mara Swamp. Thus, flow levels reaching Tanzania must be high enough not only to sustain the reserve but also to meet Tanzanian extractive water needs.

This assessment for the Mara River has applied a structured and scientifically sound process for determining the requirements of the reserve flow and thus is an essential step towards estimating the amount of water available for consumptive use. It is important to note that this is a first assessment of the reserve based on the best available data and expertise of the scientific team. Continued monitoring of the river's flow levels and ecological status will be critical to determine if the prescribed flow regime is sufficient, if more water needs to be set aside for the reserve, or if more water can be permitted for consumptive use.

1. Introduction

Originating on the Mau Escarpment of Kenya, among swamps and remnants of a once expansive forest, headwater streams of the Mara River begin a remarkable journey. At nearly 3000 m above sea level, an average of 1400 mm of rain falls every year at the river's source. Where forests remain, the rainwater percolates through the dense canopy into the soil and ultimately into the seeps and springs that form the Nyangores and Amala Rivers (Fig. 1). These rivers exit the forest and descend over 1000 m on the southern slope of the escarpment, supporting farmers, pastoralists, and growing urban centers in the region. They also carry headwater rains to the more arid lands downstream.

The Nyangores and Amala Rivers meet at the base of the escarpment to form the upper Mara River, which flows on a gentler gradient through wooded grasslands used primarily for livestock grazing but increasingly for small- and large-scale agriculture as well. Annual rainfall in this region drops below 1,000 mm, and the main channel of the river provides the only permanent source of surface water for people and animals. As the Mara continues into the protected areas of Masai Mara National Reserve and across the Tanzanian border into the Serengeti National Park, it is joined by the Talek and Sand Rivers. Here the Mara River sustains one of the greatest spectacles of the natural world—the annual migration of millions of wildebeest, zebra and antelope that arrive in the Mara Basin during the dry season in search of water and forage. The Mara River also sustains a thriving tourism industry built around this natural phenomenon.

After exiting the protected reserves, the Mara re-enters a zone of small farms and grazing lands inhabited by hundreds of thousands of rural Tanzanians. In this arid zone the Mara River is a lifeline for survival and a major resource for future economic development. Near its mouth at Lake Victoria, the Mara River recharges the vast wetland complexes of the Mara Swamp which support fisher communities.

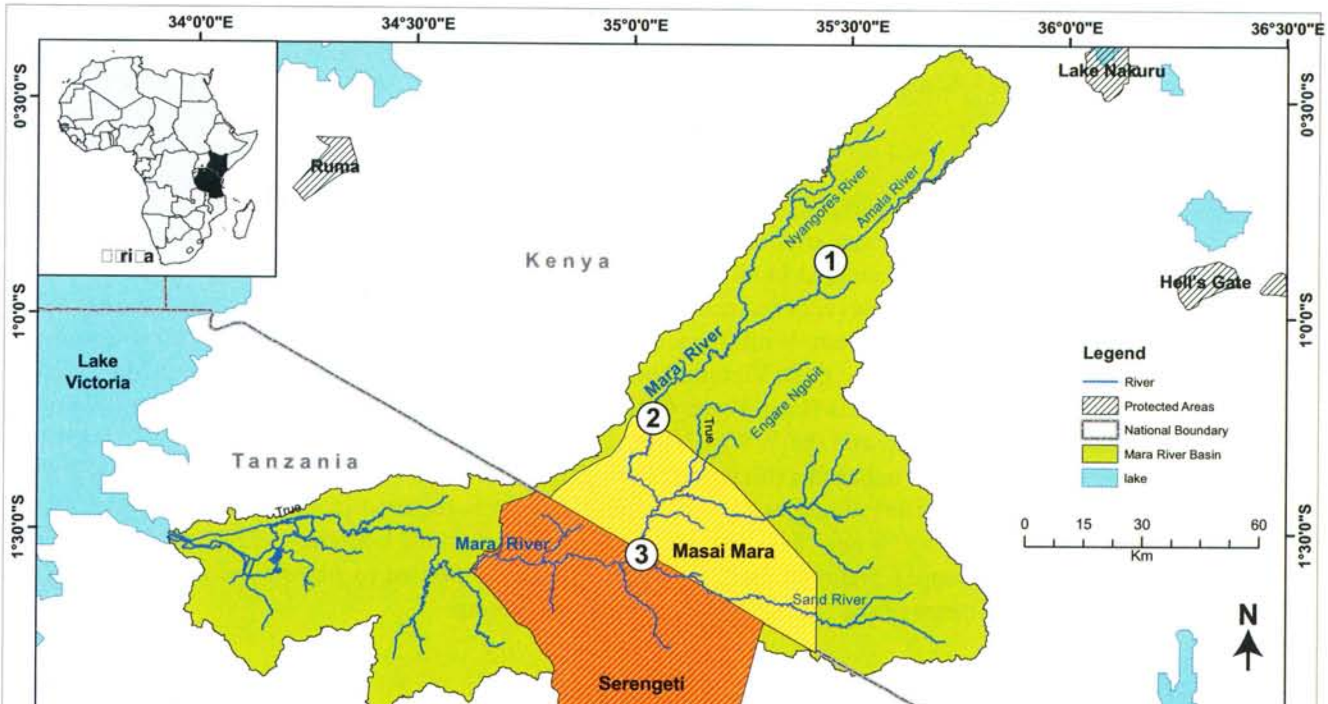


Figure 1: Site map of the transboundary Mara River Basin and the three study sites used in the Environmental Flow Assessment.

The wetland is also critical nursery habitat for economically important fish species of Lake Victoria. Once in the lake, the waters of the Mara begin their second life, as headwaters of the Nile River.

In total, the Mara Basin covers 13,750 km^2, and in addition to water, the river provides food, important plants, fertile soils, and critical habitat to people and wildlife. However, in such an arid system, the many demands for these resources are sometimes incompatible. Clearing of the forest and increased cultivation in the upper catchment is believed to have increased sediment loads and altered the hydrograph of the river. Without the forest to moderate the flow of water into the system, both seasonal floods and droughts are becoming more extreme. Further downstream, increases in the amount of irrigated agriculture and industrial activity such as mining have led to higher rates of water abstraction. In addition, the river provides the primary domestic water source for nearby towns and settlements, many of which lack any kind of sewage or water treatment facilities. By the time the Mara River reaches the protected reserves, it has passed through the hands of hundreds of thousands of Kenyans, and hundreds of thousands of Tanzanians await the river's waters downstream of Serengeti National Park.

Demands on the river continue to grow. Human population in the Mara River Basin is growing at an annual rate of more than 3% (Hoffman 2007). This has been accompanied by a 55% increase in agricultural lands in the last fourteen years at the expense of nearly a quarter of the basin's forests and grasslands (Mati *et al.* 2005). In addition to the associated effects of deforestation, water abstractions for livestock, agricultural irrigation and other industries are on the rise. The Mara is not a large river, and ever increasing abstractions are certain to, at some point in the future, severely degrade the riverine ecosystem and even impinge upon the most basic water needs of people living along the river. The effects of such a dry down would be profound, both to people, livestock, wildlife, and the basin's economy. For example, it could very likely cause a crash in the wildebeest populations, leading to a breakdown in the entire migration cycle that sustains the Masai Mara-Serengeti ecosystem. The implications of a disruption to such a significant natural process are far-reaching, including not only devastation to the tourism industry that supports so much of Kenya's and Tanzania's economies, but also a change in the entire structure of the ecosystem.

There are clearly significant management challenges to be faced in the Mara River Basin. Because of the interconnected nature of river systems, choices that are made in one portion of the river basin implicitly impact those living downstream. People must make choices about what goods and services they want the river to provide, and then work together across district and national boundaries to manage the entire system, from top to bottom. The science of environmental flows has become the accepted way of sustaining river ecosystems, for people and nature, into the future.

The Kenya Water Act (2002) and Tanzania Water Resources Management Act (2008) both support the principle of maintaining environmental flows in river systems and call for this reserve to be set for all rivers and to be considered in all water allocation plans (Box 1). The reserve for a given river is generally defined as the level of instream flows necessary to provide for basic domestic use as well as to sustain the river ecosystem. With financial support from the United States Agency for International Development (USAID), the Lake Victoria South Catchment of the Kenya Water Resource Management Authority and Lake Victoria Basin Water Office of Tanzania, in partnership with the Global Water for Sustainability Program and the WWF-Eastern Africa Regional Programme Office (WWF-EARPO), have joined forces to undertake this environmental flow assessment and to establish the reserve of the Mara River. This effort aimed to determine the flow levels required to maintain the reserve for the Mara River from near where the river exits the Mau forest to the boundary of Masai Mara National Reserve and Serengeti National Park. Further work will be needed to address the water needs of the reaches downstream of the Serengeti and in the Mara Swamp.

Table 1: Characteristics of the Mara River

Basin size	~13,750 km^2; 65% in Kenya and 35% in Tanzania
Rainfall	1400 mm/year in the Mau Escarpment to 500-700 mm/year in the dry plains of NW Tanzania
Elevation range	3000 m asl to 1300 m asl
River length	~395 km
Source	Mau forest complex, Kenya
Outlet	Lake Victoria near Musoma, Tanzania
Main tributaries	Nyangores River, Amala River, Sand River, Talek River, Borogonja River
Larger basin	Lake Victoria Basin which feeds the Nile Basin

Box 1: Environmental Flows and the Law

In 2002 and 2008, both Kenya and Tanzania passed new legislation aimed towards ensuring access to safe water resources for all people, as well as sustaining the valuable ecosystems upon which these people depend. The principle of environmental flows is evident in the wording of these laws.

The Kenya Water Act (2002)

The Kenya Water Act (2002) defines the "reserve, in relation to a water source, [as] that quantity and quality of water required (a) to satisfy basic human needs for all people who are or may be supplied from the water resource; and (b) to protect aquatic ecosystems in order to secure ecologically sustainable development and use of the water resource." The Water Act further states that "the Minister, the Authority and all public bodies shall, when exercising any statutory power or performing any statutory function in relation to the water resource concerned, take into account and give effect to the requirements of the reserve (Part III, 13 (3))."

The Tanzania Water Resources Management Act (2008)

The Tanzania Water Resources Management Act (2008) defines the reserve as "the quantity and quality of water required for (a) satisfying basic human needs… and (b) protecting aquatic ecosystems" and states that "the Minister shall…determine the reserve for the whole or part of each water resource which has been classified... and the Minister, the National Water Board, Basin Water Boards and all public bodies shall, when exercising any statutory power or performing any statutory duty, take into account and give effect to the requirements of the reserve (Section 37, 1-3).

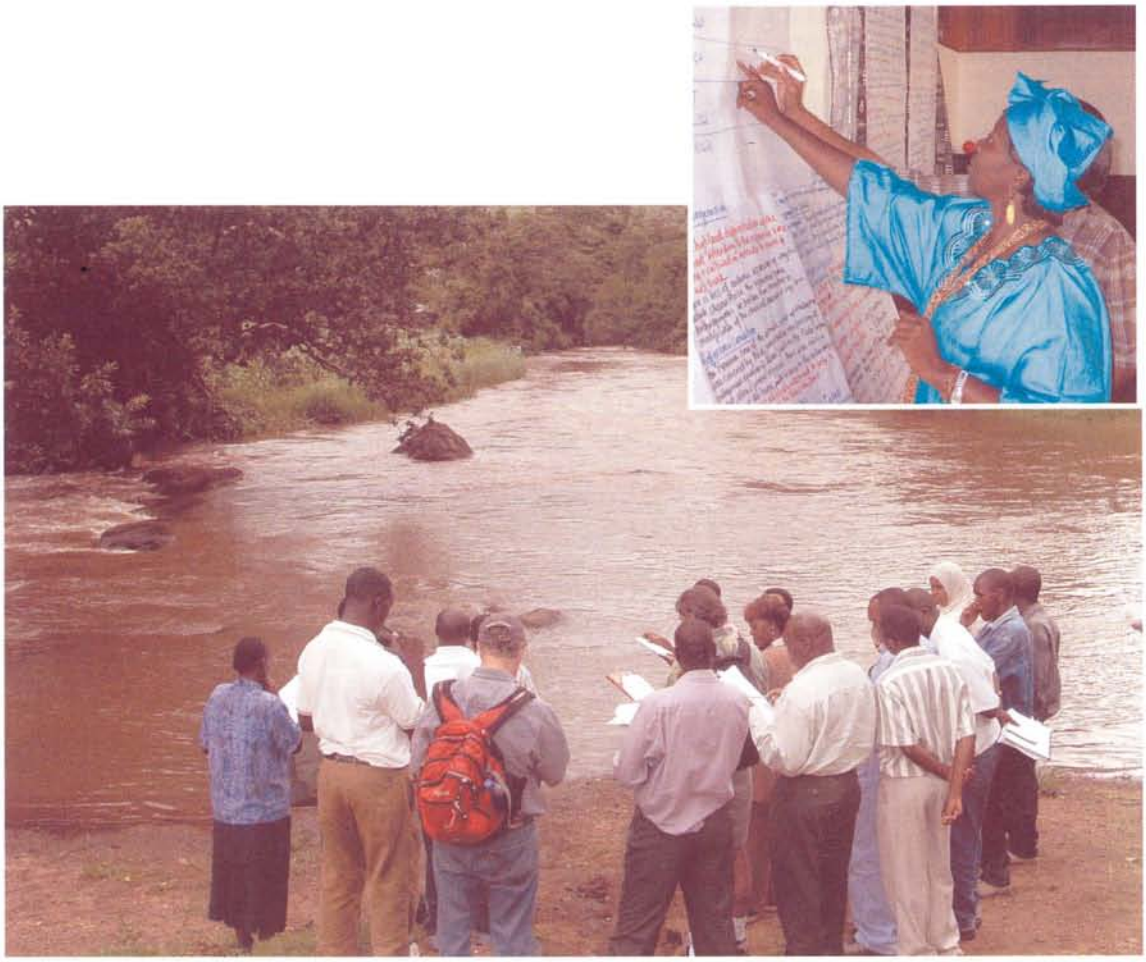


Figure 2: The environmental flows technical team at work – the team of specialists visits a study site and, inset, EFA Coordinator Doris Ombara leads a group discussion at the initial workshop.

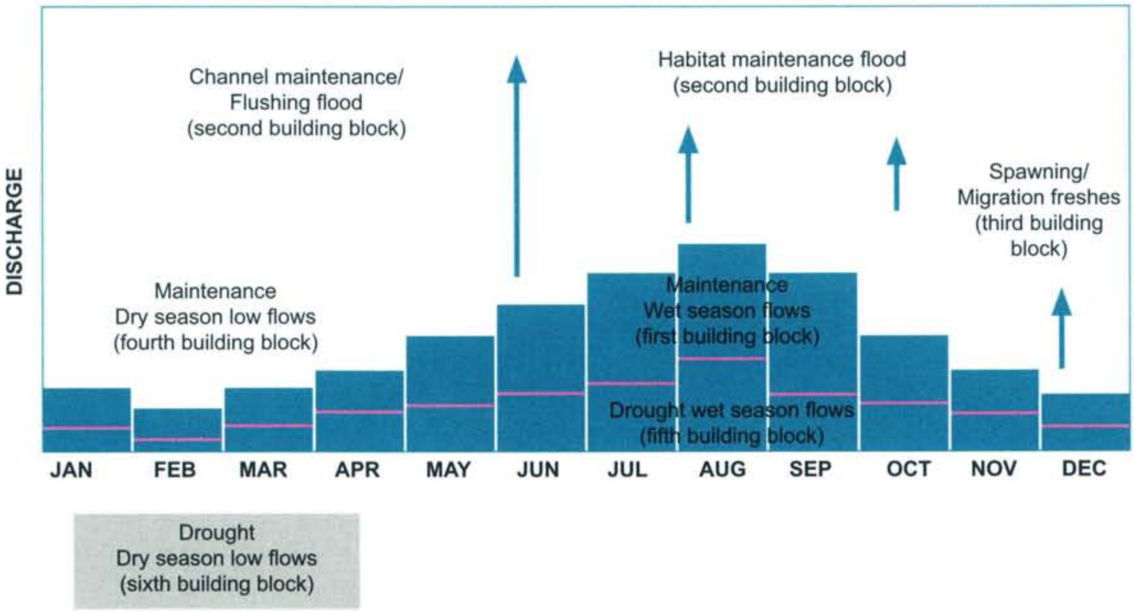


Figure 3: River Building Blocks classify the most critical elements of the flow regime needed to maintain physical and biological processes. Both habitat maintenance and channel maintenance floods compose the second building block.

2. Objectives and Methods

Environmental Flow Assessments (EFAs) are becoming the global standard for determining the amount of water required to sustain aquatic ecosystems and satisfy basic human needs, accounting for both components of the reserve. EFAs are structured, science-based approaches to determining how much water must be left in the river to protect the aquatic ecosystems and meet Resource Quality Objectives (RQOs). Many different methodologies exist worldwide; however, the Building Block Methodology, refined in field studies in South Africa during the 1990's, is among the most widely applied holistic methods that address both the structure and function of all components of the river ecosystem (King et al. 2000).

The Building Block Methodology is based on the understanding that river ecosystems have evolved under a given flow regime. Consequently, the native animals and vegetation composing the ecosystem can cope with naturally occurring low-flow conditions, and may even require these lows to function properly. Similarly, the ecosystem may rely on naturally occurring higher flows and floods. The primary building blocks of a river's flow regime thus include the minimum flow requirements during the driest months of a year, the minimum flows during the wettest months, and geomorphologically and ecologically important floods (Fig. 3).

These minimum flow levels and floods are recommended for both drought years, when flow levels are below normal and the management objective is to simply ensure the basic survival of the system, and maintenance years, when flow levels are high enough that normal ecological processes are maintained. Prescribed floods consist of small annual floods that flush out stagnant pools and inundate riparian zones, as well as less frequent but larger floods, that serve to maintain natural channel structure and inundate the larger floodplain (See Annex 2: Environmental Flow Building Blocks). Identification and maintenance of the most important components of a river's flow regime will serve to maintain the natural biota of the river, the river's natural functions and services, and the natural channel and habitat structure present in the river.

This Mara EFA was launched during an initial workshop in 2006 convened to provide technical guidance on the methodology to an international team of specialists recruited to undertake the analytical components of the assessment (Fig. 2). Specialists included a geomorphologist, hydrologist, hydraulic engineer, aquatic ecologist, riparian ecologist, water quality specialist, and socioeconomist. These specialists came from universities in Kenya, Tanzania, the USA, and the Netherlands. Specialists focused on critical indicators that could be used in future monitoring to determine if in-stream flows are sufficient to maintain desired ecological processes. Box 2 lists some of the critical indicators used in this assessment.

The main objective of the Mara EFA was to determine the necessary reserve for the Mara River, as defined in the Kenya Water Act (2002) and Tanzania Water Resources Management Act (2008), from near where the river exits the Mau forest to the protected areas of the Serengeti-Mara Ecosystem. In order to identify critical components of the natural flow regime that maintain physical and ecological processes, the team of specialists identified three appropriate study sites and conducted site assessments of physical, biological and social indicators. Status of critical indicators was related to in-stream flow levels using hydrological and hydraulic analysis (See Fig. 2: River Building Blocks) to ensure that indicators can be sustained in the long run. Finally, the specialists reconvened to decide upon a modified flow regime for the river that would serve as the reserve. Steps in the BBM are shown in the BBM flow chart (Fig. 4).

Box 2: Critical indicator variables that can be used to monitor health of the river ecosystem

1. Functioning of natural sediment generation processes
    a. Presence of stable river banks
    b. Intact riparian zones
    c. Absence of large-scale erosion denuding landscapes
    d. Absence of excessive fine-scale sediment deposition in river channel

2. Occurrence of a variety of instream and riparian habitats to provide habitat for diverse species
    a. Adequate distribution of pools, runs and riffles
    b. Presence of lateral and channel bars
    c. Vegetated riparian zones that receive periodic inundation

3. Presence of sensitive species that reflect suitable water quality levels
    a. Rare or threatened fish species that depend on appropriate timing of variable flows for feeding and reproduction
    b. Sensitive invertebrate species that indicate subtle fluctuations in water quality and pollution levels
    c. Important riparian plant species that depend on seasonal inundation for germination

4. Adequate provision of human needs by water resources
    a. Year-round accessibility of water for domestic purposes
    b. High water quality to reduce the occurrence of disease
    c. Maintenance of tourism-dependent processes, such as water for wildlife habitats

Reserve flows are not for the purpose of protecting the fish and insects chosen as indicators. Rather, the reserve is intended to protect the ecological processes and services indicated by the presence of these species, such as degradation of contaminants, breakdown of organic matter and erosion control. These processes are critical not only to the health of the river, but primarily to the health of the human communities that depend on it, many of whom rely on it as their primary source for drinking water.

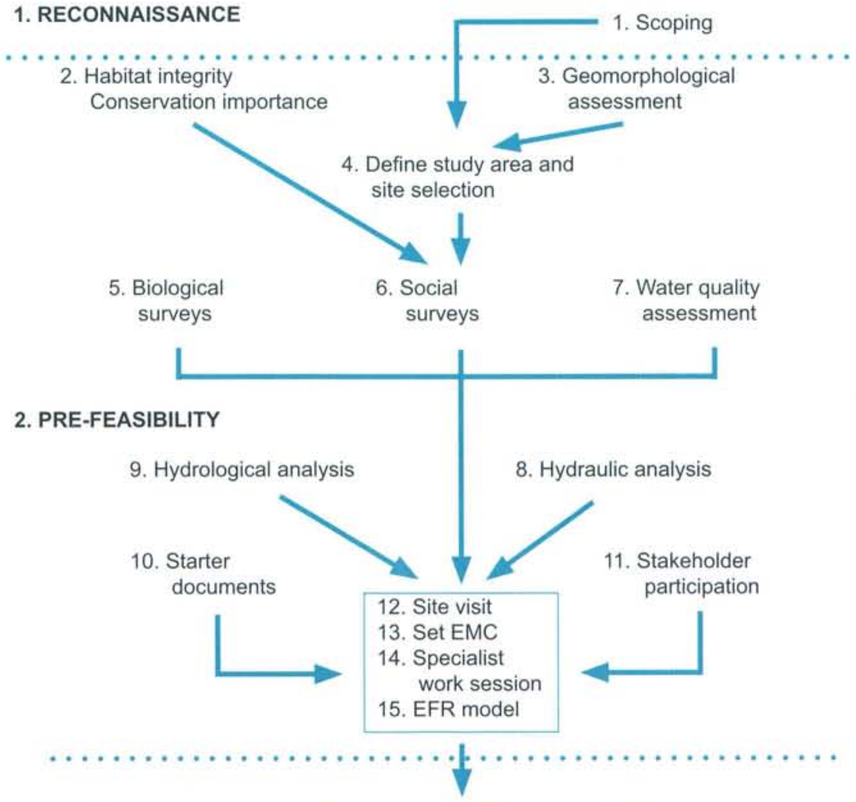


Figure 4: Steps in the Building Block Method (King et al. 2000)

2.1 Site Selection

Site selection began with geomorphological surveys that classified the river into three uniform macro-reaches based on gradient, channel pattern and bed structure. During initial field visits, the multidisciplinary group of specialists chose a representative site for each macro-reach (Fig. 1). The selected sites exhibit fluvial processes characteristic of the macro-reach, as well as represent the interests of multiple stakeholders in the basin. Additionally, these sites incorporate small-scale habitat diversity; as such, all sites were placed on 100 meter-long, straight stretches of the river that included runs, pools and riffles.

Site 1: Located on the Amala River, a main tributary to the Mara, at Amala River Bridge within Kapkimolwa village, at an altitude of 1,860 m a.s.l. This is at the border between Bomet and Narok Districts. The land around this site was dominated by small-scale settlement with the main land use practices being subsistence farming and cattle rearing.

Site 2: Located just outside the boundary of the Masai Mara National Reserve on the middle Mara River at an altitude of 1,687 m a.s.l. The land outside the reserve is a mixture of Maasai Group Ranches and large-scale irrigation farming. The other main economic activity within the area

Site 3: Located near the Mara Bridge on the border between the Masai Mara National Reserve and Serengeti National Park, at an altitude of 1470 m a.s.l. Because this site is within the two major protected areas of Kenya and Tanzania, the only land use in the vicinity is wildlife rangeland and the only economic activity is tourism.

Site assessments were conducted during March 26-31, and July 16-21, 2007, corresponding to low flow and medium flow conditions, respectively.

2.2 Classification of Sites: Present Ecological State and Resource Quality Objectives

In order to appropriately target management activities, the Lake Victoria South Catchment Management Strategy identifies Resource Quality Objectives (RQOs) for each of the catchment's major river basins. These RQOs are determined according to natural hydrological boundaries, social and economic development patterns and communal interests of the people. The water resources are classified as being of high (1), medium (2) or low (3) importance to ecology (E), livelihood (L) and commercial development (C). According to this strategy, the Upper Mara was categorized E1L2C3, indicating the area is of high importance for ecological concerns related to water resources management, medium importance for livelihoods acknowledging the importance of small-scale subsistence farming, and relatively low importance for commercial development. The Lower Mara was ranked E1L2C2, indicating a high importance for ecological purposes, and medium importance for livelihood activities, with a majority of the population still dependent of water resources for subsistence farming; however, commercial activity is also of medium importance, acknowledging the importance of tourism and larger scale farming enterprises.

To align the EFA process with the catchment management strategy in targeting management strategies, physical and biological components at each site were ranked according to their present and desired ecological state. Present Ecological State (PES) recognizes the natural, or reference, conditions at each site and includes a judgment of how far each site has changed from those conditions. Sites could be ranked from A (natural) to F (critical/extremely modified). Then sites were assigned a Trajectory of Change, indicating whether each component was getting better or worse under the current river management regime. Sites were also classified according to their Ecological Importance and Sensitivity (EIS), indicating their importance for maintenance of ecological diversity and system functioning on local and wider scales, their ability to resist disturbance and their capability to recover from disturbance.

Finally, sites were assigned an Ecological Management Category (EMC), summarizing the overall objective or desired state for each site. Sites could be ranked from A (natural) to D (largely modified); categories E and F were excluded from consideration because they were not considered sustainable.

Although categories varied somewhat among site components, the summary for all three sites was the same. The PES at all study sites was ranked as B, indicating some degree of modification from the natural state. Furthermore, all sites were found to be declining in quality under the current management regime. This is cause for concern, as all sites were also ranked Very High in their EIS. Pristine conditions are not likely to be achievable in this system given its importance to the Livelihood sector; however, the RQO's for both the Upper and Lower Mara indicate high ecological importance. Thus, an EMC of category B was chosen, suggesting management actions act to maintain current levels of system structure and functioning and to prevent further modification and degradation.

3. Assessment Results

3.1 Physical Indicators

3.1.1 Hydrology

Hydrological analysis of the study sites provides information on the past and present flow regime of the river. A river's flow regime includes not only the quantity of water that flows in its channels, but also the timing of small, annual floods and larger channel-shaping floods. The hydrologic analysis is an important input to the overall environmental flow assessment process because it establishes boundary conditions of flow in which all other components of the assessment must fit. In order to determine historic patterns of flow in the Mara and its tributaries, data were collected from three different river gauging stations on the Amala River at the town of Mulot, the Nyangores River at the town of Bomet, and the Mara River at Mara Mines. Hydrologic data from these sites were extrapolated to fit the three chosen study sites (Sites 1-3). Data were compiled to present historical flow records at different time scales and in wet and dry years. Data were also used to calculate flow duration curves and flood frequency and low flow recurrence intervals.

Results indicate there are two annual peaks in flow levels in the Mara River. One occurs from March to June, and the second occurs from November and December (Fig. 5). Peak flows increase the further one goes downstream in the basin. At Site1, in the upper reaches of the basin on the Amala River, these peak flows reach approximately 30 m^3/s in an average year. During a dry year peak flows may reach only 8 m^3/s, while during a wet year peak flows may extend over 150 m^3/s. At Site 3, in the lower Mara straddling the Kenya-Tanzania border, peak flows can reach 300 m^3/s in an average year, but may vary from 90 to over 400 m3/s, depending on whether it is a dry or wet year (Fig. 5). Along the entire length of the river, low flows can approach 1 m^3/s or less in both wet and dry years, although the river has not dried up completely at the study sites in the past fifty years of monitoring. Many other tributaries, however, such as the Sand and Talek Rivers, do stop flowing during the dry season. Historical flow data is presented below for Site 3, in the lower Mara. Data for Sites 1 and 2 can be found in Annexes 3 and 4, respectively.

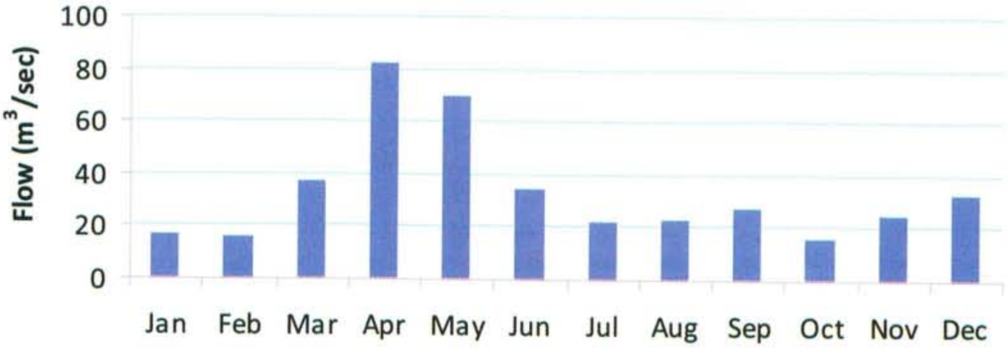


Figure 5: Monthly flow at EFA Site 3 on the Mara River, averaged over all the years of record (1970-1990).

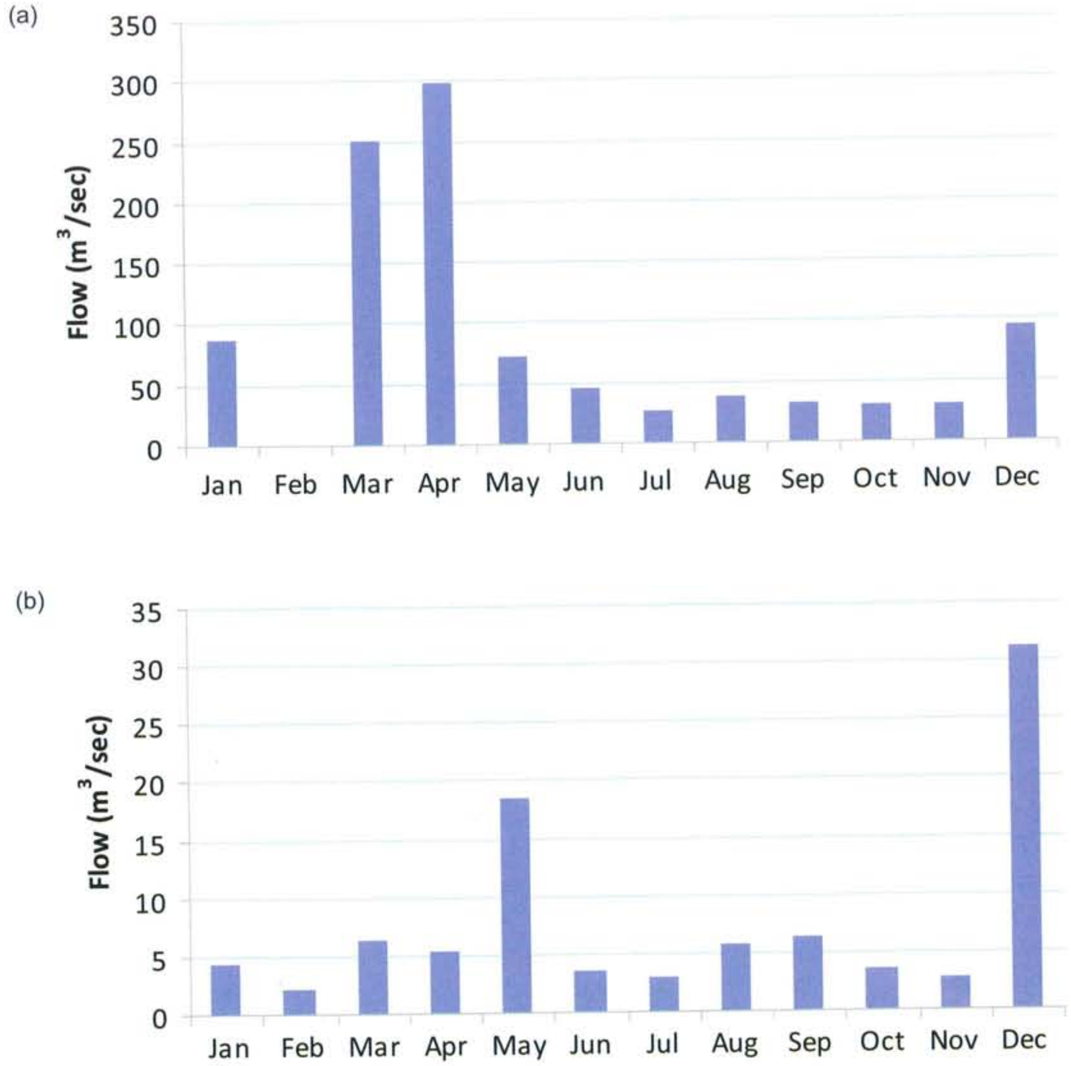


Figure 6: Average monthly flows shown for EFA Site 3, on the Mara River in the Lower Mara Basin, during a wet year, 1990 (a) and dry year, 1986 (b). There was no data available for February 1990.

Monthly mean flows on the Mara River at Site 3 were averaged over 20 years to estimate the percent of time the river is likely to exhibit different flow levels. The resulting flow duration curve is pictured in Fig. 7 and indicates, for example, that flow at Site 3 exceeds 11 m^3/sec 50% of the time and exceeds 0.9 m^3/sec 95% of the time. The percent of time that any flow is exceeded can be determined from the curve in a similar manner. The default standard for determining the reserve in Kenya is the flow level that is exceeded 95% of the time, or Q95. As can be seen on the flow duration curve below, Q95 levels are often very low flows that may be unable to sustain many components of a healthy ecosystem.

Flow data can also be used to estimate the recurrence intervals of specific low flows and floods. Low flow analysis suggests the Mara River generally experiences very low flows on an annual basis, and although it is unlikely the river will go completely dry, flow levels at the Kenya-Tanzania border (Site 3) may fall as low as 1 m^3/s every two years (Fig. 8). Flood frequency analysis indicates annual flood events also occur, with larger, channel-shaping floods occurring every 2-3 years (Fig. 9).

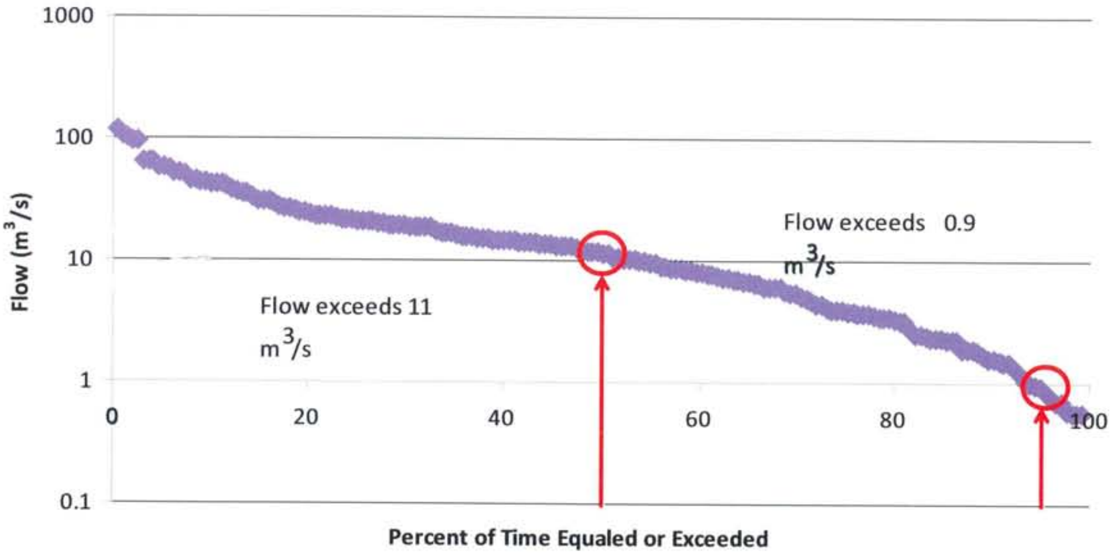


Figure 7: Monthly flow duration curve calculated for mean flow levels over the period of record (1970-1990) at EFA Site 3 on the Mara River at the Kenya-Tanzania border.

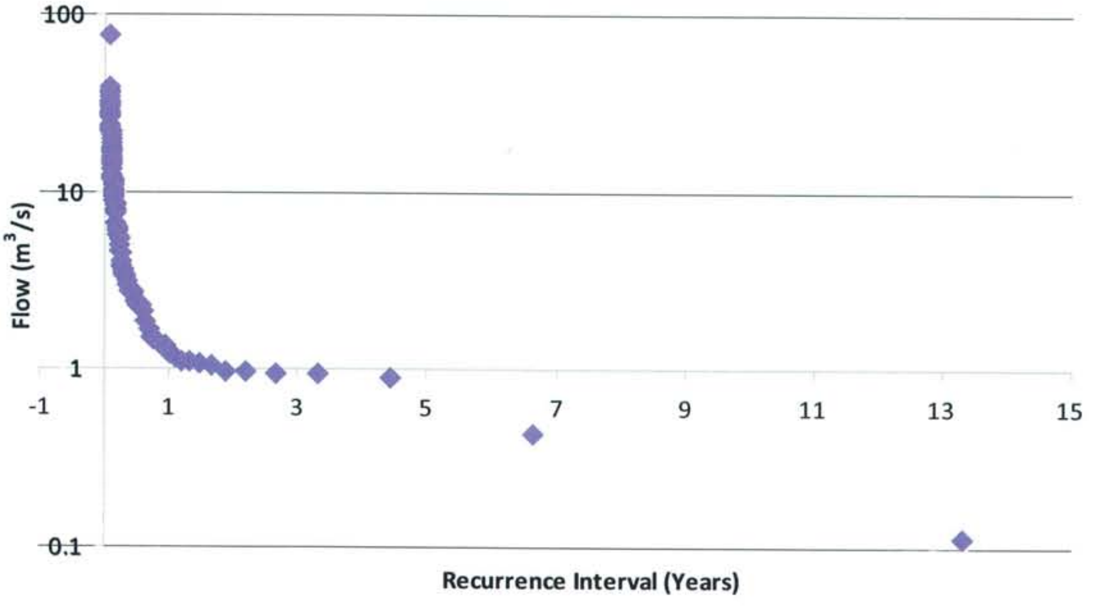


Figure 8: Low flow recurrence calculated on a monthly basis over the period of record (1970-1990) at EFA Site 3, on the Mara River in the Lower Mara Basin.

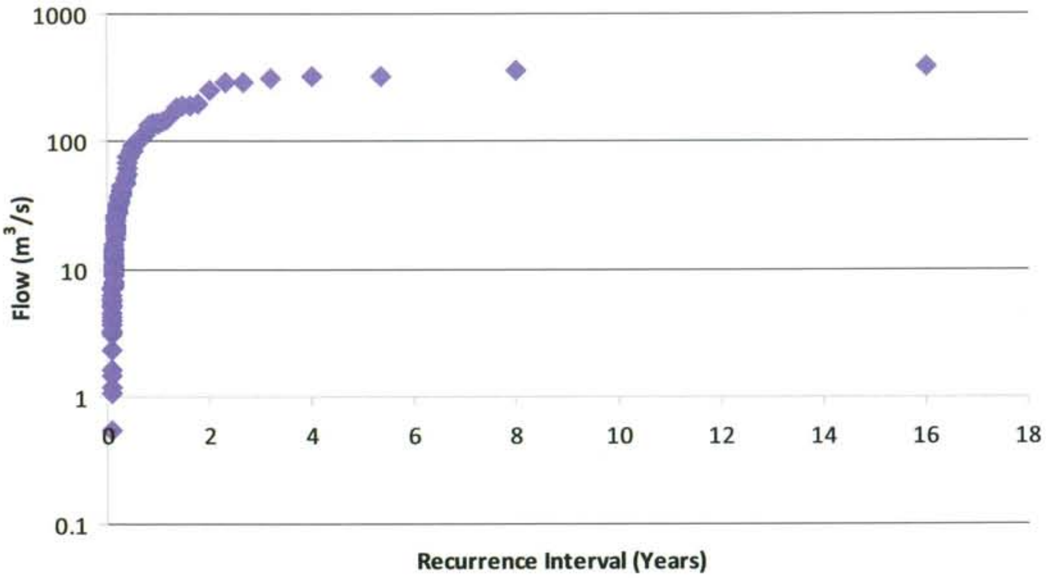


Figure 9: Flood frequency recurrence calculated on a monthly basis over the period of record (1970-1990) at EFA Site 3, on the Mara River in the Lower Mara Basin.

3.1.2 Hydraulics

The hydraulic analysis of the study sites provides information on how discharge, width, depth, wetted perimeter and velocity are related in the river reaches. The combination of geomorphology and local hydraulics is the primary determinant of the availability of physical habitat which, in turn, is a major determinant of ecosystem function. Thus the hydraulic analysis is a critical input to the other components of the assessment. The hydraulic analysis differs from the hydrologic analysis in that it focuses on instantaneous fine-scale relationships between discharge, depth, and velocity rather than longer term flow patterns. The hydraulic conditions are therefore the main link between the ecological requirements for habitat conditions (in terms of flow depth, velocity, wetted perimeter, etc.) and the hydrology (in cubic meters per second).

Hydraulic cross-sections were established along 67-77 meter reaches at each site in order to capture the variability in habitat types and hydraulic regimes (Fig. 10). Each site included transects through sections of riffles, pools and runs. The geometry of each transect was carefully surveyed, and the results indicate a surprising level of consistency in macro-channel geometry between each site (Fig. 11). At each site the river had cut approximately 8 meters below the surrounding land levels, and the width of the macro channel ranged from 45 m at Site 1 to 55 m at Sites 2 and 3.

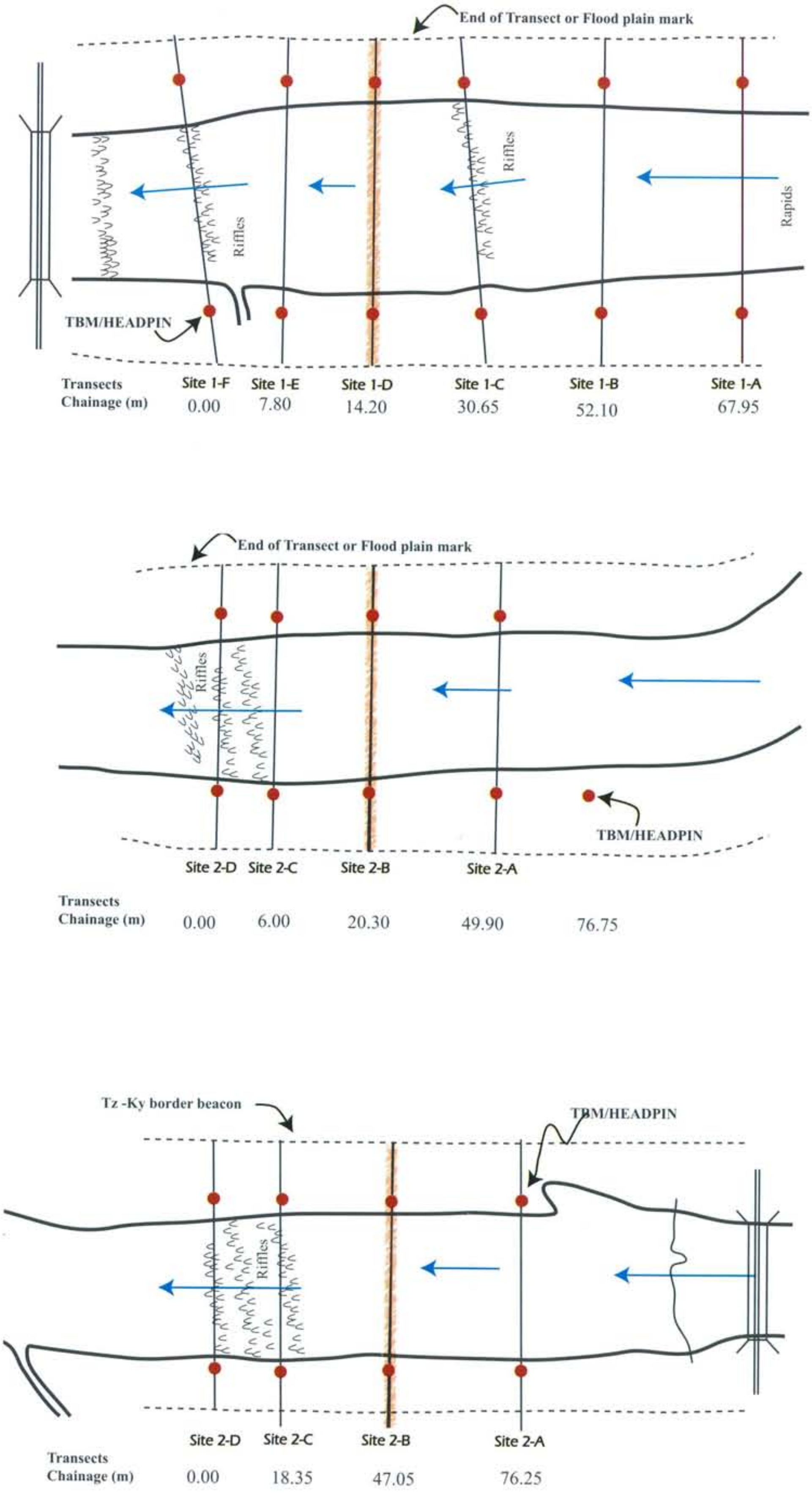


Figure 10: Six transects were surveyed at EFA Site 1 (a), and four transects were surveyed at Sites 2 (b) and 3 (c) in order to capture the variability of habitat types. Cross-sectional views of transects highlighted in red are shown in Figure 11.

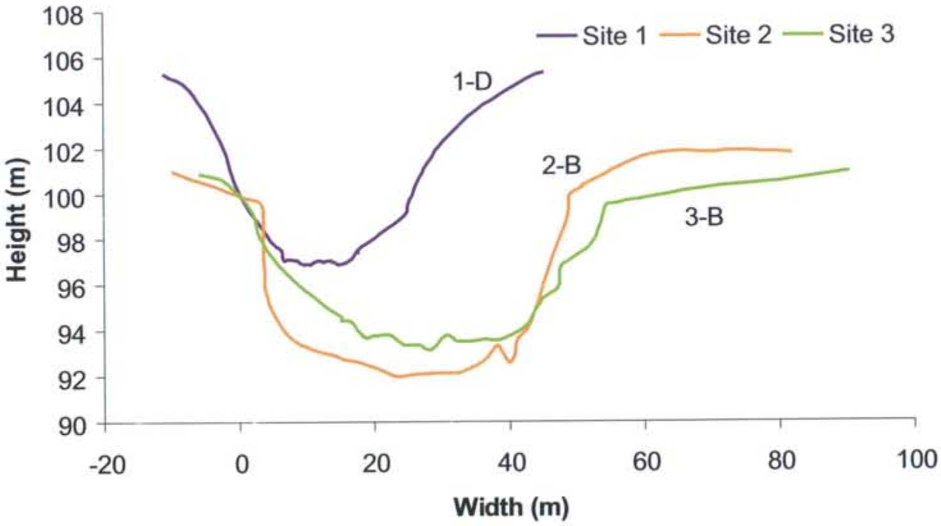


Figure 11: Cross-sectional plots of select transects (labeled with letter) at each study site. Widths and depths of macro-channels (the valleys cut by the rivers) are quite similar among sites.

The hydraulic characteristics of the river varied between sites and between sampling events (Table 2). As expected, the Amala River at Site 1 had the lowest flows. During the March sampling event, the discharge of the Amala was only 1.2 m^3/s, which accounted for only 18% of flow downstream at Site 2. During July, discharge in the Amala was 7.9 m3/s or nearly 50% of flow at Site 2. The largest discharge measured during the study was 16.9 m^3/s at Site 2 during the July event. The total width of the water surface was approximately equal at Sites 2 and 3 at 27 to 30 m. By contrast, the width of the water surface at Site 1 was only 10 to 12 m.

Table 2: Summary of hydraulic characteristics measured at the study sites during March and July of 2007

Site	Statistic	Measured hydraulic flow parameters (2007)				
		Total width of water surface, W (m)	Total area, A (m^2)	Total discharge, Q (m^3/s)	Cross section mean velocity, V_m (m/s)	Water Surface Level, WSL (masd)
Site 1: Amala River	March	10.1	4.7	1.2	0.30	97.4
	July	12.0	10.5	7.9	0.77	98.0
Site 2: Mid Mara River	March	27.7	10.9	6.8	0.63	92.9
	July	27.1	17.8	16.9	0.96	93.1
Site 3: Lower Mara River	March	27.2	20.5	7.5	0.38	96.2
	July	30.2	28.6	15.9	0.57	96.6

The data from the survey transects and hydraulic measurements were applied to a Physical Habitat Simulation Model (PHABSIM), which was used to calculate a series of relationships between a given discharge level and other flow parameters, including water depth, flow velocity, wetted perimeter and water surface width (Fig. 12). The model was calibrated with data collected during low flows and model performance was tested with medium flow data. These relationships were used by the other specialists in the final workshop to arrive at Environmental Flow Recommendations (EFR) for the Mara River.

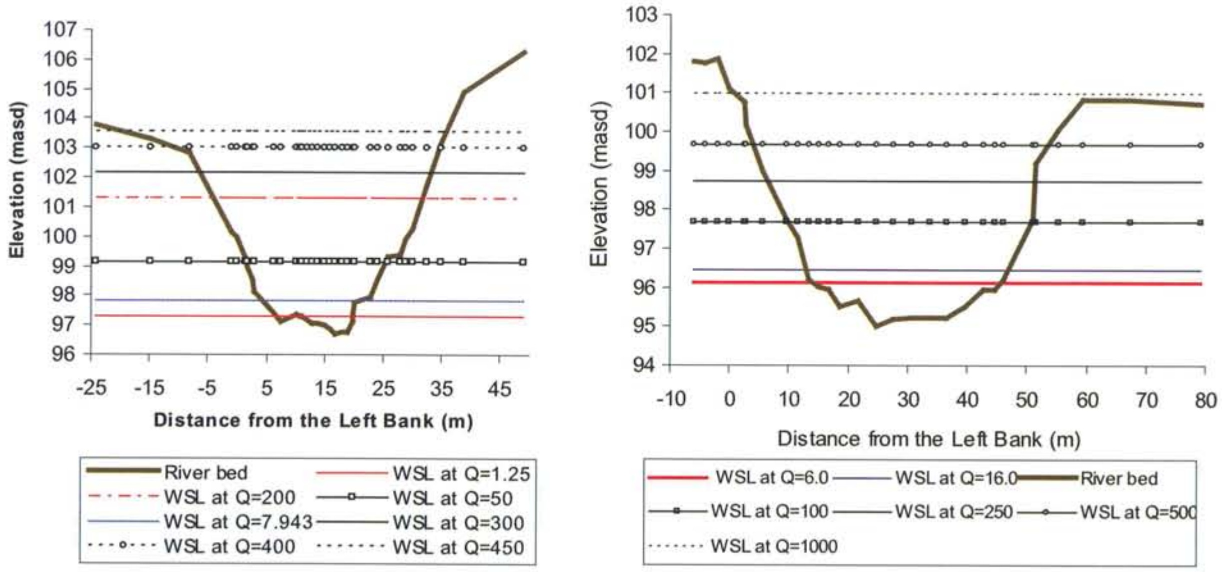


Figure 12: Simulation results of Water Surface Level (WSL) in meters above site datum (masd) as a function of discharge, Q (m^3/s) at EFA Sites 1-D and 3-D on the Mara River.

From these model projections, various flow parameters can be graphed as a function of discharge in order to determine critical flow levels (Fig. 13). For example, the wetted perimeter and width of a river are the baseline indicators of how much aquatic habitat is available at any particular discharge. Relationships between wetted perimeter and discharge at all three plots generally have a characteristic shape: steeper at low discharges with one or multiple break points. These break points may correspond to water rising over channel features such as bars and boulders, or an irregular channel bed or banks. Once water fills the channel and begins to rise up the stream banks, the rate of increase of wetted perimeter for each unit increase of discharge decreases. This process creates a break in slope, an inflection point, in the plot of wetted perimeter to discharge. This break point is important in defining minimum stream-flow requirements (Gippel and Stewardson, 1998). Wetted width to discharge plots showed similar shapes to the wetted perimeter curves. In addition, the hydraulic depth curve shows a break point at a discharge of 90 m^3/s, beyond which the increase in depth is very minimal.

3.1.3 Geomorphology

The geomorphological analysis of the study sites provides information on the shape of the river channel and accumulation of sediments arising from fluvial processes such as erosion, transport and deposition. Understanding how flows affect the shape of the channel and accumulation of sediment is critical because this physical habitat influences the nature of the riverine ecosystems. Sediments are an important component of this study, as they are the dominant physical feature transported and altered by the river. Within the Mara River Basin, the natural sediment generation processes are believed to have been altered by recent land-use change.

All three study sites showed some degree of terracing, along with the presence of areas accustomed to intermittent flooding. All sites also had active channel banks and in-stream sandbars, indicating the occurrence of active processes such as erosion and sediment deposition. The upper-most Site 1 at Kapkimolwa showed fairly low levels of erosion, with less than 10% of the riverbank along this site affected by undercutting, and low levels of sediment accumulation on the riverbed. Site 2 at the Mara Safari Club had significantly higher levels of erosion, with up to 75% of the riverbank deeply

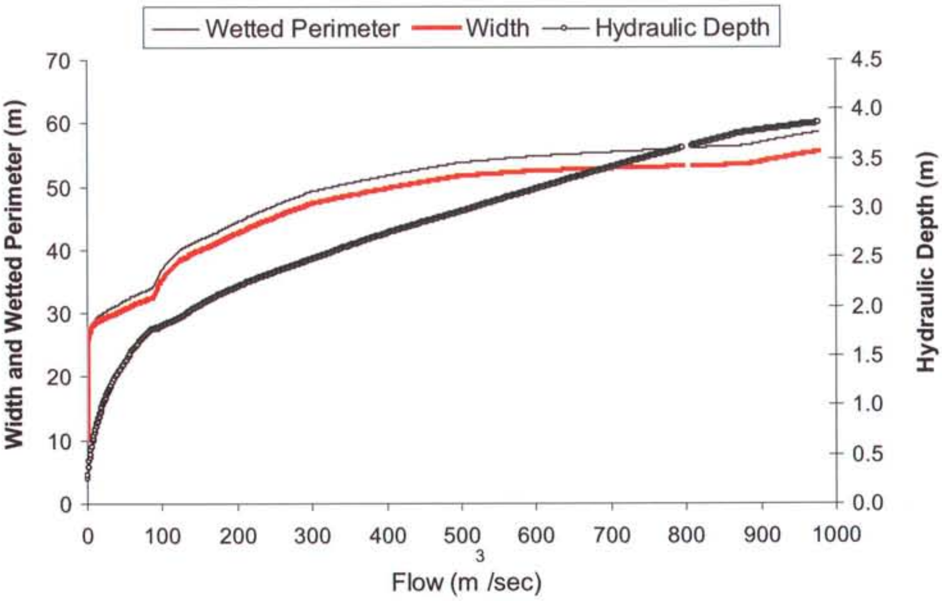


Figure 13: Simulated relationships between key ecological parameters (wetted width, wetted perimeter and hydraulic depth) and discharge at Site 3-D on the Lower Mara. These parameters were used by the ecologists on the EFA team to establish flow requirements for indicator fish, insects and riparian vegetation.

undercut. These areas were accompanied by a lack of vegetation along the riverbanks and deep gullies forming along moderately trampled human and wildlife trails. This was the most heavily impacted reach of river in terms of geomorphology. At Site 3 near the Kenya-Tanzania border in the protected areas, both the riverbanks and bed were in good condition, although vegetation was sparse and wildlife trails had formed gullies traversing the riparian zone (see Fig. 14).

Figure 14: Deep gullies formed along the riparian zone by wildlife trails.

At Site 1, annual normal floods during wet years are necessary to maintain firm, well-vegetated mid-channel bars and banks. Infrequent large flood events, approximately every five years, are required to maintain the macro channel features, such as terraces and wider banks. Small floods during dry periods are needed to flush out accumulated silt and sediment deposits from the riverbed. At Site 2, one normal flood event during wet years is necessary to maintain active channel features, such as sandbars, benches and terraces of the main channel. One large flood every five to ten years is needed to maintain the high terraces and floodplain of the macro channel. At Site 3, frequent normal floods are necessary in both wet and dry years to maintain sandbars, benches and terraces of the active channel. Infrequent but extreme flood events are necessary at this site to maintain the high terraces and floodplain of the macro channel, to transport sediment of larger size, and to reconstruct macro channel features that may have been degraded by external disturbances.

3.1.4 Water Quality

The water quality assessment provides information on the present characteristics of the river and considers the influences of altered flow levels on the presence and concentration of compounds that could be harmful to humans and aquatic life. Water quality is defined as the physical, chemical, biological and aesthetic qualities of water that determine its fitness for human use as well as for maintenance of a healthy ecosystem (DWAF 1996). In order to evaluate overall water quality in the basin and identify potential threats, a water quality survey was done throughout the length of the Mara River Basin in May-June, 2005 and 2006, and the findings were incorporated into the EFA. Water samples were analyzed for temperature, pH, electrical conductivity, total dissolved solids, salinity, turbidity, total suspended sediments, dissolved oxygen and nutrients. A subset of samples was further analyzed for the presence of heavy metals and pesticides. The influences of flow levels were considered in relation to the mobilization of contaminants during high flows, the formation of isolated pools that may develop dangerous water contamination during low flows, and the general concentration of contaminants in the river during low flows.

The basin-scale assessment found that water quality was generally acceptable, as no parameters were measured at concentrations exceeding national or international water quality standards. Temperature, conductivity, total dissolved solids (TDS) and salinity all increased on the Amala River from the source to the confluence; however, levels on the Nyangores remained consistent. Conductivity, TDS and salinity are measures of the mineral content of natural waters, and low conductivity and TDS are often characteristic of forested rivers; however, it's thus far difficult to tell if differences between these rivers are natural or the result of anthropogenic changes (WQBAR 2007). Total dissolved nitrogen (TDN), dissolved organic nitrogen (DON), ammonium (NH4+), total dissolved phosphorous (TDP), and phosphates (PO43-) were all much higher at Silibwet, a site on the Nyangores River, in 2005 than any other site, but this effect was not as pronounced in 2006. These high levels of nutrients may be due to fertilizer use in this tea-producing region. Levels were below World Health Organization (WHO) maximum contaminant levels for drinking water but may be contributing to eutrophication downstream.

Total mercury (THg), which ranged from 1.09 – 11.20 parts per trillion (ppt), and aluminum (Al), which ranged from 60.5 – 8194 parts per billion (ppb), were well below WHO standards for drinking water, and Kenyan and Tanzanian effluent standards. The levels were higher inside the protected areas than up- or down-stream; however, given the tendency of these metals to bond to sediments, these elevated levels may be related to the higher levels of total suspended solids found within the reserves, as those samples were taken after heavy rainfall events (WQBAR 2007). Because these heavy metals bioaccumulate and biomagnify in nature, even low levels may result in harmful accumulation in wildlife and people.

Water quality is strongly influenced by variables other than flow—specifically, natural and anthropogenic inputs of chemical compounds upstream of a given site. However, flow recommendations made by the EFA focused on direct impacts of flow on water quality, assuming proper pollution control measures are instituted at and above the sites. The primary objectives for recommended flows at all three sites were to maintain low flows at levels high enough to dilute natural and treated anthropogenic waste products and to maintain levels of turbulence sufficient to promote water aeration. Flow objectives also sought to maintain floods at levels sufficient to flush side channels and isolated pools that might otherwise become stagnant and accumulate waste.

Specifically, flows no less than 0.1 m^3/s were recommended for Site 1 in order to maintain dissolved oxygen at a level of 5 mg/L, THg at levels less than 1 μg/L and pesticides less than 1 part per billion (ppb). It was also recommended that turbidity be less than 100 NTU during base flows, although this objective must be reached by controlling upstream erosion rather than controlling in-stream flows. For Sites 2 and 3, flows were recommended to be no less than 1 m^3/s in order to maintain high water quality, although acceptable turbidity levels during base flows were increased to 200 NTU. For Site 3, flows were recommended to maintain PCB levels at less than 0.5 ppb.

3.2 Biological Indicators

3.2.1 Riparian Vegetation

Riparian vegetation is a good indicator of both low flow and high flow requirements. Individual species have different and often highly specific inundation and soil moisture requirements for their regeneration. Significant alterations in the natural flow regime of a river may eliminate overbank flooding or affect the floodplain water tables, which could lead to the loss of some species important for human use. The vegetation component of this study aimed to address three primary questions:

1) What important vegetation components are present at the selected study sites?
2) How does that vegetation relate to instream flows?
3) Which species at each site can serve as an indicator of appropriate flow regime?

During vegetation surveys, sample plots were systematically placed along transects running perpendicular from the river bed to the edge of the riparian forest. A list of plant species was recorded for each transect, along with species cover, abundance, height and structure. Vegetation zones along the transects were classified according to dominant plant species. The list of species and their horizontal distribution across the channel were analyzed by a classification approach, yielding information on the natural flow regime of the river.

The surveyed cross-section at Site 1 (Amala) showed a successive progression from sedge to grasses in the wet areas to herbaceous species and eventually to shrubs and small and large trees on the drier banks. This succession suggests a relationship with soil moisture content; for example, the wetter west bank had dominant perennials while the steep, overhanging east bank was drier and dominated by annual herbs. There were also several areas that had been cleared for cultivation or were already abandoned, as well as evidence of heavy grazing by livestock. At Site 2 (Middle Mara), large trees such as *Diospyros abyssinica* and *Prunus africana* dominated the banks, declining into isolated thickets of shrubs 30 m away from the channel. This zonal delineation in response to bank terracing suggests the intact influence of flooding dynamics, linked to magnitude, duration and return period of high and low flows. At Site 3 (Lower Mara), woody vegetation was dominated by dry-area shrubs. The only large trees present were *Acacia hockii* and one *Ficus* sp., typical of seasonally drained grasslands. There were also herbaceous species present indicating anthropogenic land disturbance, as well as evidence of heavy grazing by wildlife.

Table 3: Indicator plant species at each of the EFA study sites and their ecological and anthropological roles.

Site	Species	Ecology	Human Uses
1	*Vangueria madacascariensis*	Found in riparian vegetation and areas with high ground water	Food, medicine, fire wood, carvings, bee forage
	Euclae divinorum	Found near water courses and areas with ground water	Food, medicine, fire wood, timber, dye, fodder, bee forage
	Carissa edulis	Found on clay soils in valley bottoms and near seasonally flooded areas.	Food, medicine, bee forage, dye
2	*Prunus africana*	Occurs in moist forest and riverine vegetation.	Medicine, fire wood, charcoal, timber, bee forage
	Vangeria apiculata	Widespread in evergreen forests near water, riparian and wetland forests.	Food, fire wood
3	*Grewia bicolor*	Found in wooded grassland in sandy and rocky clay soils.	Food, medicine, fire wood, fodder, fiber, tool and weapon wood
	Dicrostachys cinerea	Found in bush land and wooded grass land.	Fire wood, spear shafts, fodder, bee forage, live fences
	Croton dichogamus	Occurs in dry bush and forest margins, often around rocky outcrops	Medicine, fire wood

At Site 1, maintenance flows throughout the year are needed to maintain density and appropriate age structure of *Syzygium cordatum* and *Warbugia ugandensis*. At Site 3, maintenance flows and flood events are important to foster recruitment potential and sustain appropriate density and age structure of *Prunus africana*, *Diospyros abyssinica* and *Warbugia ugandensis*. At all sites, maintenance flows are necessary to recharge the groundwater table in order to sustain woody species. Maintenance flushing floods are critical to maintain marginal vegetation species for bank integrity and to enhance seed germination and dispersal.

3.2.2. Macroinvertebrates

Aquatic invertebrates are very sensitive indicators of water quality and flow regime in rivers and overall ecological health of the system. Species used in these surveys included insects, worms, mollusks and crustaceans that occur on the riverbed or along the channel margins. Aquatic invertebrates were sampled at all sites using the SASS 5 protocol, and a total score was calculated for each site that accounted for the number of different taxa present and the sensitivity of those taxa to water quality (Dickens and Graham 2002).

At Site 1 (Amala), 9 different taxa were documented, yielding a fairly low sensitivity score (Table 4). This suggests the river is in reasonable condition at this site; however, substantial habitat degradation has occurred due to small-scale anthropogenic activities such as grazing livestock and subsistence agriculture (Chutter 1998). Site 2 (Middle Mara) had an even lower sensitivity score and a reduction in the number of documented taxa to only 8. This indicates increased deterioration in water quality from the first to the second site. Site 3 (Lower Mara) showed further deterioration, with a substantial change in sensitivity score and a reduction of the number of taxa to 7. Because this site was located within the protected areas, human impacts were minimal; however, upstream degradation continued to impact these downstream locations.

Table 4: Total number of macroinvertebrate taxa, sensitivity of taxa (SASS), average sensitivity score per taxon (ASPT) and water quality interpretation for each EFA site in the Mara River Basin.

Site	Total # Taxa	Total SASS score	ASPT	Water Quality
Site 1	9	38	4.2	Significant deterioration in water quality and habitat diversity
Site 2	8	32	4.0	Significant deterioration in water quality and habitat diversity
Site 3	7	25	3.6	Major deterioration in water quality and habitat diversity

At Site 1, adequate flow levels are required to maintain populations of *Baetidae* and *Hydrosychidae*, as some species are eliminated when the water becomes stagnant. As *Hydrosychidae* require water rich in phytoplankton, a current velocity of 0.6-1.0 m/s is recommended. At Sites 2 and 3, the target flow-dependent species were *Libellulidae* (see Fig. 15) and *Coenagrionidae*. Nymphs of these species are favoured by low flow conditions that foster prey species and provide protection from aquatic predators. In contrast, adults rely on marginal vegetation and are favoured by periodic inundation of the banks. High flows are also necessary for drift to promote recolonization of disturbed biotopes in order to increase diversity in general.

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

Figure 15: Dragonfly (*Libellulidae*) nymph at both Sites 2 and 3.

3.2.3. Fish

Although fisheries are not a substantial component of people's diet or income in the upper or middle stretches of the Mara River, fish populations are excellent indicators of river health in terms of water quantity and quality, which in turn provides other important services to people. Fish were sampled in surveys at each study site using gillnets placed in all available river habitats (i.e., riffles, runs and pools). After a standardized period of time, the nets were hauled and data were collected on number and abundance of species, length and weight of individuals, and reproductive condition. Fish species were also characterized according to their environmental guild, a classification system that groups species that respond similarly to changing hydrology and geomorphology (Welcomme *et al.* 2006).

All three study sites had an appreciable amount of instream habitat, which is positively correlated with species diversity. Surveys yielded 110 specimens belonging to 6 species (Fig. 17). All four of the previously documented species in the Mara River were captured in these surveys, indicating little to no change in the fish species composition in the river. In addition, *Oreochromis alcalicus grahami*, a species that appears in the IUCN Red List as "vulnerable", was documented at Site 1 (Amala). *Labeo victorianus*, an endemic fish species to the Lake Victoria basin, was documented at all three sites. The numbers and weights of fish captured increased from upstream to downstream, and more fish were captured in the wet versus the dry season and in pools versus riffles. With regard to species habitat use, more *Labeo* were caught in riffle/run sections than in pools and more *Mormyrus* were captured in pools than in riffles.

Upon capture, fish were examined for their reproductive status. Overall, about 50% of the adult individuals of the most numerous fish species in the Mara River— *Barbus*, *Labeo* and *Mormyrus*— were carrying ripe gonads, which indicates reproductive activity. In all species there were more adult individuals carrying ripe gonads in March 2007 than July 2007. In this system gonadal maturation appears to be cued by first rains and the rising water levels, increased turbidity and temperature decreases that accompany them. Spawning triggered by early spring rains may allow these populations to rapidly colonize newly formed water bodies that are temporarily connected to the main channel, and it may allow migratory spawners, such as *Labeo*, the necessary flow levels to move to upstream nurseries.

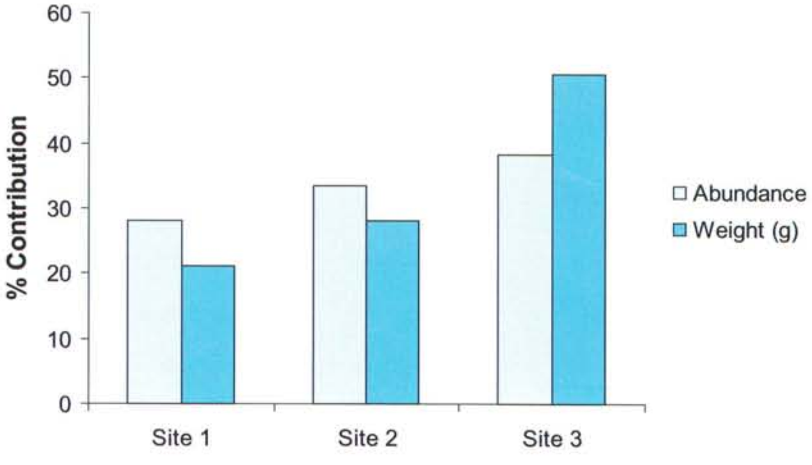


Figure 16: Comparison between the three study sites of fish catch in terms of abundance and grams. Site 3 was responsible for approximately 50% of the total catch by weight.

Critical flow regime characteristics can be further ascertained by studying the environmental guilds of fish present in the river. For example, both *Labeo* and *Barbus* are members of the lotic guild, characterized by species that require relatively high dissolved oxygen levels and generally migrate along the river channel. They also have one breeding season that is closely linked to peak flows, as described above. As such, these species are very sensitive to reductions in water quality and quantity as well as changes in timing of flow events.

Mormyrus represents the pool guild, characterized by species generally inhabiting the slack regions of back eddies where emergent and floating vegetation may occur. These species rely on the delicate balance between pool and riffle and respond negatively to any influence that changes this balance.

Finally, both *Oreochromis* and *Clarias* represent the eurytopic guild, characterized by fish that inhabit the riparian zone and may move into floodplains during high water. As these species are tolerant of low levels of dissolved oxygen, exhibit repeat breeding that is independent of the hydrograph, and are highly flexible in both behaviour and habitat use, they are generally the most robust populations to system change. However, they can be negatively affected by changes in riparian structure.

Table 5: Species and their environmental guilds documented during March and July sampling at BBM sites, listed as present (+) or absent (-).

Site	*Labeo victorianus* (lotic)	*Barbus altianalis* (lotic)	*Barbus kersetenii* (lotic)	*Mormyrus kannume* (pool)	*Oreochromis grahami* (eurytopic)	*Clarias gariepinus* (eurytopic)
1	+	+	-	-	+	-
2	+	+	+	+	-	+
3	+	+	-	+	-	-

According to this method of assessment, *Labeo* and *Barbus* were the most sensitive species documented in the Mara River, and flow recommendations made for these species would be suitable for all other species. A threshold depth of 0.2 m is needed to allow upstream migration of the larger-bodied members of these species. Dry season base flows in a drought year should maintain inundation of the riffles, requiring a minimum average depth of 0.25 m to achieve 50% coverage of riffles at Site 1 and Site 2, and 0.35 m at Site 3. These flows would generate current velocities ≥ 0.3 m/s at the three sites, which are suitable for *Labeo victorianus*. Wet season base flows must inundate lower banks and benches, allowing the input of nutrients from those systems to the river as well as fish passage over larger obstacles. Wet season high flows must inundate the floodplains to recharge wetlands, facilitate nutrient transfer and provide access to fish requiring floodplain nursery grounds.

3.3 Social Indicators

The upper reaches of the Mara River Basin have the highest population densities and the majority of people living there depend on small-scale agriculture and animal husbandry. In the middle reaches of the Mara, the main livelihoods are nomadic pastoralism or participation to some degree in the tourism industry, although there is also commercial agriculture in this region. The lower reaches of the Mara River in Kenya pass through Masai Mara National Reserve. As this is a protected area, human population is limited and clustered around hotels and lodges. Crossing into Tanzania the river supports Serengeti National Park and then flows through a region of mixed small-scale agriculture and pastoralism. Communities living adjacent to the Mara Swamp also depend upon fish harvested from the wetland system. A large proportion of people in the Mara River Basin live below the poverty level.

The first component of the Reserve flow addresses the basic water needs of people in the basin. The Kenya Water Resources Management Rules (GoK, 2007) defines "basic human needs" as the quantity of water required for drinking, food preparation, washing of clothes, bathing and basic sanitation, and assumes it to be equal to 25 litres per person per day. Based on projections of population increases in the Mara Basin (Table 6), meeting the minimum needs of people in the basin will require 0.2 m^3/s of flow in 2010 and 0.3 m^3/s of flow in 2020. This assumes that all residents in the basin draw their basic water needs directly from the river. These flows represent only a small fraction of river discharge

a) *Barbus altianalis* (Site 1, March 2007).

b) *Labeo victorianus* (Site 1, March 2007).

c) *Oreochromis alcalicus grahami* (Site 1, July 2007).

d) *Barbus kerstenii* (Site 2, March 2007).

e) *Mormyrus kannume* (Site 2, March 2007).

f) *Clarias gariepinus* (Site 2, July 2007).

Figure 17: Fish species documented during the EFA sampling efforts in March and July, 2007

The most socially relevant indicator of the health of the Mara River is its ability to provide necessary resources for human populations that depend on it. As human populations increase, there is increased demand for those resources by sometimes conflicting interests. People must decide which resources are critical enough to their livelihood that they are worth protecting. A thorough understanding of the utilization, quality and trajectory of riverine resources can help stakeholders work together to ensure the long-term health of the river and all who depend on it. Data on population growth and increasing water demand were collected. Surveys and interviews were also conducted in communities dependent on the Mara River to determine the primary resources and services the Mara River provides. Participants were asked to rate the importance of those resources and also to identify current anthropogenic threats to the river ecosystem.

and are accommodated by the larger flows required to protect the second component of the reserve flow, which is ecosystem health. It should be noted, however, that these minimum requirements will represent a larger proportion of total flow in smaller headwater rivers and in sub-catchments with high population densities. Thus it may not always be possible to assume that basic human needs are accommodated by flows to protect ecosystems. Moreover it is important to acknowledge that river water must be treated prior to consumption in order to meet the objectives of the MDGs.

Table 6: Population and daily water demand projections (assuming 25 litres/day/person) within the Mara River Basin

	2010		**2020**		**2030**	
	Population	**Daily Water Demand (m^3)**	**Population**	**Daily Water Demand (m^3)**	**Population**	**Daily Water Demand (m^3)**
Kenya	556,497	13,912	705,448	17,636	894,268	22,357
Tanzania	282,204	7,055	361,251	9,031	462,437	11,561
Total	838,701	20,967	1,066,699	26,667	1,356,705	33,918

(Adapred from Hoffman 2007)

Surface flows are the major sources of water for people living throughout the river basin, but in the more arid middle and lower reaches, the main channel of the Mara River is an especially important source of water for human populations. The primary use of the river is for domestic water, although livestock and agricultural irrigation in the upper and middle stretches also rely on the river. In the middle stretch, large-scale commercial farmers have permits allowing for water abstraction. In addition to water, the river ecosystem provides other resources relied upon by local communities, including fish, wildlife, soil and vegetation. Surveys conducted in the Basin illuminated the many resources provided to local communities by an intact riverine ecosystem, and the state of ecosystem health desired by the community to ensure the provision of those services (Table 7).

A resource prioritization chart indicated the most important resource provided by the river was water, followed by vegetation and then the river ecosystem itself. Local communities were also asked to identify current anthropogenic threats to the river ecosystem. They included river bank erosion by livestock, high concentrations of pollutants due to human use and destruction of riparian vegetation by cultivation. All of these threats were exacerbated in the dry season, when other water sources ran dry and usage was concentrated in the Mara. Overall, people agreed they had seen a decline in resource abundance in the last several decades, including reductions in riparian vegetation, water quality and the abundance and diversity of aquatic life in the river and large game in the upper stretches, and increases in river bank erosion.

Table 7: Summary of the variety of ways communities utilize the Mara River

River resources	Resource use	Desired state of the river
Water	Water for livestock	Sufficient water to provide for livestock, even during droughts, while maintaining acceptable quality for human consumption
	Domestic use	High enough water quality for human consumption at all times, including low sediment and impurity loads. The need for point of use disinfection is recognized as well.
	Irrigation farming	Sufficient water to sustain crops during the dry season when precipitation is low*
	Habitat for fish	Dynamic flow regime to cue fish breeding events
	Recreation, e.g. swimming	Sufficient water to allow swimming
	Industrial use, e.g. water mills, mines	Sufficient water to maintain industry practices*
	Generation of hydroelectric power.	Sufficient water levels for hydroelectric power generation*
	Cultural /religious practices, e.g. baptism	Presence of deep pools where people can carry out cultural practices
Fish	Food	Healthy fish populations
Vegetation	Habitats for wildlife	Intact riparian zone that provides habitat and camouflage for wildlife
	Food	Healthy populations of important food plants
	Medicine	Flow regimes that foster growth of medicinal herbs that are only found in the riparian zone
	Construction material	Intact riparian zones that provide habitat for vines used in construction of the Maasai manyattas
	Cultural/traditional artifacts e.g. rungus	Intact riparian zones that provide habitat for culturally important tree species
	Charcoal	Presence of large tree species that may be used in charcoal production
Soil sediments	Soil sediments for art works on houses	Functioning sediment generation process to provide fertile soil
	Sand harvesting	Functioning sediment generation process to provide sands
Wildlife	Tourist attraction e.g. crocodile and hippopotamus	Intact habitat to foster thriving wildlife populations
River ecosystem	Cultural practices (e.g. baptism, circumcision, naming ceremonies)	Sufficient vegetation and deep pools of water to meet cultural needs of the community
	Hotel sites	Adequate water supply and stable river banks to allow construction of hotels and restaurants

**Some of these uses reflect local people's desire for flows beyond the reserve to meet extractive water needs as well. These additional needs were acknowledged but not included in final recommended reserve flows. These needs are to be met by flows exceeding the reserve.*

3.4. Determining Flow Recommendations

The EFA Team met in October, 2007, to determine the flow regime needed to meet the Resource Quality Objectives (RQOs). Each specialist presented the necessary flow requirements for his or her component of the river system for each of the environmental flow building blocks (see Annex 2: Environmental Flow Building Blocks). Specialists explained their motivations for all flow requirements and described the potential consequences of not meeting the requirement. During the process, a consensus was sought among the specialists of the minimum flows and floods that will suffice to achieve the RQOs. Based on the specialists' recommendations for average flows during key months of the year, the hydrologist extrapolated these recommendations across the entire year in a manner that simulated the natural shape of the river's historical hydrograph. The modified hydrograph, with associated floods, serves as the recommended reserve flow. These reserve flow recommendations were compared with the historical hydrograph for each site in order to determine the amount of water available for extractive use.

4. Flow Recommendations for the reserve

The EFA determined that during maintenance years the reserve is met and ample water is available for extractive uses. At Site 3 on the border between Kenya – Tanzania and Masai Mara National Reserve – Serengeti National Park, the reserve accounts for, on average, 35% of the average monthly flow recorded over the 26 years of available flow data from the nearest gauging station. At Site 1 on the Amala River, the recommended reserve flows account for 25% on average of recorded flows during maintenance years. It is important to note, however, that the percent of flow held in the reserve varies over the course of a year, mirroring the natural highs and lows of the system. The majority of water available for abstraction is therefore concentrated in a few months when flows are high. Far less water is available for abstraction during dry season months.

The situation during drought years is quite different, as the assessment found that, presently, the reserve is not being met during several months of the year at Sites 1 and 2. There could be several explanations for this discrepancy. First, this is an initial assessment of the recommended reserve; continued monitoring could reveal that required reserve levels are lower than prescribed here. Second, the prescribed reserve levels could prove to be accurate, but levels of abstraction could be unsustainably high during drought years and need to be reduced. Third, prescribed reserve levels could be accurate and abstraction levels could be reasonable, but land-use practices in the upper catchment may have sufficiently altered the hydrograph of the river such that drought year low flows are unnaturally low, suggesting that land rehabilitation in the upper catchment is necessary for the reserve to be restored.

The observation that drought year reserve flows are not being met in the upper and middle reaches of the Mara may be the first clear evidence of a trend toward unacceptable alterations of the Mara River's flow regime. Upstream impacts are necessarily linked to downstream resources, and poorly managed water abstraction above the wildlife reserves will ultimately affect the downstream reaches as well. Furthermore, the reserve estimates in this assessment have not taken into account the environmental flow requirements of the Mara Swamp, which may be different. The reserve also does not include flow volumes necessary to meet the extractive water needs of Tanzanian communities and industries between Serengeti National Park and the Mara Swamp. Thus, flow levels reaching Tanzania must be high enough not only to sustain the reserve but also to meet Tanzanian extractive needs.

Following are the results for the recommended average monthly reserve flows and flood events for both maintenance and drought years, for each of the three sampling sites (Tables 8-10). These results are also shown graphically in comparison to average monthly flow recorded over the length of record.

Table 8: Environmental flow requirements for Site 1 in the upper Mara River Basin. FDC- Flow Duration Curve; MCM- million cubic meters; MAR- median annual runoff.

Building Blocks		Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Maintenance EFR Base Flows	Magnitude (m^3/s)	1.3	1.3	1.3	1.7	1.7	1.5	1.5	2.0	1.9	1.5	1.3	1.3
	Depth (m)	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3
	Volume (MCM)	3.5	3.1	3.5	4.4	4.4	3.9	3.9	5.4	4.9	4.0	3.3	3.4
	FDC % present	72%	72%	72%	63%	63%	67%	67%	59%	61%	67%	72%	72%
Higher Flows	Magnitude (m^3/s)				12	12			38	12			
	Depth (m)				0.8	0.8			1.4	0.8			
	Duration (d)				2	2			2	2			
	Return Period (y)				1	1			1	1			
	Volume (MCM)				2.1	2.1			6.6	2.1			
	FDC % present				20%	20%			5%	20%			
Drought EFR Base Flows	Magnitude (m^3/s)	0.3	0.3	0.3	0.3	0.4	0.3	0.3	0.6	1.0	0.4	0.5	0.5
	Depth (m)	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.3	0.2	0.2	0.2
	Volume (MCM)	0.8	0.8	0.8	0.8	1.1	0.8	0.8	1.7	2.6	1.0	1.3	1.2
	FDC % present	95%	95%	95%	95%	92%	95%	95%	85%	76%	92%	89%	89%
Higher Flows	Magnitude (m^3/s)									4			
	Depth (m)									0.5			
	Duration (d)									1			
	Return Period (y)									1			
	Volume (MCM)									0.4			
	FDC % present									43%			

Maintenance EFR	Base Flows	Higher Flows	Total	**Drought EFR**	Base Flows	Higher Flows	Total
Volume (MCM)	47.6	12.8	60.4		13.6	0.4	14.0
as % of MAR	17.8%	4.8%	22.6%		5.1%	0.1%	5.2%
MAR (MCM)	266.9						

Table 9: Environmental flow requirements for Site 2 in the middle Mara River Basin. FDC- Flow Duration Curve; MCM- million cubic meters; MAR- median annual runoff

Building Blocks		**Jan**	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sept**	**Oct**	**Nov**	**Dec**
Maintenance EFR Base Flows	Magnitude (m^3/s)	4.1	4.0	4.0	6.5	7.0	6.0	6.0	8.0	7.8	5.8	4.4	4.3
	Depth (m)	0.3	0.3	0.3	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.3	0.3
	Volume (MCM)	10.9	9.7	10.7	16.7	18.7	15.7	15.9	21.4	20.1	15.5	11.3	11.5
	FDC % present	76%	78%	78%	66%	63%	69%	69%	60%	61%	70%	75%	74%
Higher Flows	Magnitude (m^3/s)					16	16	16	75				
	Depth (m)					0.5	0.5	0.5	1.0				
	Duration (d)					1	1	1	3				
	Return Period (y)					1	1	1	1				
	Volume (MCM)					1.4	1.4	1.4	19.4				
	FDC % present					37%	37%	37%	3%				
Drought EFR Base Flows	Magnitude (m^3/s)	1.2	1.1	1.0	1.0	1.3	1.3	3.3	3.1	4.0	2.2	1.7	1.5
	Depth (m)	0.2	0.2	0.2	0.2	0.2	0.2	0.3	0.3	0.3	0.3	0.2	0.2
	Volume (MCM)	3.3	2.6	2.7	2.7	3.4	3.3	8.7	8.4	10.4	5.9	4.3	4.1
	FDC % present	96%	97%	98%	98%	95%	95%	83%	85%	78%	90%	94%	95%
Higher Flows	Magnitude (m^3/s)					25							
	Depth (m)					0.6							
	Duration (d)					2							
	Return Period (y)					1							
	Volume (MCM)					4.3							
	FDC % present					25%							

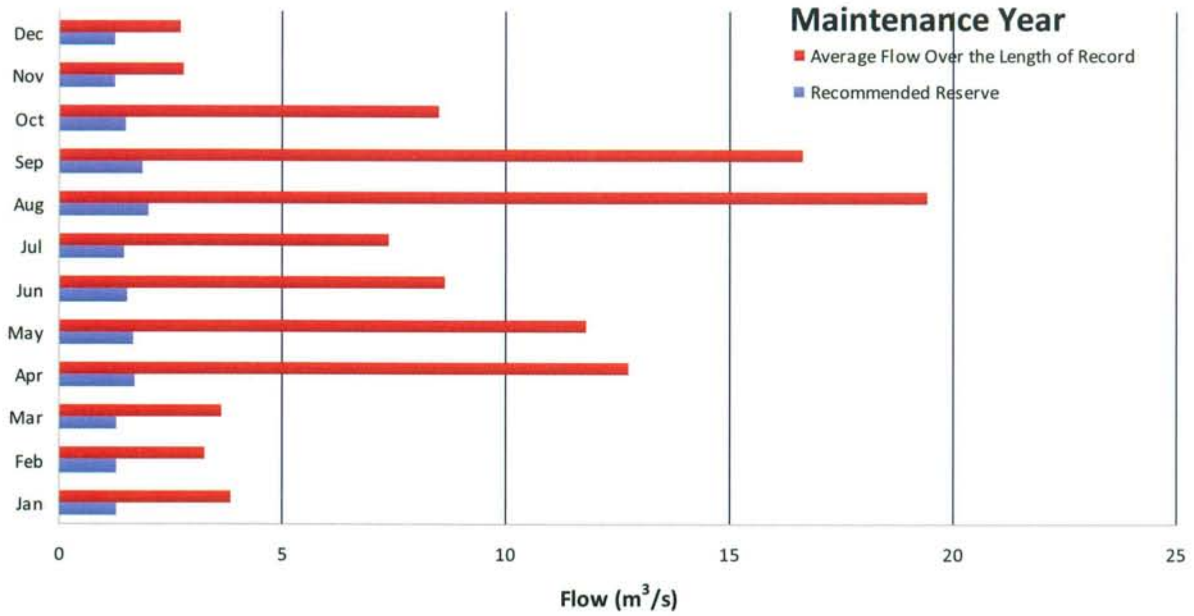
Maintenance EFR	Base Flows	Higher Flows	Total	**Drought EFR**	Base Flows	Higher Flows	Total
Volume (MCM)	198.6	23.6	222.2		72.6	4.3	76.9
as % of MAR	35.2%	4.2%	39.4%		12.9%	0.8%	13.7%
MAR (MCM)	563.5						

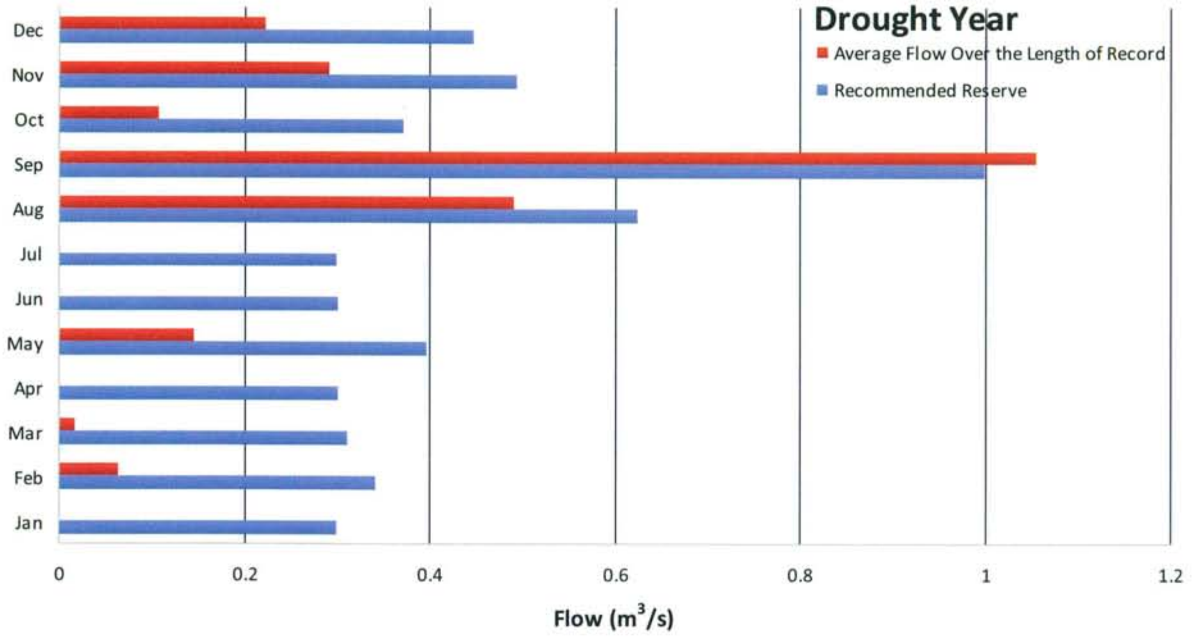
Table 10: Environmental flow requirements for Site 3 in the lower Mara River Basin. FDC Flow Duration Curve; MCM-million cubic meters; MAR- median annual runoff

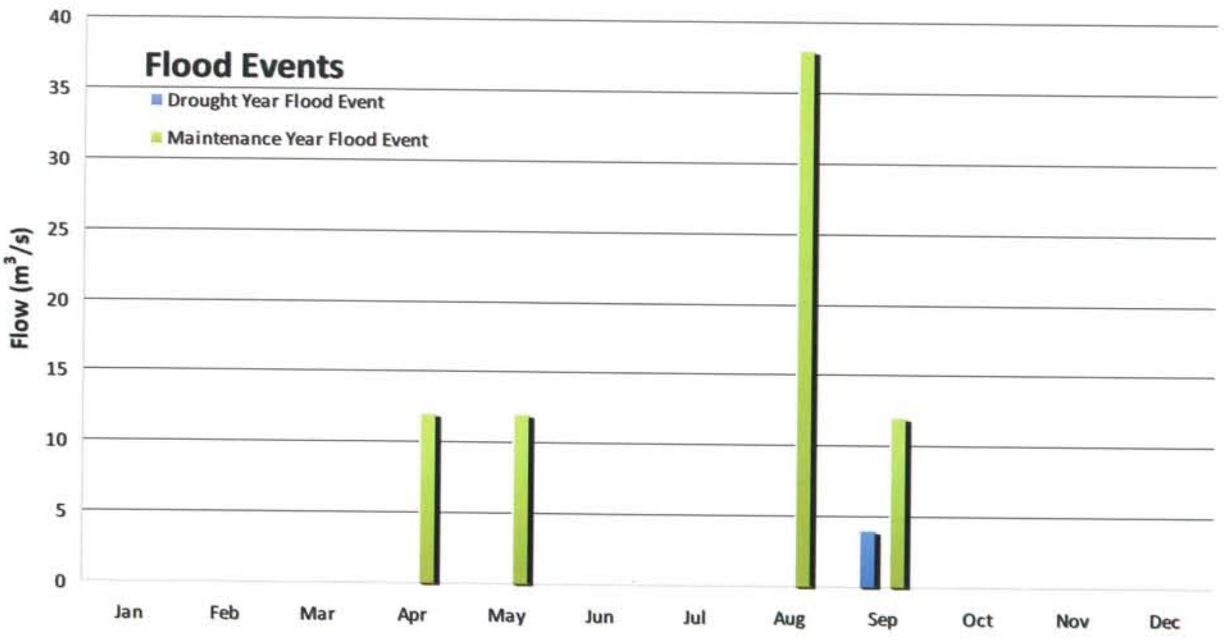
Building Blocks		**Jan**	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sep**	**Oct**	**Nov**	**Dec**
Maintenance EFR Base Flows	Magnitude (m^3/s)	6.1	6.0	7.9	15.0	15.0	9.4	6.6	6.8	8.2	6.0	6.9	6.1
	Depth (m)	0.6	0.6	0.7	0.9	0.9	0.7	0.6	0.6	0.7	0.6	0.6	0.6
	Volume (MCM)	16.5	14.5	21.1	38.9	35.6	22.3	18.9	19.2	20.7	16.4	18.8	18.2
	FDC % present	66%	67%	60%	37%	37%	55%	64%	63%	59%	67%	63%	66%
Higher Flows	Magnitude (m^3/s)				90	25	25	25					
	Depth (m)				1.8	1.1	1.1	1.1					
	Duration (d)				3	2	2	2					
	Return Period (y)				1	1	1	1					
	Volume (MCM)				23.3	4.3	4.3	4.3					
	FDC % present				3%	19%	19%	19%					
Drought EFR Base Flows	Magnitude (m^3/s)	2.4	2.0	2.4	4.2	6.0	4.3	3.9	4.2	4.5	3.4	2.5	2.7
	Depth (m)	0.4	0.4	0.4	0.5	0.6	0.5	0.5	0.5	0.5	0.5	0.4	0.4
	Volume (MCM)	6.4	4.8	6.4	11.0	16.1	11.1	10.4	11.2	11.7	9.0	6.4	7.1
	FDC % present	83%	87%	83%	73%	67%	72%	74%	73%	72%	78%	82%	82%
Higher Flows	Magnitude (m^3/s)					20							
	Depth (m)					1.0							
	Duration (d)					2							
	Return Period (y)					1							
	Volume (MCM)					3.5							
	FDC % present					27%							

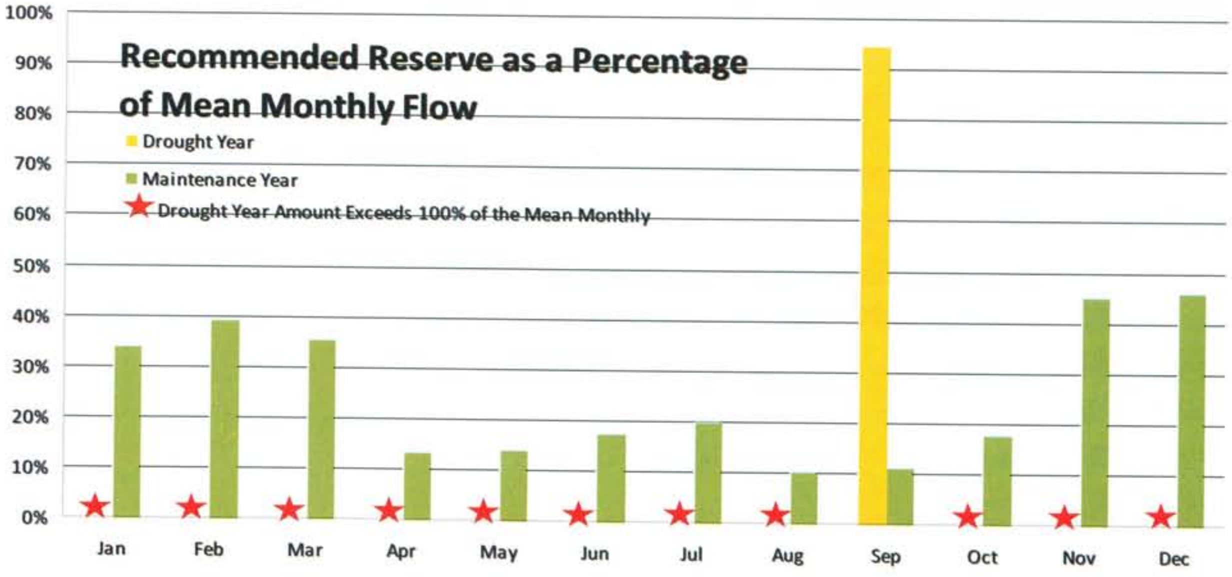
Maintenance EFR	Base Flows	Higher Flows	Total	**Drought EFR**	Base Flows	Higher Flows	Total
Volume (MCM)	260.9	36.3	297.2		111.5	3.5	115.0
as % of MAR	46.2%	6.4%	52.6%		19.7%	0.6%	20.3%
MAR (MCM)	564.92						

Site 1

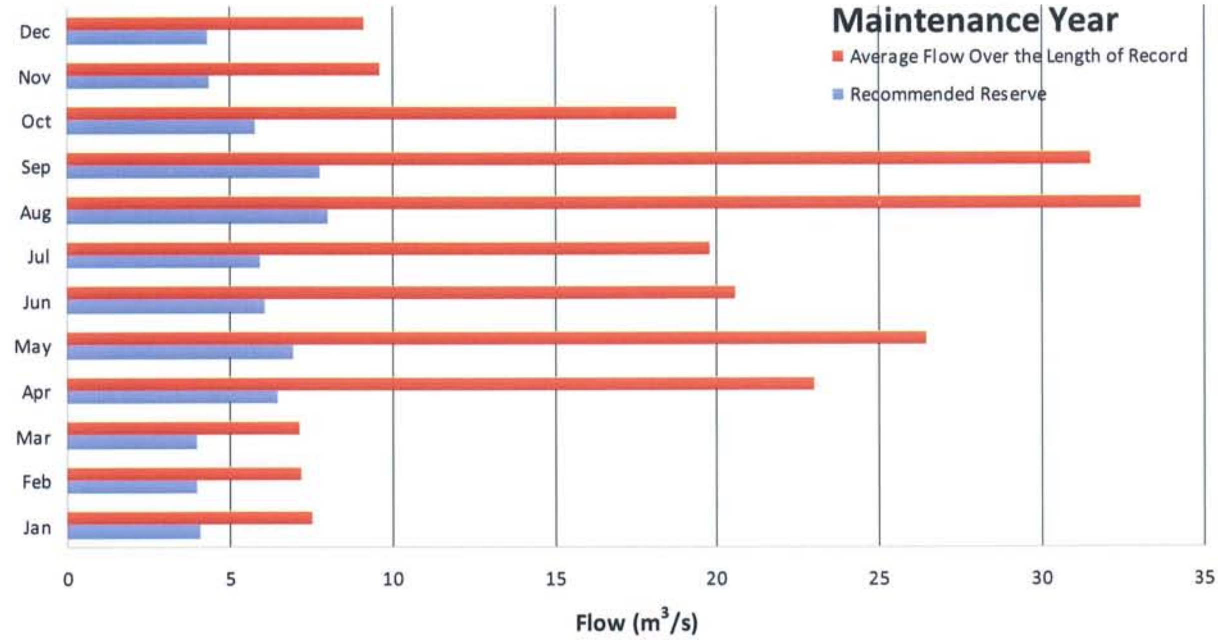

Maintenance Year
■ Average Flow Over the Length of Record
■ Recommended Reserve
Dec
Nov
Oct
Sep
Aug
Jul
Jun
May
Apr
Mar
Feb
Jan
0
5
10
15
20
25
Flow (m³/s)

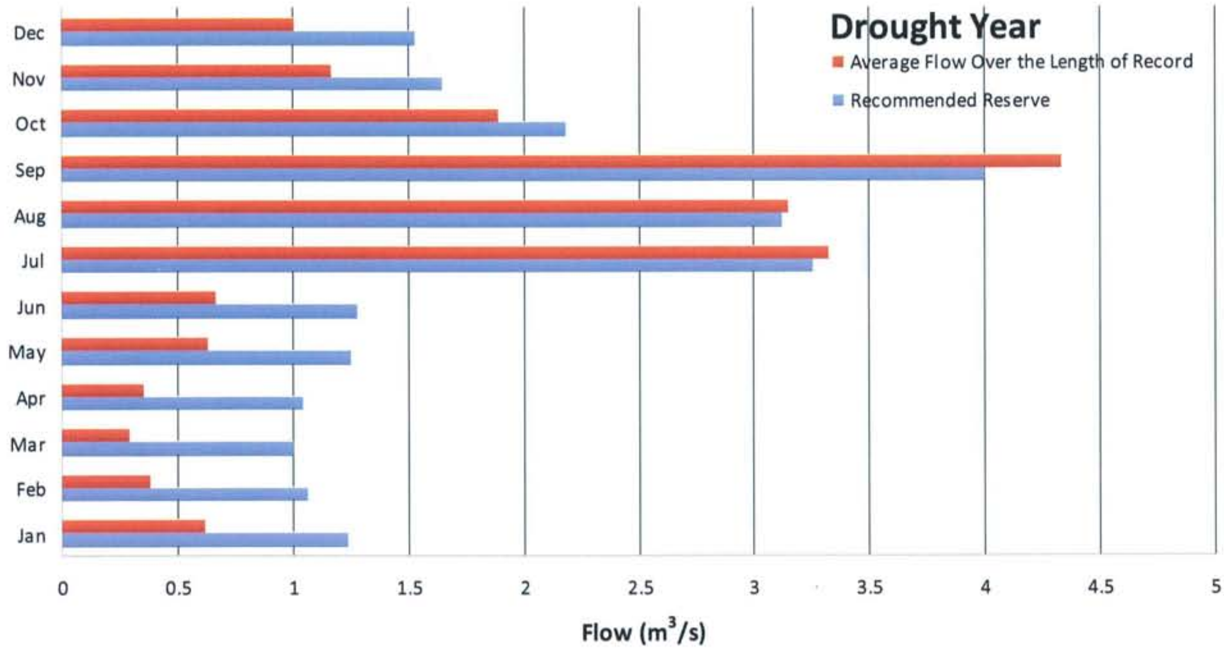

Drought Year
■ Average Flow Over the Length of Record
■ Recommended Reserve
Dec
Nov
Oct
Sep
Aug
Jul
Jun
May
Apr
Mar
Feb
Jan
0
0.2
0.4
0.6
0.8
1
1.2
Flow (m³/s)

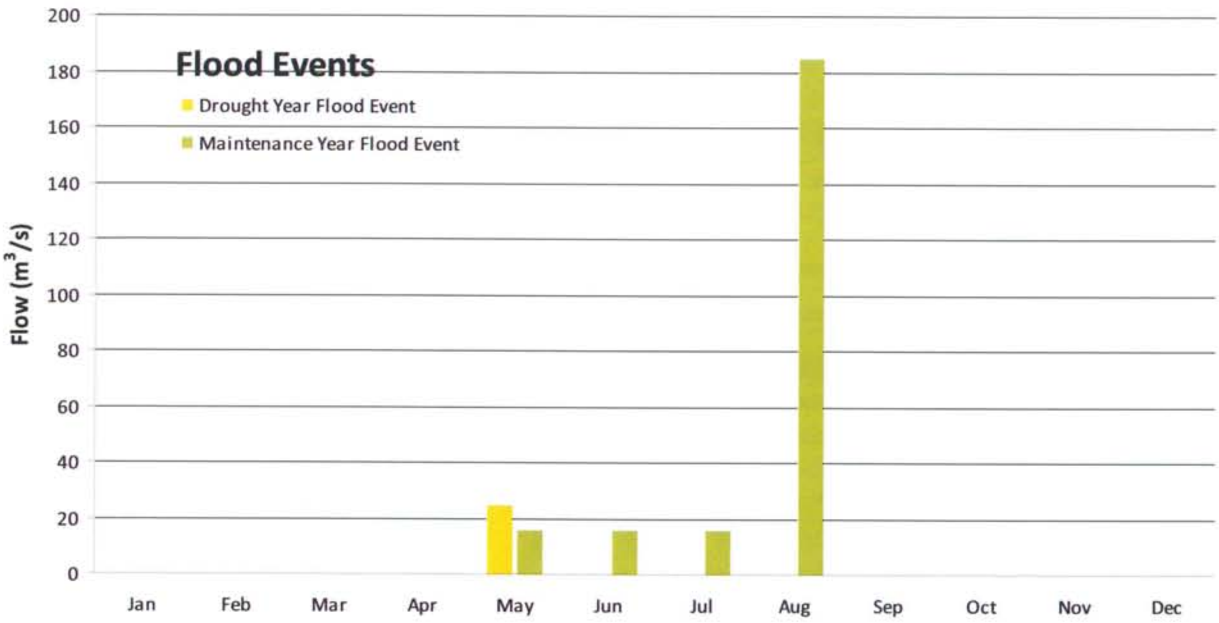

Flood Events
Drought Year Flood Event
Maintenance Year Flood Event
Flow (m³/s)
40
35
30
25
20
15
10
5
0
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec

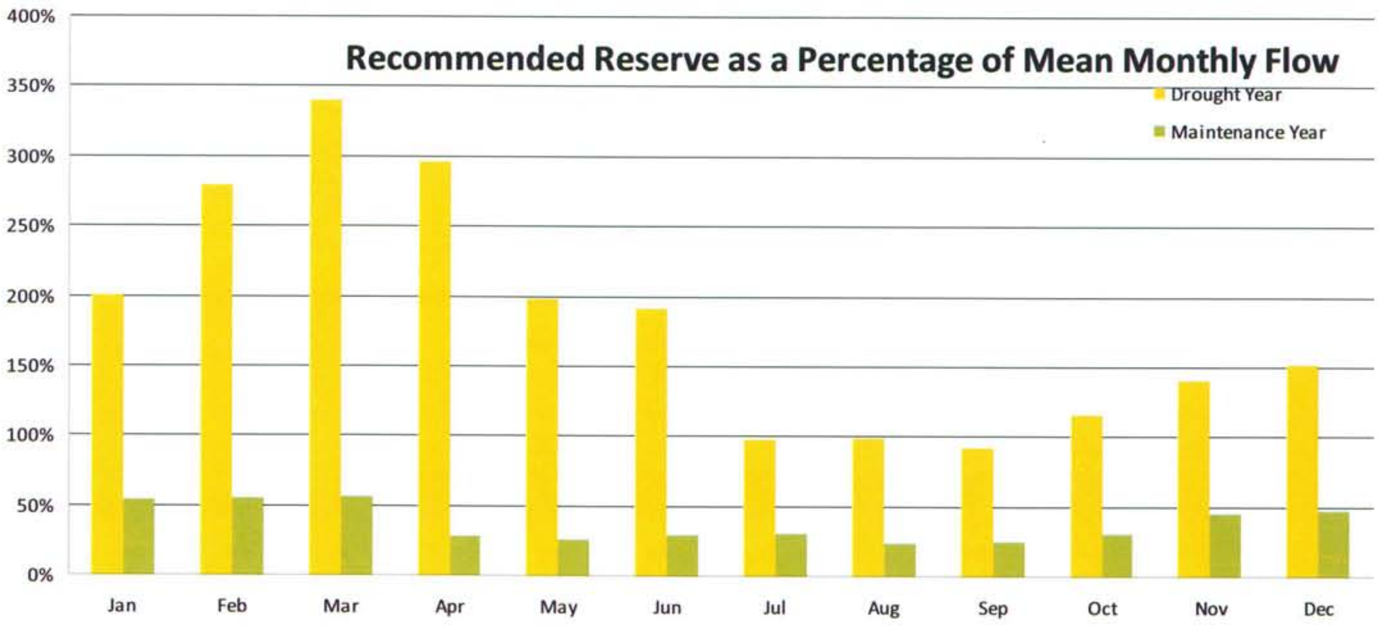

Recommended Reserve as a Percentage of Mean Monthly Flow
Drought Year
Maintenance Year
Drought Year Amount Exceeds 100% of the Mean Monthly
100%
90%
80%
70%
60%
50%
40%
30%
20%
10%
0%
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec

Site 2

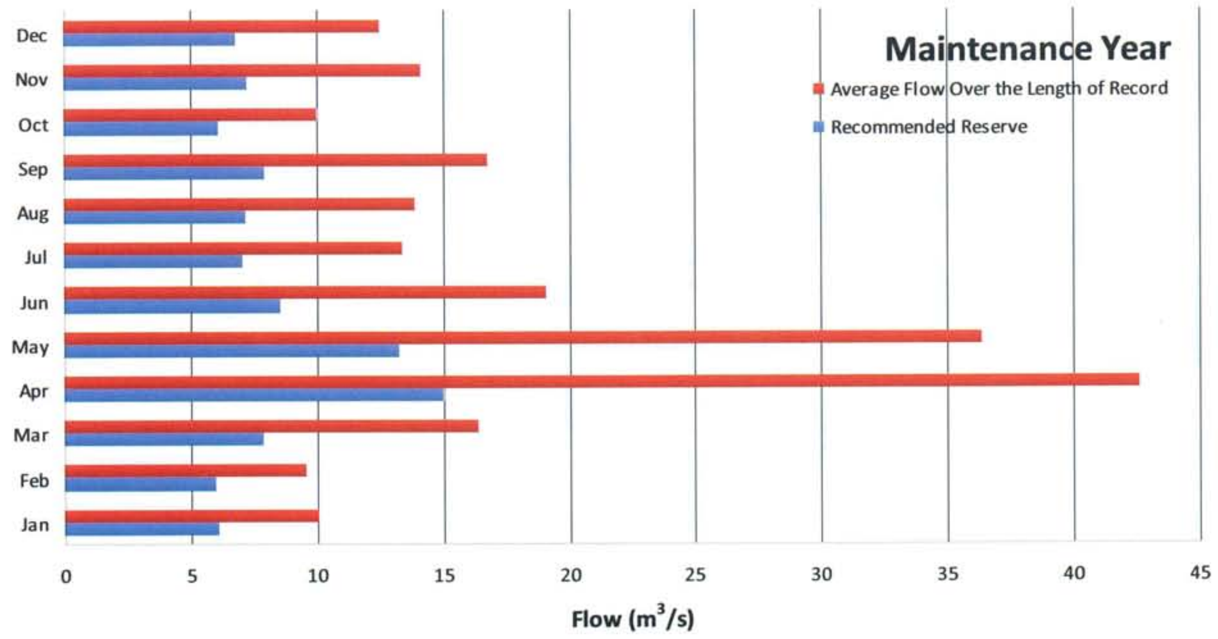

Maintenance Year
Average Flow Over the Length of Record
Recommended Reserve
Dec
Nov
Oct
Sep
Aug
Jul
Jun
May
Apr
Mar
Feb
Jan
0
5
10
15
20
25
30
35
Flow (m^3/s)

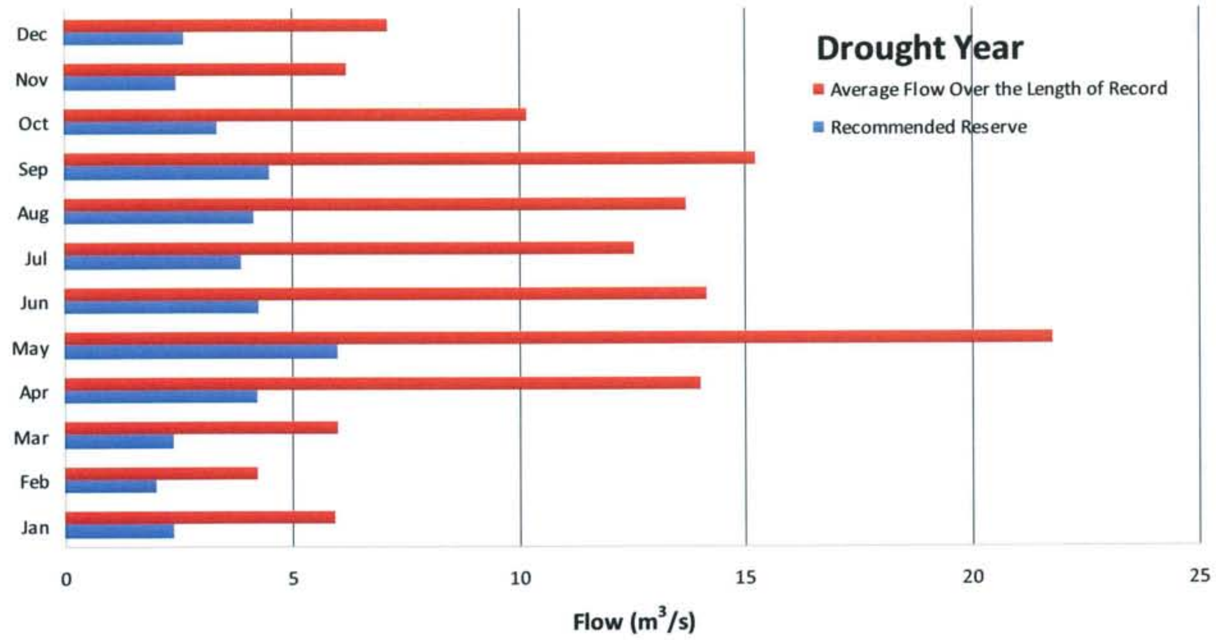

Drought Year
Average Flow Over the Length of Record
Recommended Reserve
Dec
Nov
Oct
Sep
Aug
Jul
Jun
May
Apr
Mar
Feb
Jan
0
0.5
1
1.5
2
2.5
3
3.5
4
4.5
5
Flow (m^3/s)

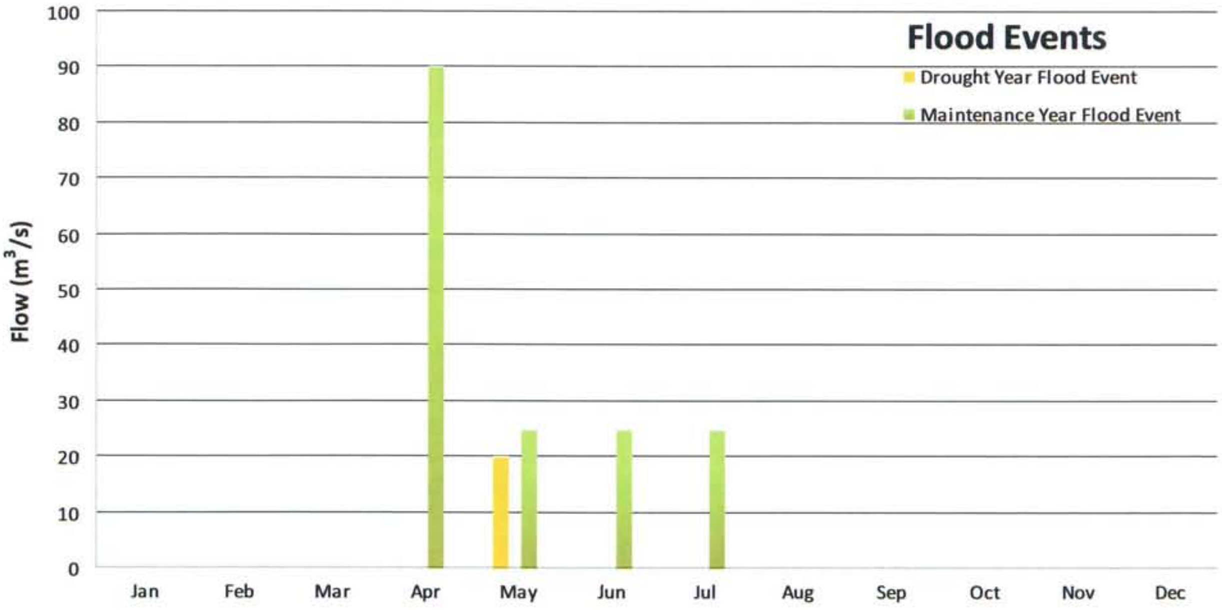

Flood Events
Drought Year Flood Event
Maintenance Year Flood Event
Flow (m³/s)
200
180
160
140
120
100
80
60
40
20
0
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec

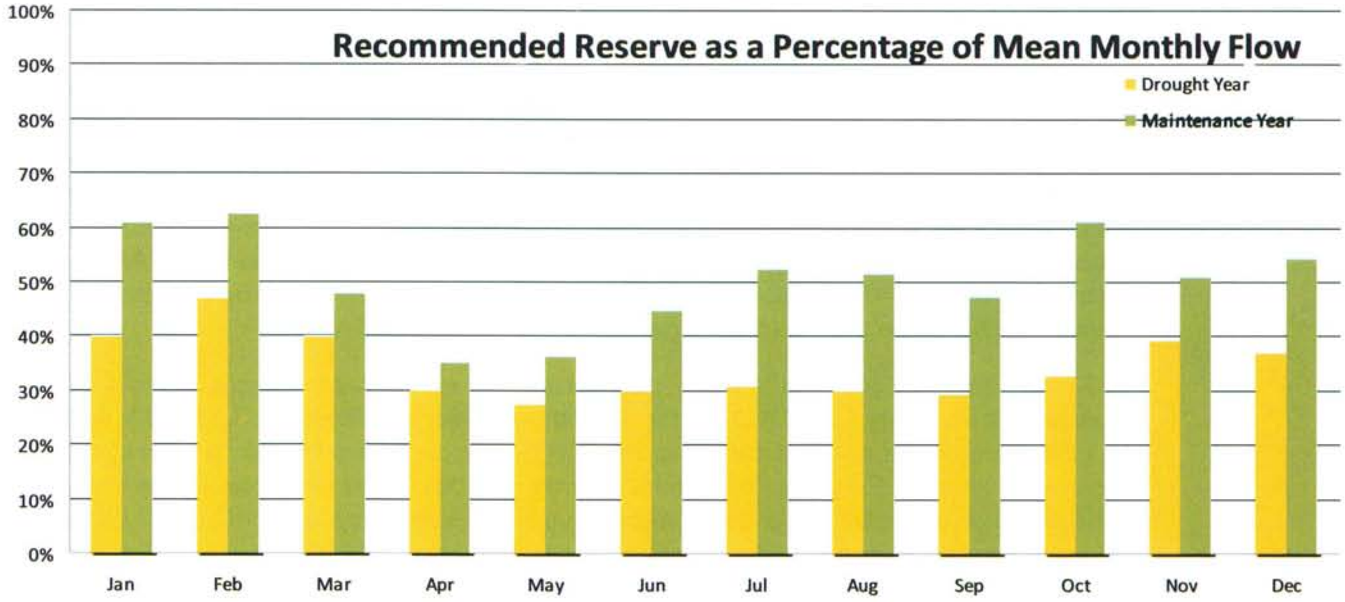

Recommended Reserve as a Percentage of Mean Monthly Flow
Drought Year
Maintenance Year
400%
350%
300%
250%
200%
150%
100%
50%
0%
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec

Site 3


Maintenance Year
Average Flow Over the Length of Record
Recommended Reserve
Dec
Nov
Oct
Sep
Aug
Jul
Jun
May
Apr
Mar
Feb
Jan
0
5
10
15
20
25
30
35
40
45
Flow (m^3/s)


Drought Year
Average Flow Over the Length of Record
Recommended Reserve
Dec
Nov
Oct
Sep
Aug
Jul
Jun
May
Apr
Mar
Feb
Jan
0
5
10
15
20
25
Flow (m^3/s)


Flood Events
Drought Year Flood Event
Maintenance Year Flood Event
Flow (m³/s)
100
90
80
70
60
50
40
30
20
10
0
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec


Recommended Reserve as a Percentage of Mean Monthly Flow
Drought Year
Maintenance Year
100%
90%
80%
70%
60%
50%
40%
30%
20%
10%
0%
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec

5. Recommendations for Implementation and Monitoring of Reserve Flows

The Mara River currently has no major dams acting to significantly modify its flow regime. Thus, flow prescriptions must be achieved by improving management of the catchment and controlling permits for abstractions. The unequal distribution of flows throughout the year also poses the challenge of developing and implementing sustainable technologies for harvesting and storing wet season runoff for consumptive use during dry months.

Specific recommendations for the implementation of reserve flows are as follows:

1. Implement a comprehensive monitoring system on the Mara River to enable daily monitoring of the flow levels at multiple points in the basin
2. Improve monitoring of permitted and non-permitted abstractions to reduce illegal abstractions and to develop an estimate of current abstraction levels
3. Develop a system to easily communicate to water permit holders the current state of the river and the implications for their permitted abstraction amounts
4. Build capacity among water resource managers to consider reserve flow requirements in all water resource permitting in the basin
5. Build capacity among water users in the basin in regards to the importance of maintaining reserve flows, implementing soil and water conservation practices and reporting illegal abstractions
6. Develop sustainable methods of harvesting and storing wet season flows for consumptive use during dry seasons
7. Improve soil and water conservation practices in the upper catchment in order to improve dry season low flows
8. Continue to monitor the river's flow levels and ecological health in order to refine reserve flow recommendations

The Mara is a transboundary river and therefore the above recommendations must be closely coordinated between responsible institutions in the two countries. In both Kenya and Tanzania, the responsibility for water resource management occurs at multiple levels: national, basin, catchment and local. Both countries have national policies that recognize the importance of the reserve and call for its protection and consideration in all water resource decisions. They also both have independent regulatory bodies—National Environmental Management Authority in Kenya and National Environmental Management Council in Tanzania—that are not part of any particular Ministry. These agencies can prove invaluable in enforcing the national environmental policies protecting reserve flows.

In Kenya, the Mara River falls under the management of the Lake Victoria South Catchment Management Authority (LVSCMA) in the Ministry of Water and Irrigation. LVSCMA, located in Kisumu, directs water resource use and management in the catchment through the development and implementation of a Catchment Management Strategy (CMS). This document guides the general policies and procedures used for decision-making processes regarding water resources. Inclusion of the recommendations of this EFA in the CMS would establish a legal requirement and mandate that District level actions be in line with its recommendations. The CMS also enforces the Water Resource Management Rules (2007), which require off-channel storage basins for all abstraction permit holders, to provide water during times when abstractions may be curtailed to protect the reserve flow.

At the basin scale, the Sub-regional Water Resources Management Authority (WRMA) in Kericho is the local agency responsible for monitoring the river, issuing abstraction permits and regulating and enforcing the CMS. They also have the authority to rescind permits or revise allowable abstraction levels, dependent on the status of the system. In the CMS, for instance, the system may be designated "red" during drought periods indicating that certain permitted users are required to reduce or cease abstractions. WRMA is also responsible for monitoring the river's flow levels, providing crucial information for ensuring maintenance of the reserve as well as for determining the amount available for abstraction. As such, it will be the responsibility of WRMA to account for recommended reserve flow levels in their issuing of new abstraction permits, as well as to determine the annual status of the river (i.e., drought or maintenance year) and enforce the "traffic colour" regulation system. It is also the responsibility of these water agencies to monitor permit holders to ensure abstraction within the permitted levels, as well as to take legal action against those found engaged in illegal abstraction.

In Tanzania, the Mara River falls under the management of the Lake Victoria Basin Water Office (LVBWO), located in Mwanza, in the Ministry of Water and Irrigation (MOWI). They are currently drafting a water resource use and management plan for the catchment to implement Tanzania's Water Resources Management Act (2008), and protection of the reserve is included in this plan. At the basin level, the Sub-catchment Water Office, located in Musoma, is responsible directly for the Mara River. They are legally mandated to enforce LVBWO's management plan through monitoring and regulation. At an even more local level, water resource use is regulated by a District Water Engineer in the Ministry of Local Government. Each district has developed a Water Master Plan that is approved by the MOWI, and abstraction permits are first applied for through the District Water Engineer.

At the most grassroots level, local Water Resource User's Associations (WRUAs) in Kenya and Catchment Area Committees (CACs) in Tanzania are citizen groups comprised of water resource stakeholders in the basin. Once a WRUA or CAC has formed and been recognized by the Ministries of Water and Irrigation, it can provide valuable assistance in local monitoring and regulation of water flows and abstractions. Members of these groups will be instrumental in conveying the importance of reserve protection and maintenance of environmental flows to their local communities. They are also well-suited to provide additional knowledge and information regarding the effectiveness of the prescribed flow regime at maintaining the health of the river system.

Transboundary issues related to management of the Mara River and the equitable sharing of its economic benefits between Kenya and Tanzania should be addressed through the Lake Victoria Basin Commission of the East African Community. This effort will also benefit from the participation of the newly formed Mara Transboundary Water Users Forum. Eventually, a transboundary reserve flow and surplus flow should be agreed-upon by Kenya and Tanzania under the auspices of the East African Community.

This EFA for the Mara River has applied a structured and scientifically sound process for determining the requirements of the reserve and thus is a first step towards estimating the amount of water available for consumptive use. It is important to note that this is a first assessment of the reserve based on the best available data and expertise of the scientific team. Continued monitoring of the river's flow levels and ecological status will be critical to determine if the prescribed flow regime is sufficient, if more water needs to be set aside for the reserve, or if more water can be permitted for consumptive use.

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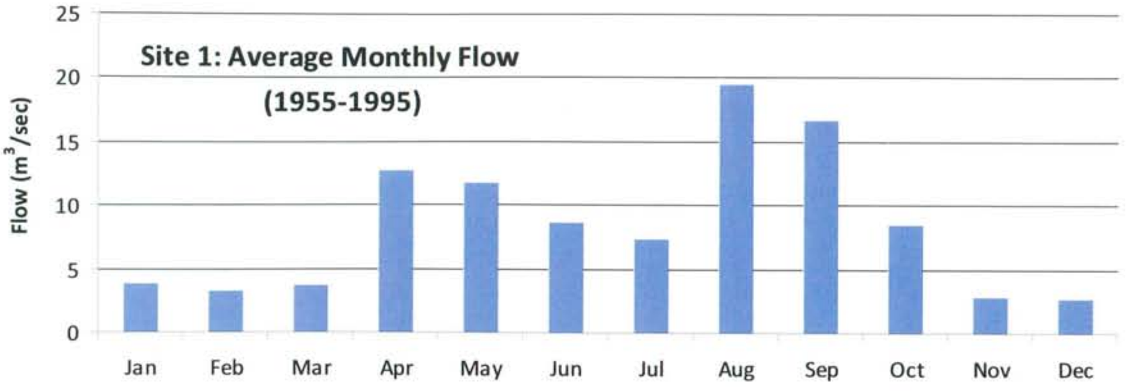
Annex 1: Participants in the Mara Environmental Flow Assessment

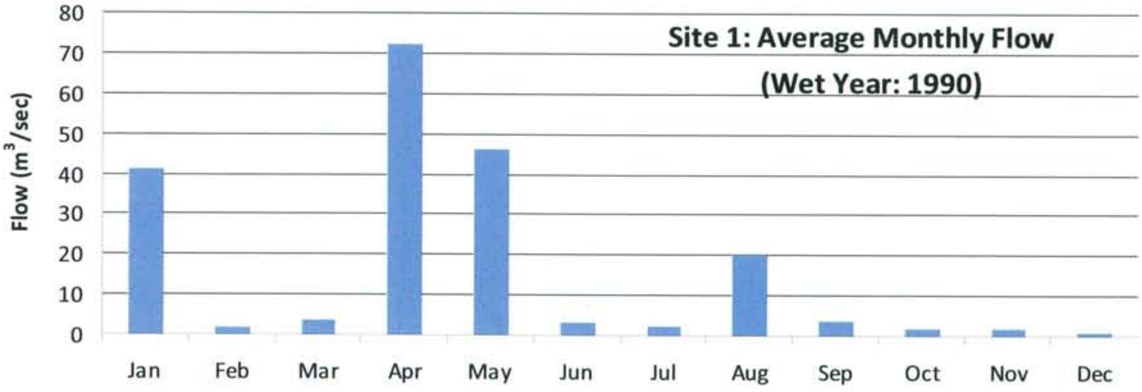
Participant groups	Name	Organization
Kenya Water Agency	Margaret Abira, Regional Manager	Lake Victoria South Catchment Area, Water Resources Management Authority
	Bilancio Maturwe, Sub-Regional Manager	Lake Victoria South Catchment Area, Water Resources Management Authority
	Willis Memo, Community Coordinator	Lake Victoria South Catchment Area, Water Resources Management Authority
Tanzania Water Agency	Lusekelo Mwambuli, Basin Hydrologist	Lake Victoria Basin Water Office, Ministry of Water and Irrigation
	Sariro Mwita, Water Officer	Lake Victoria Basin Water Office, Ministry of Water and Irrigation
Protected Areas Representatives	Samson Lenjir, Lead Ecologist	Masai Mara National Game Reserve
	James Wakibara, Lead Ecologist	Serengeti National Park
	Emanuel Gereta, Retired Lead Ecologist	Serengeti National Park
EFA Team	Doris Ombara Okundi, Coordinator	WWF-EARPO, Mara River Basin Management Initiative
	Joseph Ayieko, Riparian Vegetation Specialist	Egerton University, Kenya
	Christopher Dutton, Research Associate	Florida International University, USA
	Michael McClain, Water Quality Specialist	Florida International University, USA
	Assefa Melesse, Hydrologist	Florida International University, USA
	Joseph Muthike, Technical Coordinator and Geomorphologist	Consultant
	Preksedis Ndomba, Hydraulic Engineer	University of Dar es Salaam, Tanzania
	Leah Onyango, Socioeconomist	Maseno University, Kenya
	Amanda Subalusky, Aquatic Ecologist	Florida International University, USA
	Rashid Tamatamah, Fish Specialist	University of Dar es Salaam, Tanzania
	D. Victor Wasonga, Invertebrate Specialist	National Museums of Kenya
Workshop Facilitators	Doris Ombara Okundi	WWF-EARPO
	Jay O'Keeffe	UNESCO IHE, The Netherlands
	Michael McClain	Florida International University, USA
WWF Staff Participants	Musonda Mumba, Freshwater Programme Coordinator	WWF-EARPO, Kenya
	Fred Mngube, MRBMI Coordinator	WWF-Tanzania, Mara River Basin Management Initiative

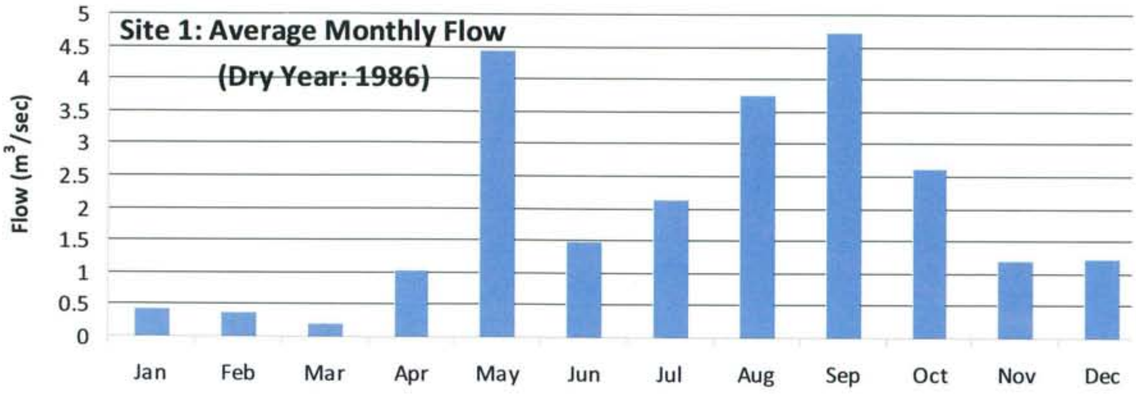
Annex 2: Environmental Flow Building Blocks

Flow Building Blocks	**Definitions**	**Functions**
Drought Year Low Flows	The low flow requirements during the driest month of a drought year	• Maintain hydrological connectivity in the system • Maintain inundation of critical habitats (eg., riffles) • Sustain flow-sensitive species • Provide natural variability to maintain diverse species assemblage
Drought Year High Flows	The low flow requirements during the wettest month of a drought year	• Maintain active channel flows to inundate benches and sustain emergent vegetation • Permit fish passage over obstacles
Maintenance Year Low Flows	The low flow requirements during the driest month of a maintenance year	• Provide natural variability to maintain diverse species assemblage
Maintenance Year High Flows	The low flow requirements during the wettest month of a maintenance year	• Cue migration and spawning in fishes • Inundate macrophytes and emergent vegetation along banks • Displace dominant competitors and allow drift of species into new habitats, promoting increases in species diversity • Maintain groundwater recharge for riparian species
Small Annual Floods	Small pulses of higher flow that occur in the drier months	• Cue spawning and migration in fishes • Inundate surrounding floodplains to facilitate lateral migration of fauna • Facilitate nutrient transfer between floodplains and the river • Allow germination and seed dispersal of riparian vegetation • Prevent sediment build-up on river bed, thus increasing habitat variability for invertebrates • Maintain active channel features • Flush out organic matter, thus improving water quality
Major Flood Events	Major peaks in the river's flow level that occur at a given recurrence interval	• Maintain macro channel features and provide diversity of physical habitats • Scour bed of sediment deposits • Inundate and recharge larger floodplain, allowing for nutrient transfer

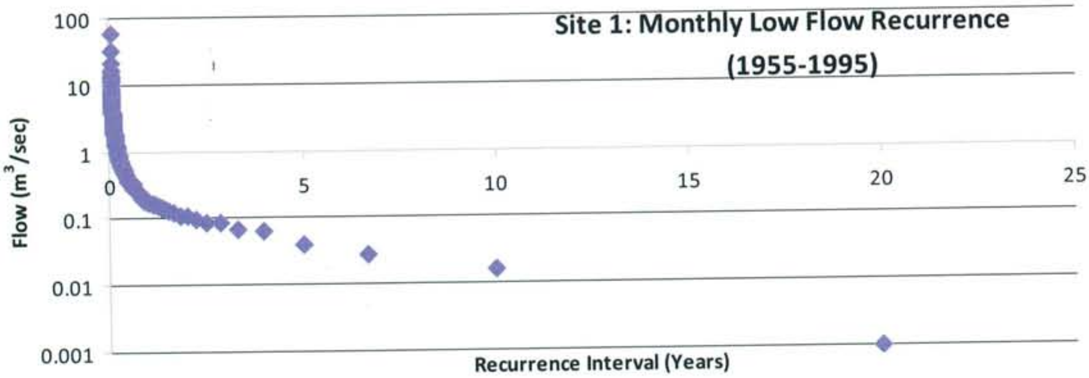
Annex 3: Historical Flow Relationships for EFA Site 1

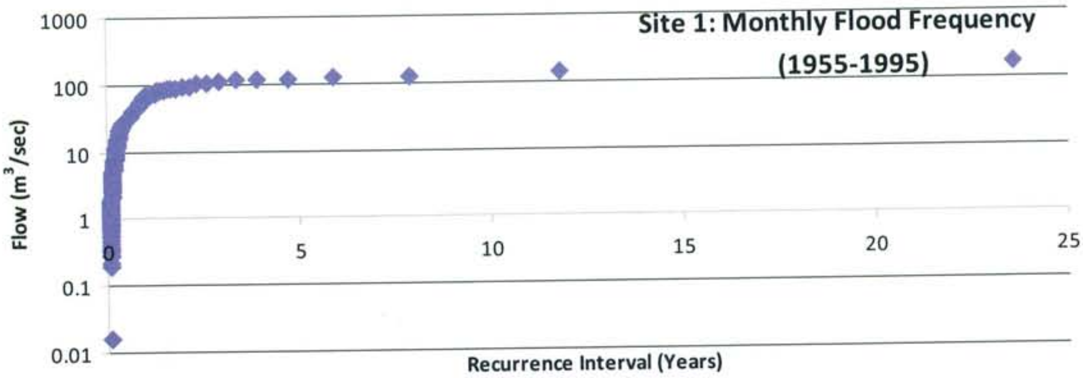




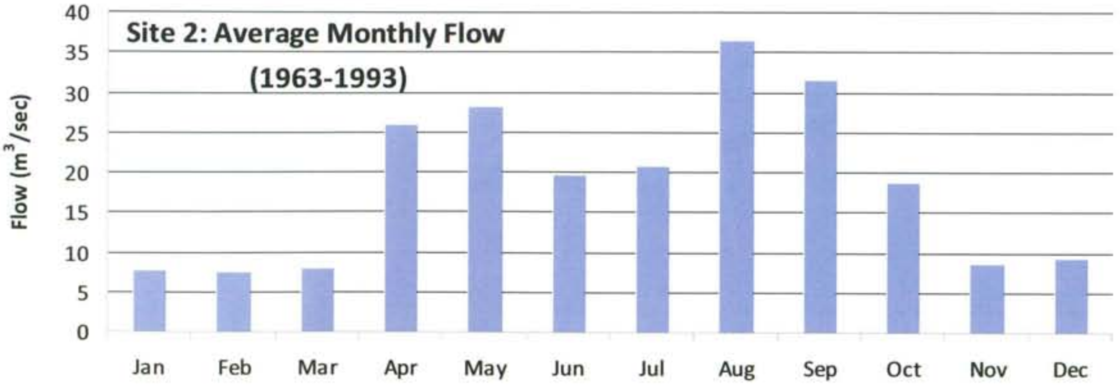


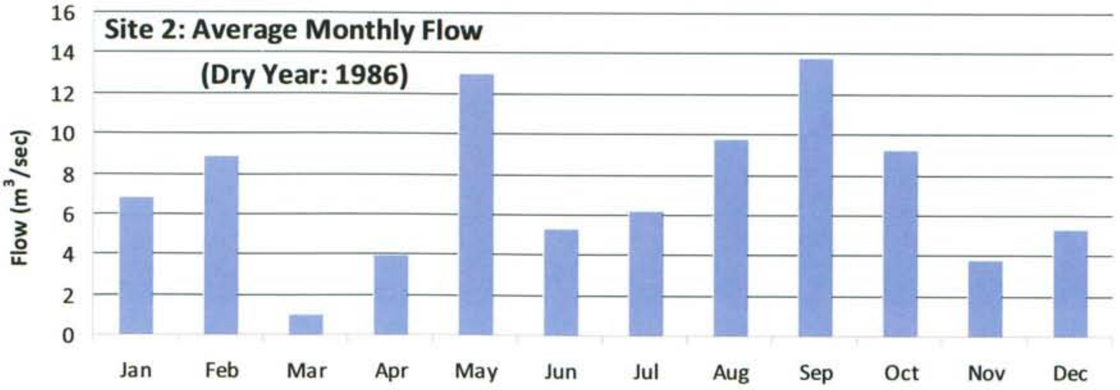

Site 1: Monthly Flow Duration Curve
(1955-1995)
Flow (m³/sec)
100
10
1
0.1
0.01
0.001
0
20
40
60
80
100
120
Percent of Time Equaled or Exceeded

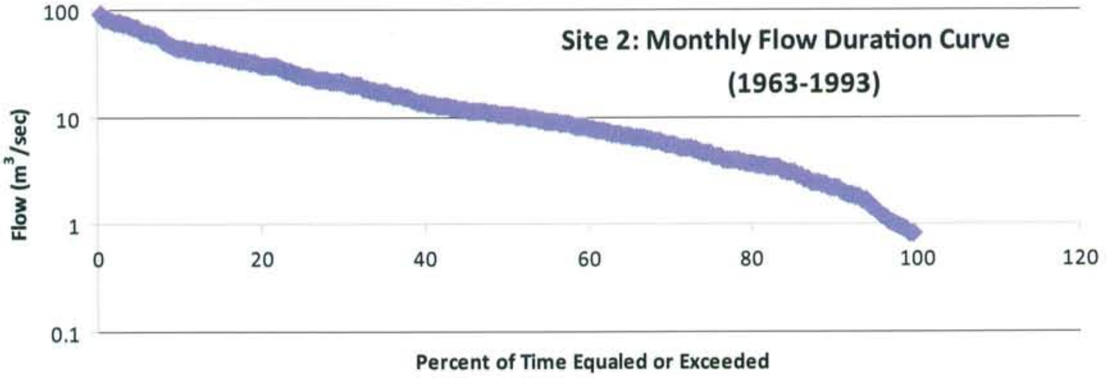

Site 1: Monthly Low Flow Recurrence
(1955-1995)
Flow (m³/sec)
100
10
1
0.1
0.01
0.001
0
5
10
15
20
25
Recurrence Interval (Years)


Site 1: Monthly Flood Frequency
(1955-1995)
Flow (m³/sec)
1000
100
10
1
0.1
0.01
0
5
10
15
20
25
Recurrence Interval (Years)

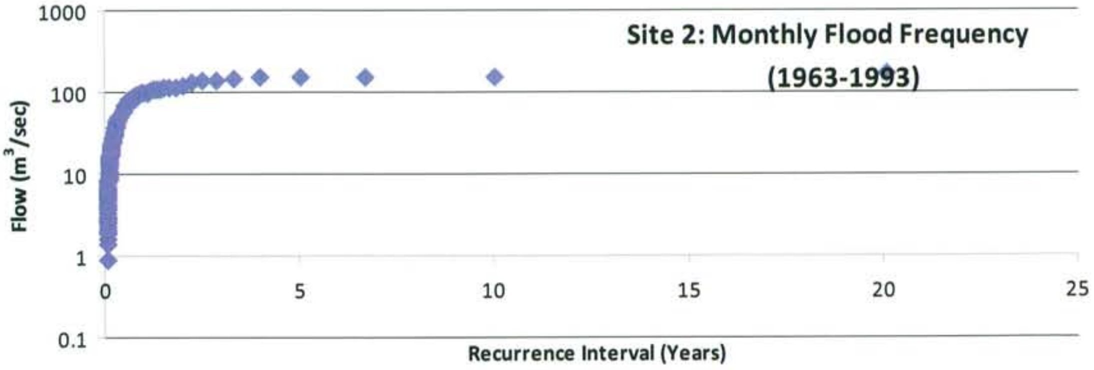
Annex 4: Historical Flow Relationships for EFA Site 2



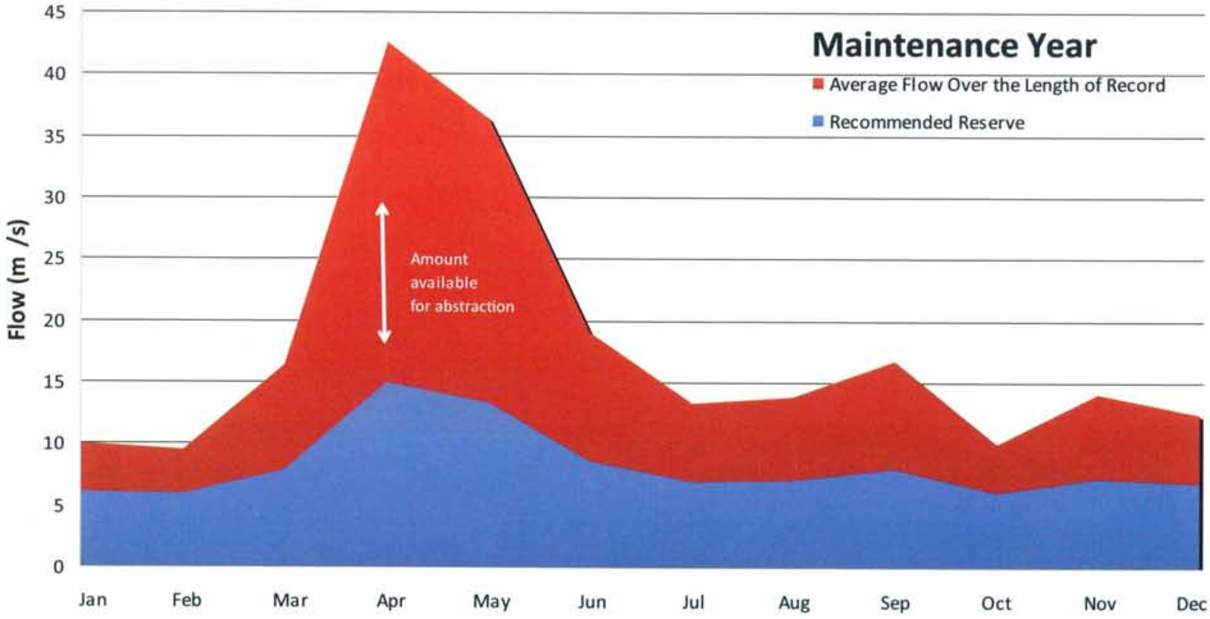


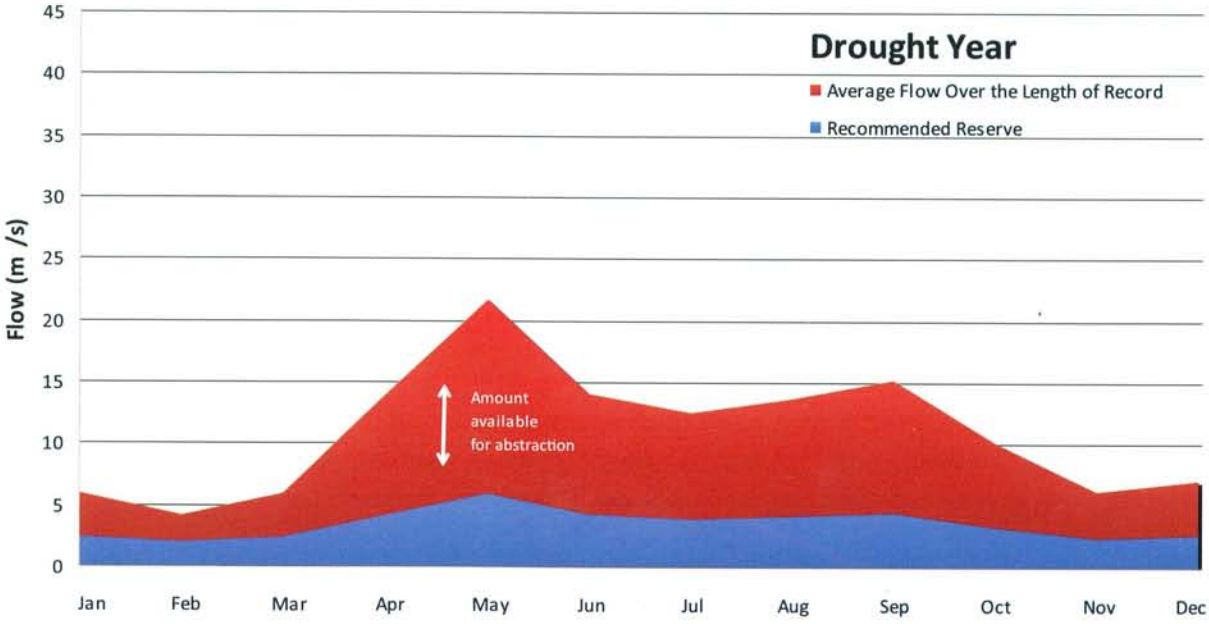

Site 2: Monthly Flow Duration Curve
(1963-1993)
Flow (m³/sec)
100
10
1
0.1
0
20
40
60
80
100
120
Percent of Time Equaled or Exceeded

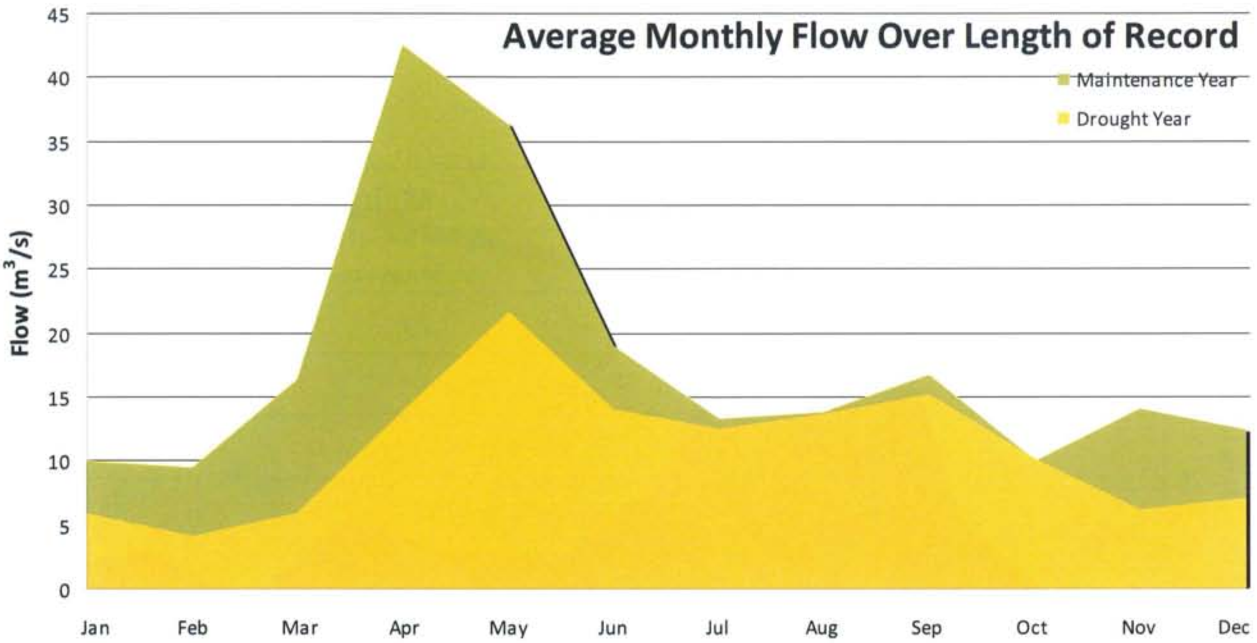

Site 2: Monthly Low Flow Recurrence
(1963-1993)
Flow (m³/sec)
100
10
1
0.1
0
5
10
15
20
25
Recurrence Interval (Years)

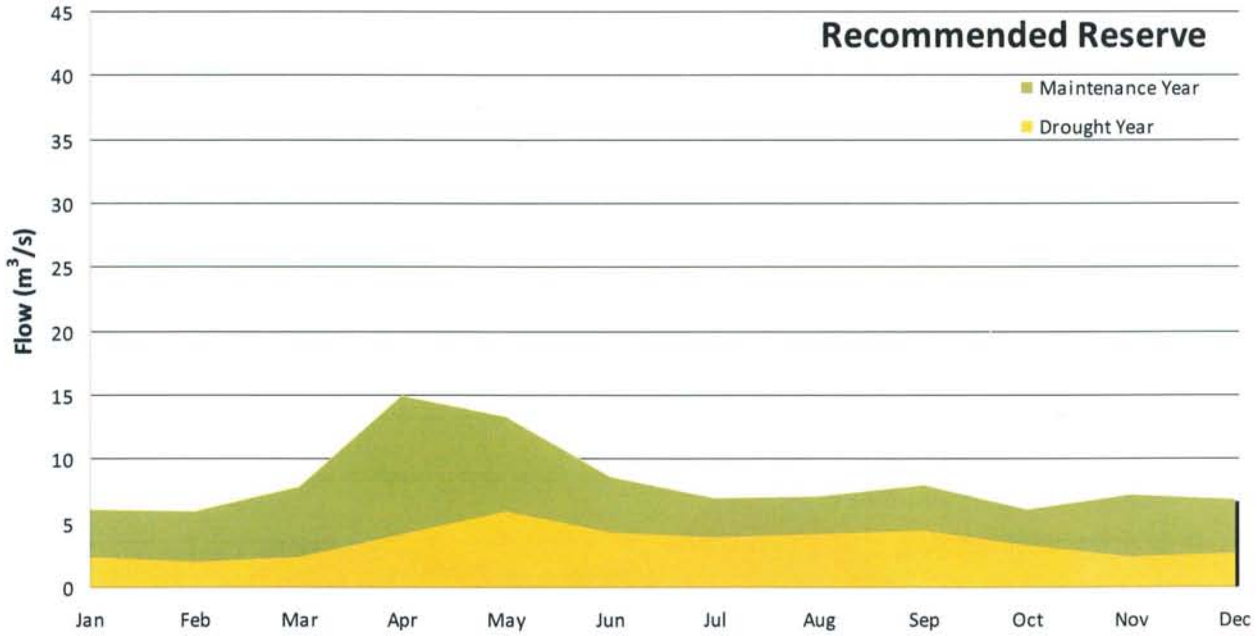

Site 2: Monthly Flood Frequency
(1963-1993)
Flow (m³/sec)
1000
100
10
1
0.1
0
5
10
15
20
25
Recurrence Interval (Years)

Annex 5: Additional Graphic Representations for EFA Site 3






Average Monthly Flow Over Length of Record
Maintenance Year
Drought Year
Flow (m³/s)
45
40
35
30
25
20
15
10
5
0
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec


Recommended Reserve
Maintenance Year
Drought Year
Flow (m³/s)
45
40
35
30
25
20
15
10
5
0
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec