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Government of the Republic of Malawi

Ministry of Water Development and Irrigation
National Water Development Programme

Independent Environmental Impact Assessment for the Upgraded Kamuzu Barrage

Final Environmental and Social Impact Assessment
Volume 2: Technical Reports

December 2013

SMEC

Celebrating 40 years 1970 - 2010

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Abbreviations

CITES	Convention on International Trade in Endangered Species of Wild Fauna and Flora
EIA	Environmental Impact Assessment
ESCOM	Electricity Supply Corporation of Malawi (Ltd)
FAO	Food and Agriculture Organization (of the United Nations)
HEP	Hydro Electric Power
IUCN	International Union for Conservation of Nature
km	kilometre
m	metres
masl	metres above sea level
NEP	National Environmental Policy
RAMSAR	The Convention on Wetlands of International Importance
TL	Total Length

Executive Summary

The Kamuzu Barrage at Liwonde across the Shire River in southern Malawi which was commissioned in 1965 is said to have outlived its design life span. The Government of Malawi is therefore planning to upgrade the Barrage to a modern structure. The upgrading includes raising the Maximum Highest Regulating Water Level of the Barrage up to 40 cm corresponding to a Malawi Lake level of 475.72 masl. In anticipation of a likelihood that this may cause environmental and social impacts in the Shire River and Lakes Malawi and Malombe and the communities that directly or indirectly obtain sustenance from the River and Lakes, an environmental impact assessment (EIA) was undertaken. The objectives of the EIA were; to identify environmentally sensitive aquatic areas/habitats which may be impacted by the proposed project; identify any locally, nationally and/or regionally rare and/or endangered species of fish that might be impacted by the proposed project; and finally to assist in the identification of potential environmental impacts and suggest mitigation measures including any potential risks to Lake Malawi's aquatic biodiversity.

The study established that the Liwonde National Park is an important refuge and breeding area for fish in the Shire River and Lake Malombe while the surrounding areas of Middle Shire River and Lake Malombe are subjected to intensive and uncontrolled fishing. After breeding, fish migrate to these areas where they are caught by fishers. The Kamuzu Barrage which is located downstream of Liwonde National Park, therefore, does not interfere with any fish migrations in the Shire River between the Park and Lake Malombe. The proposed upgraded Kamuzu Barrage thus poses essentially the same type of physical barrier to fish movements as the existing one; hence no change from the status quo. Also, downstream migration of fish will still occur as the gates are often fully open under low flow and high flow conditions. Upstream migration may also be possible during these times since by their nature, fish prefer to swim against the water current. One important way of aiding upstream migration of the fish along the Barrage is the construction of ‘fish passes’. However, heavy and uncontrolled fishing currently prevailing at the Barrage defeats the whole idea as fish would be subjected to easy and massive exploitation by fishers. It is suggested that sound management of the fisheries resource in the Park especially preventing fishing, would help maintain the fish stock in the Shire River and probably Lake Malombe.

Based on a careful analysis of the impacts and their proposed mitigation measures, this report concludes that the project of refurbishing the Kamuzu Barrage on the Shire River does not pose significant threats to the fisheries, fish resources and the aquatic habitat of the Shire River.

1 Background

The Kamuzu Barrage (also referred to as Liwonde Barrage), built across the Shire River (Figure 1), at Liwonde, was commissioned in 1965. The Barrage serves as a water regulation device for the generation of electricity about 80 kilometres down the river Shire at Nkula Falls Hydro Electric Power Station. Other water users to benefit from the operation of the Barrage include downstream irrigators, the Sugar Corporation of Malawi (SUCOMA) Plantation and town water supplies such as Blantyre city. At present, the Barrage is no longer fully operational and requires extensive maintenance.

Figure 1. Kamuzu Barrage (Photo: F. Kapute)

The government of Malawi through funding from the World Bank is therefore planning to refurbish/upgrade this Barrage to a modern structure. The upgraded Barrage includes raising the highest regulated water level by up to 40 cm to 475.72 masl. This calls for an extensive and detailed environmental impact assessment (EIA) as the change in water levels upstream and change in regulated flow downstream will result in some negative and positive outcomes whether environmental, socio-economic etc.

1.1 EIA Objectives

The purpose for this study was therefore to conduct a detailed environmental impact assessment on what could be the likely impacts of the changed water levels upstream of the Barrage and the changed flow regime downstream on aquatic habitat, fisheries and fish resources and consequently how this would eventually affect the socio-economics of the people especially those around the Shire River ecosystem who rely on fishing for their livelihood.

2 Methodology

2.1 Scope of the Fisheries Study

The scope of the Fisheries Study is as follows:

1) To identify environmentally sensitive aquatic areas/habitats which may be impacted by the proposed project;
2) To identify any locally, nationally and/or regionally rare and/or endangered species of fish that might potentially be impacted by the proposed project;
3) To assist in the identification of potential environmental impacts and mitigation measures including any potential risks to Lake Malawi's aquatic biodiversity, such as the numerous endemic fish species that live only within the shallow waters of the lake.

2.2 Area of Study

The area under study stretches from Area A (Figure 2) of the south east arm of Lake Malawi where the Shire River starts to Nkula Falls and further downstream to the lower Shire valley.

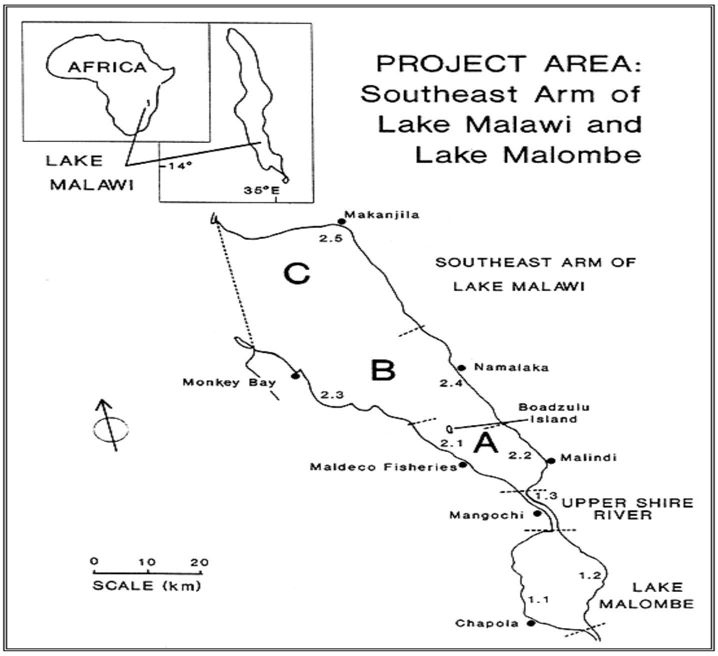


Figure 2. Map of the south east Arm of Lake Malawi and Lake Malombe

The justification is that according to the biophysical environment of the Shire River, there is no upstream migration of fish from the Lower Shire beyond the falls and rapids which start at Nkula. As such, the Upper and Middle Shire including Lake Malombe appear to be the major focus as far as changes in water levels in the Shire River are concerned.

2.3 EIA Approach

The study was under taken in two phases including a desk study and field surveys. The desk study provided the basis for the design of field studies as well as reference for validating findings at local, national and regional level.

2.3.1 Desk Study

The desk study was conducted by reviewing literature which includes Government Frame Survey Reports, academic research and publications as well as surfing the web for relevant comparative studies and reference material. Documentation pertaining to the construction and review of impacts of the existing Barrage at Liwonde were also reviewed.

2.3.2 Field Surveys

2.3.2.1 Collection of Fish Samples

The focus of this work concentrated on the section of the Shire River from its mouth at the south east arm of Lake Malawi to Nkula Falls where the river flows into a series of rapids then into a wide valley (Lower Shire). The justification here is that as far as fisheries resources are concerned, changes in water levels as a result of the upgraded Barrage at Liwonde would only affect (if any at all) fish and fishing activities up to the escarpments (falls) at Nkula. Beyond Nkula Falls (which is the first fall in a series from the mouth of the Shire River), no migration of fish is possible from the Lower Shire upstream due to the rapids and the high and rocky waterfalls.

Samples of fish were collected from randomly selected areas in the Shire River in early October 2011. Samples were collected from the south east arm of Lake Malawi at Namiasi from fishers using beach seine (Figure 3) to catch the fish.

Figure 3. Fishers operate the beach seine at Namiasi (Area A of south east arm of Lake Malawi, Photo: F. Kapute)

From the south east arm of Lake Malawi, the next lot of fish samples was collected from the Upper Shire River section between the mouth of the Shire River (Figure 4) and Bakili Muluzi Bridge at Mangochi Boma (Figure 5).

Figure 4. Mouth of the Shire River from the south east arm of Lake Malawi near Mpondasi in Mangochi (Photo: F. Kapute)

Samples from Lake Malombe were purchased from fishers at Mpinganjira (a fish selling point near one of the beaches of Upper Lake Malombe). One problem faced during collection of fish samples from Lake Malombe was that the lake is closed to fishing in October every year by the Malawi Department of Fisheries to allow the fish to breed. Normal fishing is therefore suspended during this time. However, we realized through well planned sporadic interviews with the fish sellers and buyers that the fish that we purchased at this market were actually illegally caught from Lake Malombe despite the closed season. This highlighted the difficulties faced by the Malawi Department of Fisheries in enforcing fisheries regulations.

Figure 5. Bakili Muluzi Bridge (first and new bridge on the Shire River from mouth) – RIGHT: part of the old bridge (Photo: F. Kapute)

Collecting fish samples from the section of the Shire River between Lake Malombe and Kamuzu Barrage was very difficult also because this stretch of the river forms part of the Liwonde National Park which is a protected/restricted area from fishing. During our preliminary visit to Liwonde National Park prior to the inception of this work, we had firsthand experience of illegal fishing activity continuing in the Shire River section of the National Park (Figure 6).

However, as was the case with Lake Malombe, we managed to buy fish samples at Kamuzu Barrage which after detailed scrutiny, revealed that most of the fish that is sold at the Barrage is predominantly the Shire strain of the tilapia (*Oreochromis shiranus*) and is actually poached from the National Park. It is clear therefore that the Park acts as a reservoir of fish stock which upon migration is caught by fishers in the peripherals of the Park and sometimes even within the Park. At the Kamuzu Barrage (Figure 1), fish samples were sourced from fishers using scoop nets and cast nets (Figures 7 and 8 respectively).

Figure 6. Illegal fishing (fishers in a dugout canoe shown by arrow) in the protected area of the Shire River at Mvera (Photo: F. Kapute)

Fishers here usually use the scoop (Figure 7) and cast nets (Figure 8) to catch riverine fish species moving downstream with the strong water currents at the Barrage when the doors have been opened to allow water downstream to Nkula Falls Hydro Electricity Power Station. Fishing using scoop nets is thus only active when the Barrage gates are opened.

Figure 7. Scoop nets are one of the most dynamic and active gears heavily used at Kamuzu Barrage when the gates are open (Photo: F. Kapute)

No active fishing is documented for the section of the Shire River between Kamuzu Barrage and Nkula Falls Hydro Electricity Power Station as evidenced by the Malawi Department of Fisheries which did not have fisheries data available for the area.

Figure 8. Cast nets are also used to catch fish in the Shire River around Kamuzu Barrage (Photo: F. Kapute).

The Shire River in this area meanders (Figure 9) through a remote area where fishing is highly uncoordinated and fish catch data is not documented (personal communication, Malawi Department of Fisheries).

Figure 9. The narrow and meandering Middle Shire River near Nkula Falls (Photo: F. Kapute)

We managed to collect fish samples at Nkula Falls Electricity Supply Corporation of Malawi (ESCOM) dam (water intake, Figure 10) where water from the Shire River is kept before being channelled into a tunnel to the hydro electricity generation power houses. The commonly used gear here was hand lining and sometimes use of fish traps.

Figure 10. ESCOM intake at Nkula Falls – end point of the Shire River before rapids (Photo: F. Kapute)

Thus, in summary, fish samples were collected from Area A of the south east arm of Lake Malawi, the Upper Shire (between the mouth and Lake Malombe), Lake Malombe, section of the Shire River in the Liwonde National Park, Kamuzu Barrage and finally at Nkula Falls where the terrain of the river drops into rapids before going into the Lower Shire. Fish catches were collected/purchased fresh sometimes live from fishermen using a variety of fishing gears ranging from beach seines, gill nets, scoop nets, hand lines, cast nets and mosquito nets.

2.3.2.2 Identification of Fish Species and Data Collection

The catch from all fishing gears sampled was divided where necessary into three categories, small fish, catfishes and all big cichlid and non-cichlid fishes. Fish in each category were sorted and identified to species level. Standard length (mm) and whole weight was recorded (g) using a calibrated measuring board and a battery operated electronic weighing scale respectively. Length frequencies and catch data were raised to the total catch where sub-sampling was done. The type of fishing gear and areas where fish were caught were also documented.

2.3.2.3 Determination of Environmentally Sensitive Hot Spots and Endangered Fish Species in the Shire River System

During the field survey, environmentally vulnerable hot spots/areas were examined i.e. the aquatic habitat of the Shire River and species of fish likely to be impacted by the project. This was done by referring to literature and soliciting views from fishers and other stakeholders about past and current trends in fish catches and species composition as well as issues of environmental degradation.

2.3.2.4 Statistical Data Analysis

The data were entered into computer Microsoft Excel spreadsheet for analysis. The data were analysed for species composition (diversity), gear selectivity, size distribution by species, weight by species and total length by gear by way of plotting length frequency histograms.

Size-specific selectivity of Mosquito nets and Kambuzi beach seine fishing gear was modelled using the logistic model (Butterworth et al. 1989; Booth and Punt 1998) described as:

$$P = \left(1 + \exp^{-(L - L_{50/\delta})}\right)^{-1}$$

where P is the selectivity of the gear on a fish of size L, L_{50} is the size-at-50%-selectivity or the mean length at which 50% of fish are retained in the net (mean length at first capture), and δ is a parameter related to the size range over which the selectivity changes from values near 0 to values near 1. As δ tends to zero, this function approaches knife-edged selection (Butterworth *et al.* 1989).

The size-specific selectivity of Scoop nets and Hand line fishing gears was modelled using the Gamma distribution function to compensate for the skewed distribution of fish catch data from the two fishing gears. The gamma probability density function (Malcom, 2001) is described as:

$$f(x;\alpha,\beta) = \frac{1}{\beta^{\alpha}\Gamma(\alpha)} x^{\alpha-1} e^{-\frac{x}{\beta}}$$

x is the value at which the distribution is evaluated, α is a parameter to the distribution and β is a parameter to the distribution.

3 Major Findings

3.1 The Shire River Biophysical Environment

The Shire River, the only outlet of Lake Malawi located at 35° 15' E and 14° 25' S is the largest and longest river in Malawi (Tweddle *et al*. 1979; FAO, 1993; Ribbink, 2001). It stretches over a distance of about 410 km from its mouth at the south east arm of Lake Malawi near Mangochi to the Zambezi River (35° 20' E and 17° 50' S) (Osborne, 2000).

The flow of water in the Shire River is directly affected by the highly variable flow rate in Lake Malawi (the source) creating fears that during low flow extremes, there may be a no-flow scenario in the Shire River or, that extreme high flows result in floods that could cause damage to agricultural lands, infrastructure and loss of life (World Bank, 2007). It is reported that the River outflow from Lake Malawi was once cut off because of a low Lake level between 1908 and 1935 (Parry *et al*., 2009).

It is also reported that a Lake water level of 477.2 masl in the early 1980s triggered flooding around the shoreline of the River (Parry *et al*., 2009).

The Lake Malawi - Shire River hydrological system is probably Malawi's single most important natural resource system which supports tremendous livelihoods as well as supporting important environmental functions. The River supplies over 96% of the country's power generating capacity. It is also a source of water to the major urban centres of the southern region of Malawi such as Blantyre and Limbe and the rural water users along the length of the River. Many irrigation projects have also flourished along the River (World Bank, 2007).

The Shire River is demarcated into three sections based on the geographical areas through which it flows from Lake Malawi to the confluence at Zambezi River in Mozambique, namely; the Upper, Middle and Lower Shire sections.

3.2 The Upper Shire River

The Upper Shire (Figure 11) is the stretch of about 130 km between its outlet at the south-east arm of Lake Malawi (Samama) to Matope with a total bed drop of 15 m including a 1.5 m drop from Mangochi to Liwonde (Osborne 2000). Other earlier literature (Pike, 1972) indicates the distance as from Lake Malawi mouth to Lake Malombe. The latter description appears to be realistically based on the physiography that this is a relatively flat area but also with nearly similar characteristics such as shoreline vegetation etc.

Figure 11. The mouth of the Shire River (far back) from the south east arm of Lake Malawi (Photo taken from Muluzi Bridge at Mangochi by F. Kapute)

In this area, the River flows across a submerged sand bar about 4 km to the north of Mangochi town at an altitude of 468 m above sea level (Chimatiro, 2004) resulting in the mouth of the River from Lake Malawi being low and thus has been an issue of concern about reduced water levels in the Shire River during times of low water levels in Lake Malawi.

Notably important aquatic habitats/structures within this stretch of the river are the Liwonde National Park and the Kamuzu Barrage. The Liwonde National Park is home to many riverine fish species e.g. Cyprinids such as *Opsaridium microlepis* (Mpasa) including the Shire Tilapia – *Oreochromis shiranus* and a diversity of aquatic life (Figure 12). The park has diverse vegetation ranging from the swamps, lagoons and reed-beds along the river edge, grassland in the drained areas where palm, baobab and many trees grow (www.2011africaguide.com). From Lake Malombe mouth to Kamuzu Barrage, the river stretches over a distance of about 30 km (Pike, 1972).

The Barrage at Liwonde (Figure 1) is a concrete structure, 156 m long with 14 radial steel gates and a 6.6 m carriage way providing a bridge across the River (Liabunya, 2007). It was constructed as part of the hydroelectric scheme and was commissioned in 1965 to regulate the flow of the Shire River so that water entry into the Hydro Electric Plant at Nkula Falls is equally controlled (Liabunya, 2007; Chapalapata, 2007).

Figure 12. Hippopotamus in the Shire River at Liwonde National Park

When there isn't enough water at the power station, the gates at the Barrage at Liwonde are opened and vice versa when too much water is not required at the power station. The Barrage also helps to prevent weeds from finding their way into the power stations downstream.

3.3 Lake Malombe

Approximately 15 km downstream of Lake Malawi, the River enters into Lake Malombe (Figure 13), a shallow lake (30 km by 15 km) with an area of about 450 km^2 and depth range of 5 to 7 m located at 14°40'0" S 35°15'0" E (Bell 1998). Lake Malombe is perceived to be an ox-bow lake formed due to the swelling of the Shire River. The lake therefore has similar characteristics to those of the southern part of Lake Malawi's aquatic ecology and also a high level of fish biodiversity and genetic variation. The lake is shallow, turbid and nutrient-rich, with vegetated beaches/shores. The marshy and muddy beaches or shoreline of Lake Malombe make it lack the appeal and tourism potential compared to Lake Malawi.

Lake Malombe is a polymictic lake in nature, that is, it experiences continuous and complete mixing due to its shallowness where nutrients are well recycled resulting in the productive zone extending to the bottom. It is reported that rainfall runoff contributes significantly to the productivity of the Lake (Welcomme 1985). However, despite its richness, Lake Malombe contributes about 1.2% of total fish landings in Malawi (FAO 2005).

Figure 13. Lake Malombe has a marshy and muddy shoreline (Photo: F. Kapute)

It is believed that after being dry for many years in the early 1900s, Lake Malombe refilled around the 1930s suggesting that the Lake Malombe population of fish is a relatively recent peripheral isolate (Anseeuw, 2011). Furthermore, migration of fish between the Upper Shire River and the south-east arm of Lake Malawi has also been reported (FAO, 1993).

3.4 Middle Shire River

The Middle Shire covers a distance of about 80 km starting from Matope to Chikhwawa (Osborne, 2000). Other works (Tweddle & Willoughby, 1979) refer to the Middle Shire as being from Lake Malombe to Kapichila Falls. This is the same stretch which Pike (1972) describes as the 'third section' of the Middle Shire River. The middle Shire is characterised by numerous falls and rapids and has total fall of 370 m (Osborne 2000; Tweddle & Willoughby, 1979) thus creating the potential for hydro-electric power production. The Kapichila Falls in Chikhwawa district and the Middle Shire rapids are physical and ecological barriers to the upstream migration of the Lower Zambezi fauna (Tweddle & Willoughby, 1979). Thus, fish cannot migrate from the Lower Shire to the Middle Shire because of the gorges and waterfalls. That is why species from the Lower Shire such as *Oreochromis mossambicus* are endemic to the Lower Shire and the Zambezi River.

Whilst the Upper Shire is relatively shallow and flow is slow, the water gradually increases from the middle to the Lower Shire with an annual flow of 405m^3/s at Matope (Osborne 2000).

3.5 The Lower Shire River

The Lower Shire (Figure 14) starts from the Kapichira Falls (Chikhwawa) to the end of Ndindi Marsh on the border with Mozambique (34°50'-35°17'S). It is one of the seventeen major floodplains in Africa, covering an area of more than 820 km^2 of marshes at peak floods. The marshy area of the Lower Shire valley covers an area of about 650 km^2 (Chimatiro 2004).

Figure 14. An aerial view of the vast Lower Shire River (www.game-reserve.com)

The Lower Shire River sustains an important river-floodplain fishery (where fish production is highly dependent on the quantity and quality of annual flooding regime) contributing about 11% of total fish landings in the country (Donda and Njaya 1997). The fishery in the Lower Shire which is mainly subsistence in nature with small-scale commercial operations provides livelihoods for about 4,000 people as gear owners or fishing crew members (Fisheries Department, 2003).

The fisheries in the Lower Shire like in Lake Malawi are multi-species and multi-gear and dominant fish species in the catches include *Mphende (Oreochromis* species predominantly *Oreochromis mossambicus*) representing more than 50% of the catch and Mlamba (*Clarias* spp.) contributing about 40% of the total catch).

The Lower Shire valley is categorised into three ecosystems namely; flood plain and swamp, lagoon and riverine areas. Vegetation in the Lower Shire valley is subject to tremendous seasonal variation due to i) the local rains which occur between December and April, ii) the Barrage at Liwonde which regulates the flow of the Shire River (Liabunya 2007; Chapalapata, 2007). Marshes are usually dry between August and November, and fill during December (Chimatiro, 2004). Water hyacinth (*Eichhornia crassipes*, Figure 15) is a weed causing considerable problems in the Shire River.

Figure 15. Water hyacinth plants in the Shire River (Photo: F. Kapute)

Water hyacinth and other aquatic weeds continue to cause serious problems to power generation at Nkula Hydro Electric Power Station (the first HEP Station downstream of Kamuzu Barrage) by blocking the screens at the inlet to the turbines (Mzuza, 2010; Liabunya, 2007; Chapalapata, 2007).

3.6 Fish Species Composition in the Shire River

Although the Upper Shire experiences heavy fishing, it appears that the fish catch data is scanty (Fisheries Department, personal observation) probably due to poor recording of fish catches and unregulated fishing. According to the FAO, the Upper Shire River contributes about 1% to total fish landings in the country (FAO, 2005).

A section of the River that passes through Liwonde National Park is a protected area hence closed to fishing. This contributes at least as much to the overall fish catch but also conserving many fish species whose populations are severely reduced in other areas (Figure 16).

Figure 16. Fish species in the Shire River (Photo taken at Kamuzu Barrage by F. Kapute)

In fact, it appears that most of the fish that are caught around the Kamuzu Barrage by fishers using scoop nets (Figure 7), cast nets (Figure 8) and bamboo woven fish traps (Figure 17) probably originate from the Park suggesting that the Park acts as a breeding area for the fish.

Figure 17. Fish traps, cast nets and scoop nets are heavily employed by fishers to catch fish in the Shire River (Photo: F. Kapute)

The species composition for Lake Malombe like the entire Upper Shire and the south-east arm of Lake Malawi is diverse i.e. multi-species (Figures 16 and 18).

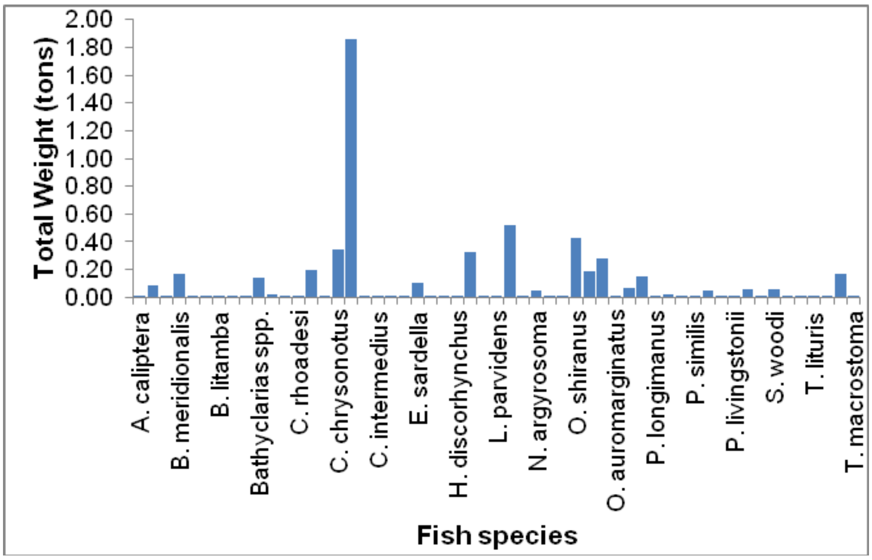


Figure 18. Lake Malombe fish catch composition (Source: Malawi Department of Fisheries)

Most of the species in the Upper Shire are also found in the south east arm of Lake Malawi and Lake Malombe probably due to migration. Though Lake Malombe supports a highly productive fishery because of its high primary productivity, uncontrolled fishing has overexploited the fish stock and what remains are small cichlids locally known as kambuzi (Weyl *et al*., 2004a & b; Banda et al., 2005; Kapute *et al*., 2008). The tilapia (Chambo) fishery which used to be vibrant in the lake has almost collapsed (Weyl et al., 2004a & b). Figure 18 shows that *Copadichromis chrysonotus* species (Utaka) also dominate the kambuzi (small cichlids) catch (Turner, 1995). *Oreochromis shiranus* (Shire River Tilapia) appears to be the most commercially abundant species which is usually sold around the Barrage either fresh or in smaller quantities processed (smoked) (personal observation).

In the Lower Shire, the fish fauna is essentially of Zambezi River Basin origin as more than 60 species are caught in this fishery, but only three namely, Mlamba (*Clarias gariepinus*), Chikano (*Clarias ngamensis*) and Mphende (*Oreochromis mossambicus*) are of commercial importance (Willoughby and Tweddle 1978). These three contribute 90% to the total fish catch. In general, the Shire River has a multi-species fishery especially the Upper and Lower Shire sections.

3.7 Breeding Seasonality and Migration of Fish in the Shire River

The riverine species usually breed during the rainy season and also when the river is flooding. The diverse ecosystems of the Shire River ranging from falls, rapids and swamps to floodplains may contributed to the varied breeding pattern of fish in the River. This is due to the fact that spawning periodicity in fish is to a greater extent influenced by abiotic factors such as hydrological regime of the river, climatic seasonality and habitat characteristics (Welcomme, 1995). For example, most of the life cycle of the fish in the Lower Shire Valley is subject to the seasonal drying of the marshes while breeding occurs during high water when feeding is also at its peak (Willoughby and Tweddle, 1978).

In the Upper Shire River, fish seasonally migrate to and from the south-east arm of Lake Malawi via the Shire River to Lake Malombe (FAO 2003). Juveniles are found in the river from May to July moving towards Lake Malombe (Seisay, 1992). This suggests why management of fish in one system leaving the other as is the case for areas around the protected Liwonde National Park is counter-productive.

In the Lower Shire, the general observation is that most of the fish species breed intensively during the rainy season although some species breed throughout the year.

3.8 State of Fish Stocks and Fisheries Management in the Shire River

Catches have tremendously declined in all natural water bodies in Malawi including the Shire River due to uncontrolled fishing effort (FAO, 1993). Many attempts to manage the fishery by the government through the Department of Fisheries such as co-management have failed resulting in exploitation of the fish resources outside management restrictions.

In Lake Malombe and the Upper Shire River the fish stocks are exploited only by the artisanal sector which employs gillnets, chambo seines, kambuzi seines and nkacha nets. In Lake Malawi, in addition to the artisanal sector, the stocks of the south-east arm are exploited by the semi-industrial and the industrial fisheries. It is reported that total annual catches from the Upper Shire River have declined from more than 1,200 tons in the early 1980s to the recent levels of around 500 tons (FAO, 1993).

In the Lower Shire, the species diversity is much less than that of the middle Shire, Lake Malombe and the Upper Shire River. Dominant and commercially exploited species by fishers which makes up about 60% of the catch (Donda and Njaya, 1997) include Mphende (*Tilapia* species), Mlamba (*Clarias* species) and Chikano (Table 1).

Fisheries in the Lower Shire are managed through five areas namely: Elephant Marsh (518 km^2), Ndinde Marsh (155 km^2), Lagoons around Chikhwawa (3.9 km^2), Bangula Lagoon (18 km^2) and Shire River (337 km^2) (Ratcliffe, 1971).

The Lower Shire and associated marshes support a Lower Zambezi fish fauna, separated physically and ecologically from the Lake Malawi fauna by a series of cataracts, rapids and falls between Matope and Chikhwawa. Current catch results for catches from the Lower Shire suggest that the fishery in the Lower Shire is picking up compared to other sections of the River.

TABLE 1. FISH CATCH COMPOSITION BY WEIGHT FOR THE LOWER SHIRE FROM 2000 TO 2010

Year	Species				Year total
	Mphende	Others	Mlamba	Chikano	
2000	1,589.31	323.43	1,433.30	148.52	3,494.55
2001	1,217.25	94.11	794.71	34.80	2,140.86
2002	1,433.40	74.51	615.25	50.31	2,173.4
2003	1,040.94	89.14	854.61	39.31	2,024.00
2004	1,329.82	197.55	665.67	99.23	2,292.27
2005	1,781.09	211.69	831.67	138.29	2,962.74
2006	2,276.09	524.88	1,286.29	307.53	4,394.78
2007	2,507.63	146.27	771.04	135.92	3,560.86
2008	5,003.15	87.42	850.69	133.02	6,074.28
2009	1,825.57	57.48	843.69	60.95	2,787.69
2010	2,627.45	146.15	1,057.22	234.62	4,065.44
Total	22,631.69	1,952.63	10,004.13	1,382.50	35,970.94

Source: Malawi Department of Fisheries; Weight in tons

Previously, the Lower Shire Valley used to contribute between 10 and 15% of the total national landings (Malawi Department of Fisheries 1989; Bulirani *et al*., 1999) and catches fluctuate (Figure 19). The system is highly productive and efficiently utilized by fishermen suggesting why catches have increased recently.

The fishery is small scale and subsistence in nature. It is pursued almost exclusively using dugout canoes from numerous permanent and temporary traditional fishing villages. The main fishing methods in the Lower Shire include seine nets, gill nets, fish traps, scoop nets, cast nets and encircling fish fence and dug-out canoes and plank boats without engines are the main fishing crafts employed. Gill nets are however, the commonest fishing gear used.

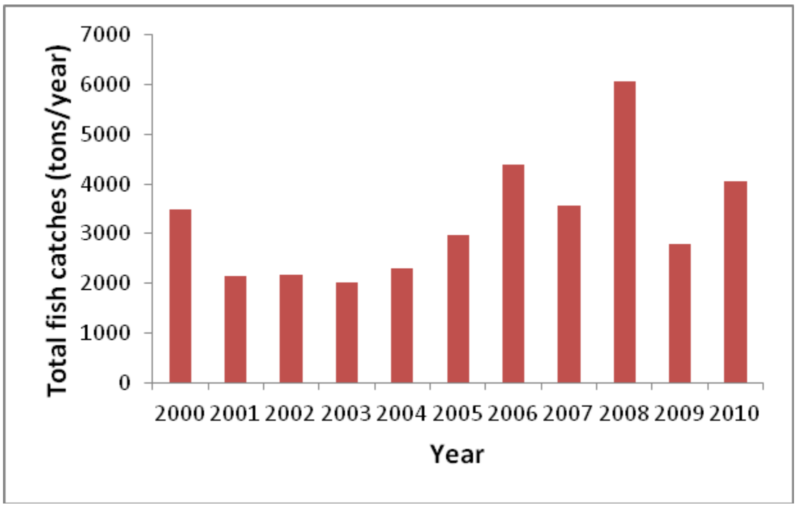


Figure 19. Lower Shire catch statistics from 2000 – 2010 (Source: Malawi Department of Fisheries)

It is reported (Chimatiro, 2004) that seasonal fluctuation of fish catches are due to the flooding pattern which seems to be influenced in part by the operations of the Kamuzu Barrage. Water Hyacinth is another current major problem in the area adversely affecting the fishery.

The challenge in managing fishery resources in Malawi is that the artisanal fishery which includes the Shire River is "open-access" in character. Due to poor enforcement by the Malawi Department of Fisheries, many fishers continue to fish without any access restrictions. In fact, as opposed to Lakes Malawi and Malombe, the fishery in the Shire River appears to be unregulated. This could explain why catch data for most parts of the Shire River is not available.

For the Shire River fishery, the only and well protected area is around Liwonde National Park. Evidence shows that fish catches in areas around the Park such as the southern tip of Lake Malombe (near the Park area) are better than the areas far from the park (FAO, 2005).

3.9 Malawi Government Policy on Fisheries

Regarding riverine and floodplain fisheries, the Malawi Government Fisheries Policy (GoM, 2001) aims at sustainable and appropriate utilisation of rivers to facilitate migration and spawning of fish and other aquatic vertebrates and the provision of nursery areas to maintain biodiversity.

The revised National Environmental Policy (NEP) places an emphasis on conservation of biological diversity (www.chmmw.org, 2011) by seeking to manage, conserve and utilise biological diversity (ecosystems, genetic resources and species) for the preservation of national heritage. The NEP is also supported by the Environmental Management Act of Malawi in providing general environmental protection through Sectoral policies (e.g. policies on land, water, fisheries, waste, and forestry) to maintain consistency.

Malawi is a signatory to a number of international conventions supporting the conservation of biodiversity such as the African Convention on the Conservation of Nature and Natural Resources, Convention on Wetlands of International Importance (RAMSAR), Convention on International Trade in Endangered Species of Wild Fauna and Flora (CITES), Convention on the Conservation of Migratory Species on Wild Animals and the Convention on Biological Diversity (www.chmmw.org, 2011).

All fisheries regulations governing the fisheries in Malawi are enshrined in the Fisheries Conservation and Management Regulations (2000). These regulations are formulated to meet the needs of the various functions of fisheries management, such as protection of the breeding stock, the juvenile fish and fishing effort. Broad categorization of these fisheries management regulations are: closed seasons, closed areas, mesh size restrictions, minimum take-able size of fish, fishing net maximum headline length, and fishing licenses.

With these regulations in place, it appears that the challenge to managing fisheries resources in Malawi is the lack of enforcement rather than good policies.

3.10 Environmentally Sensitive Aquatic Areas/Habitats which may be Impacted by the Upgraded Kamuzu Barrage Project

At the time of the field survey, it was notably clear that the water level in Lake Malawi at the south-east arm had receded tremendously as evidenced by wide sandy beaches which are usually inundated during periods of more water in the Lake (Figure 20).

During peak water levels, the vast sandy beach stretches along the Lake are submerged under water creating breeding areas for cichlids. Unfortunately, in the south east arm of Lake Malawi (Mangochi) many of these fish breeding sandy beaches have been cleared for holiday resorts which have flourished in recent years. This suggests that irrespective of whether it is peak or low water level in the Lake, breeding of fish is compromised by the fact that these sandy beaches are frequently used by swimmers, for boat landings and also for beach seine netting.

Figure 20. Receded water levels in Area A of the south-east arm of Lake Malawi (near MALDECO) at Mangochi (Photo: F. Kapute)

The area at the outflow from Lake Malawi is marshy (Figure 4) and relatively shallow due to a sand bar. Common fishing gear in this area are gill nets; the muddy and marshy beaches do not favour operation of beach seines. Fishing in this area is very active especially Chambo (tilapia) fish caught with gill nets.

The river then becomes wide (Figure 21) up to Lake Malombe and beyond to the Kamuzu Barrage. As explained earlier, the Upper Shire is a very active section for fishing activities. Many types of gear are employed ranging from beach seines, gill nets and the recent destructive light fishing using mosquito nets.

Lake Malombe is the most productive lake in Malawi with a marshy shoreline and muddy beaches – an aquatic environment which provides good habitat for fish breeding. However, Lake Malombe is the most heavily fished lake in Malawi and fish catches especially the chambo (tilapia) have declined nearly to extinction (Kapute et al., 2008).

Figure 21. The Upper Shire River at Mangochi (Left = upstream and Right = downstream) on its way to Lake Malombe (Photo: F. Kapute)

The section of the Shire River after Lake Malombe up to a few kilometres from Kamuzu Barrage is a National Park hence a protected area from fishing. The area thus acts as a breeding site for fish which later migrate to other parts of the River and into Lake Malombe.

Near the Barrage at Liwonde, huge moving masses of aquatic vegetation are seen upstream (Figure 22) descending towards the Barrage. These have been a big problem for ESCOM which spends a large effort removing weeds at the Barrage to prevent their movement into the hydro electricity power station at Nkula Falls some 80 km downstream.

The shoreline of the section of the Shire River from Lake Malombe down to Nkula Falls does not have much infrastructure (buildings) or an active agricultural industry so that much of the shoreline has not been disturbed. This suggests that this is a favourable area for fish spawning especially riverine species which are chiefly Cyprinids such as *Opsaridium microlepis* (Mpasa), *Opsaridium microcephalus* (Sanjika), *Labeo cylindricus* (Ntchira) and several Barbus species.

Figure 22. The Shire River at Liwonde – see the existing floating weed barrier across the river (Photo: F. Kapute)

As described earlier (Figure 10), the Shire River between Liwonde and Nkula is relatively narrow with many meanders and a steeper gradient. As opposed to the flat terrain between Lake Malawi and Liwonde, in this area, the topography is hilly hence the steeper gradient.

Liwonde National Park (about 580 km^2) lies on the banks of the Upper Shire River, bordering Lake Malombe to the north and encompassing a large area east of the river. It is the best described of the nine national parks and wildlife reserves in Malawi. The vegetation of the park along the Shire River is diverse ranging from the riverine swamps, lagoons and reed-beds.

During the field study, it became apparent that the National Park is by far the most environmentally important area in relation to the upgrading of the Barrage at Liwonde. The Park as mentioned earlier is home to many fish species and acts as an important breeding area for the fish. Elsewhere in the Shire River System, fish hardly have a chance to breed because of the uncontrolled heavy fishing pressure.

The existing Kamuzu Barrage is capable of regulating upstream water levels in Lake Malawi, Lake Malombe, and the upper Shire River within Liwonde National Park, when they are within the range of 473.5 to 475.3 metres above sea level (masl), as measured at the Lake. At the time of construction of the Barrage this water level increase was considered to be able to minimise the impacts of flooding upstream of the Barrage in the Shire River, Lake Malombe and Lake Malawi while still providing reliable regulated flows for hydropower generation downstream.

A Feasibility Report prepared in 2003 (NORPLAN, 2011; Norconsult and Associates, 2003) considered a 20 cm water level increase with the refurbished Kamuzu Barrage, which would lead to a regulation range of 473.5 to 475.5 masl. Historical records indicate that Lake Malawi levels have varied from a low of 469.94 masl to a high of 477.25 masl (Parry *et al*., 2009) – a maximum difference of 7.31 m well beyond the Barrage's influence. Also, the water level will not be permanently raised by 40 cm to 475.72 masl. As such, the Barrage will result in a slight increase in the duration (length of time) at which the water level will correspond to the 475.72 masl. This level is much lower than the natural fluctuations in Lake levels under which the fish species have evolved. Therefore, impact on fisheries and fish resources in Lake Malawi, and to a lesser extent, Lake Malombe and the Upper Shire River is expected to be limited.

3.11 Endangered Fish Species that are Potentially Impacted by the Proposed Kamuzu Barrage Upgrading

Apart from the Chambo (tilapia) fish stock which have tremendously declined in recent years, *Opsaridium microlepis* (Mpasa or Lake salmon), a cyprinid and a lacustrine fish species, is the most commercially sought after riverine species in Malawi. Mpasa is at the verge of extinction in Malawian natural waters due to multiple factors such as use of bad fishing methods e.g. river/stream blocking when fish are migrating for breeding; degradation of the riverine environment due to catchment destruction e.g. by farming and use of chemicals; siltation and in extreme cases drying of rivers and streams under natural climatic conditions. For these reasons, the fish was included in the IUCN Red List of threatened species in 2006 (IUCN, 2006). Although Mpasa has been fished out in nearly all rivers and streams in Malawi, there appears to be some remnants in Liwonde National Park where it is still found in abundance.

3.12 Fishing

As explained earlier, fishing in the Shire River, with an exception of the Upper and Lower Shire, is highly uncoordinated especially by the fact that some parts of the middle Shire lie within the protected zone of the Liwonde National Park. Thus, although fishing is still carried out in this area, there is no recorded catch data because it is done illegally and consequently fishers usually do not co-operate with fisheries personnel. The other part of the middle Shire up to Nkula Falls is very remote and not active as far as commercial fishing is concerned.

Fishing gear, including: gill nets, long lines, hand lines, mosquito nets, cast nets, scoop nets and fish traps (with or without weirs) are operated in the Shire River System. Dugout canoes and rafts were the common fishing crafts spotted during the current survey.

Fishing gear is generally selective in catching fish but its selectivity varies according to the design and behaviour of susceptible fish species. Two mathematical models, Gamma and Logistic were used to determine selectivity and to estimate size-at-first capture for major types of fishing gear in the Shire River System. The gear assessed included: mosquito net, kambuzi beach sine, scoop net and hand line. The major target fish groups were cichlids which comprised 61% of total landings. Sizes at capture ranged from 75 mm Total Length (TL) to 101 mm TL. Mosquito nets and kambuzi beach seines caught cichlids at smaller sizes at capture of 75 mm and 87.5 mm TL, respectively while hand lines and scoop nets landed cichlids at slightly bigger sizes of 93.4 mm and 101 mm TL, respectively.

3.13 Catch Biomass by Species and Gear

Figures 23 to 26 show species catch biomass according to the fishing gear that was used. As a multi-species fishery, a variety of gear is deliberately employed to catch different species and sizes of fish. Figure 30 shows that a majority of the fish species that are caught in beach seines are usually the small cichlids also known as kambuzi. *Placidochromis*, *Protomelas* and *Pseudotropheus* species are all categorized as kambuzi i.e. small cichlids shown in Figure 23. An exception is *Oropharynx argyrosoma*, which is a relatively small species often classified under the kambuzi fishery, the rest are generally bigger species.

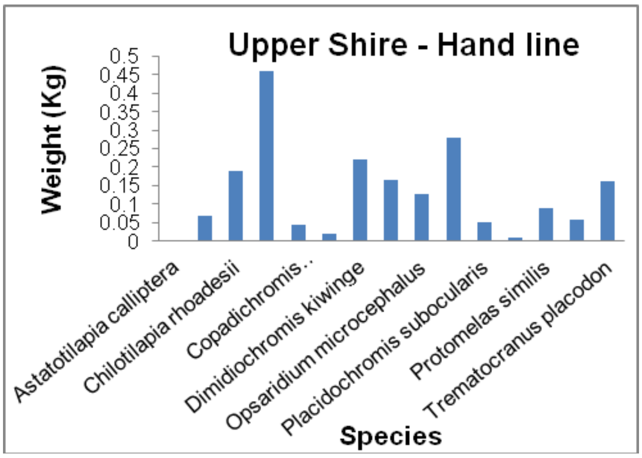
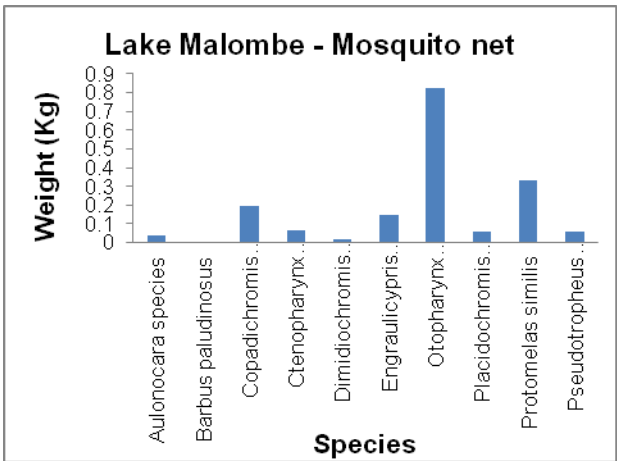


Figure 23. Species catch biomass for the Upper Shire River caught using Hand line and larger cichlids caught using Hand line from the Upper Shire (Photo: F. Kapute)

This agrees with the fact that a hand line is highly selective. Also the small cichlid (kambuzi) fishery is not well pronounced in the Upper Shire in the south east arm of Lake Malawi as is the case in Lake Malombe.

Figure 24 presents a very good parallel attribute of two types of gear – selective (gill net) and non-selective (mosquito net). In the mosquito net, there is a combination of both large and small cichlids while catches in gill nets are large cichlids and other large non-cichlid species such as *Bagrus*, *Mormerids* and *Clarids*.

At the Barrage in Liwonde, scoop nets are extensively and intensively employed to catch different species of fish. Though partly selective, scoop nets usually catch bigger fish that swim with the strong water current when the Barrage gates have been opened.



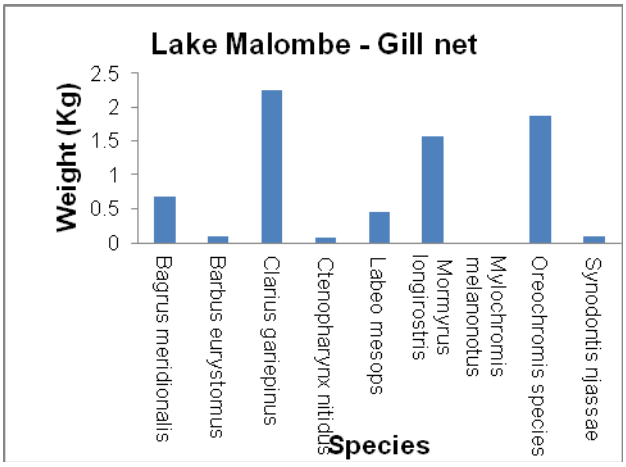


Figure 24. Species catch biomass for the Upper Shire River caught using Hand line and larger cichlids caught using Hand line from the Upper Shire

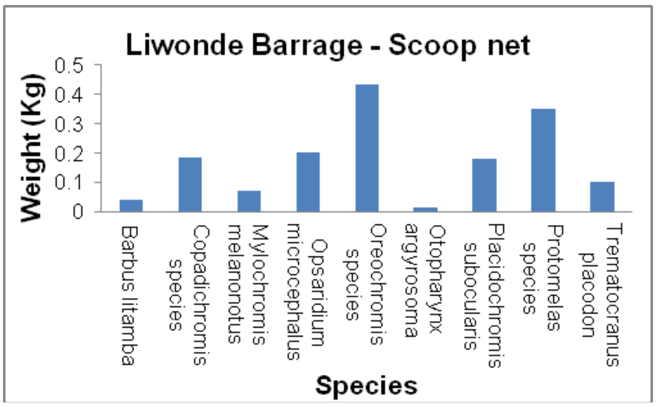


Figure 25. Species catch biomass for Lake Malombe caught using Scoop net (Photo: F. Kapute)

Apart from the cichlids, many riverine species such as *Opsaridium microlepsi* (Mpasa), *Opsaridium microcephalus* (Sanjika), and *Barbus litamba* (Thamba) are caught by scoop netters at the Barrage. This is the only site where we managed to sample many cyprinid species suggesting that indeed most of the fish caught around the Barrage actually migrate from the protected Liwonde National Park.

Hand line catches at the ESCOM Hydro Electricity Power generation intake at Nkula Falls generally comprised of *A. calliptera* (Figure 26), a beautiful "haplochromine" species found amongst vegetated areas in shallow waters (www.cichlid-forum.com).

Other species included *Oreochromis placidus* which is actually a Lower Shire River tilapia (www.fishbase.org), *Tilapia rendalli* – a Red breasted Tilapia which prefer well-vegetated water along river littorals or backwaters, floodplains and swamps (www.fishbase.org); and *O. Microcephalus* – a riverine species.

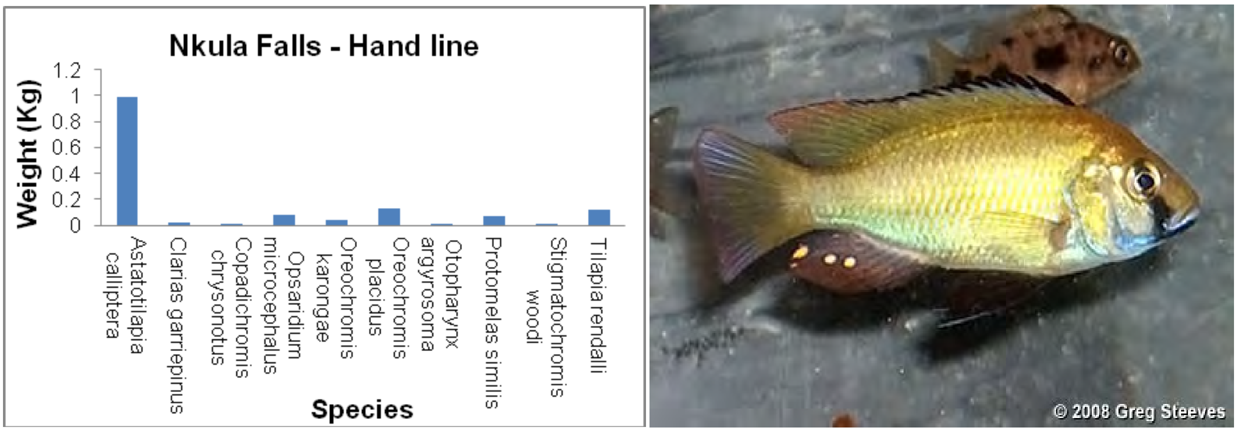


Figure 26. Species catch biomass for Nkula Falls ESCOM Intake Dam caught using Hand line (Photo: G. Steeves - www.cichlid-forum.com)

In summary, most of the fish catches are from gill nets followed by mosquito nets then beach seines.

3.14 Gear selectivity

Size distribution and size at capture of cichlids caught in kambuzi beach seines is shown in Figure 27. Size ranged from 30 mm to 180 mm TL with an average of 91 mm ± 40 mm TL. The size-at-capture was estimated at 87.5 mm TL using the logistic selection ogive.

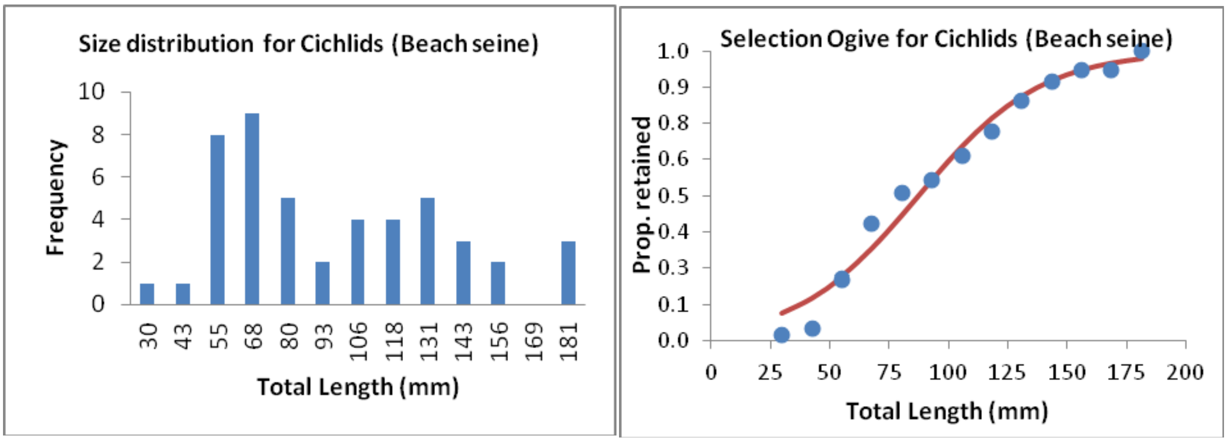


Figure 27. Size distribution, logistic selection ogive and size at capture of Cichlids caught in Beach seines

A logistic selection ogive or curve is a graphical estimation of the size (length) at which 50% of that fish stock is subjected to fishing.

Size distribution and size at capture of cichlids caught in mosquito nets is shown in Figure 28. Size ranged from 30 mm to 120 mm TL with an average of 75 mm ± 24 mm TL. The size-at-capture was estimated at 75 mm TL using the logistic selection ogive.

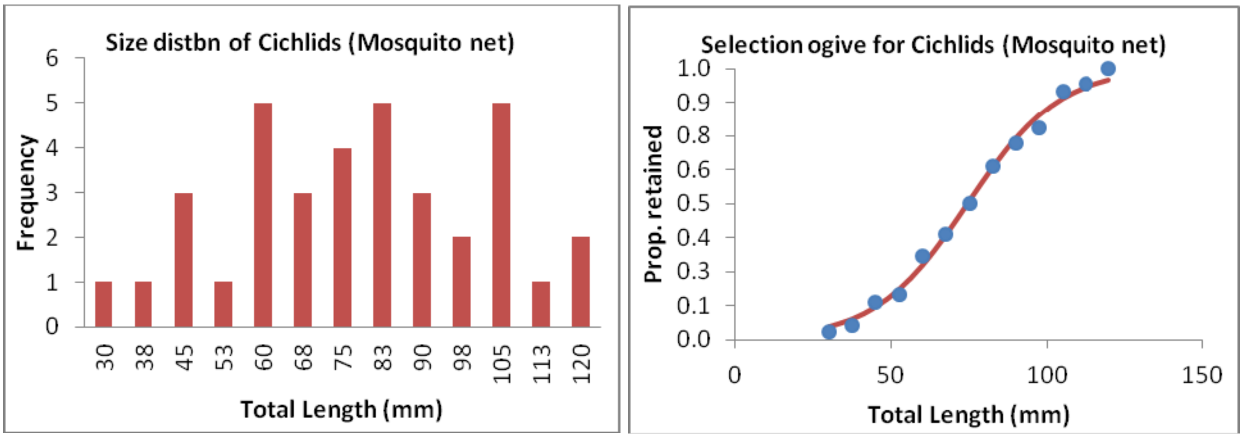


Figure 28. Size distribution, logistic selection ogive and size at capture of Cichlids caught in Mosquito nets

A small difference in the size distribution ranges and estimated size at capture for the cichlids caught in both beach seines and mosquito nets was observed supporting the fact that even the beach seines use a very small meshed net that scoops almost everything within its coverage area.

3.15 Fish Species Composition and Abundance

Like Lake Malawi, the fishery in the Shire River system which includes Lake Malombe is multi-species (Table 2). In this study, fish samples were collected from a variety of fishing gear including mosquito nets, gill nets, scoop nets, cast nets and hand lines.

TABLE 2. FISH FAMILIES AND GENERA SAMPLED DURING THE SURVEY

Family					
Cichlidae	*Bagridae*	*Clariidae*	*Cyprinidae*	*Mochokidae*	*Mormyridae*
Genus					
Astatotilapia	*Bagrus*	*Clarias*	*Barbus*	*Synodontis*	*Mormyrus*
Aulonocara			*Engraulicypris*		
Buccochromis			*Labeo*		
Chilotilapia			*Opsaridium*		
Copadichromis					
Corematodus					
Ctenopharynx					
Dimidiochromis					
Hemitaeniochromis					
Lethrinops					
Mylochromis					
Oreochromis					
Otopharynx					
Placidochromis					
Protomelas					
Pseudotropheus					
Stigmatochromis					
Tilapia					
Trematocranus					

Over 40 species belonging to 27 genera and six families were sampled in Lake Malombe, Upper and Middle Shire River (Table 2, Figures 29 - 31). The six families included Cichlidae, Clariidae, Cyprinidae, Mochokidae and Mormyridae. The most important in terms of distribution by weight were the families Cichlidae (61%), Clariidae (17%) and Mormyridae (10%) while the least important were the families Bagridae and Mochokidae with 4% and 1%, respectively (Figure 29). The family Cichlidae was the most diverse with 19 genera followed by the family Cyprinidae with four genera. All other families were represented with one genus each.

It is clear from Table 2 and Figures 29 to 31 that most of the catch in the Shire River system as is the case with Lake Malawi is dominated by cichlids (i.e. fish that brood their eggs in the mouth also known as mouth brooders) comprising about 61% of the total catch. In the riverine environment, cyprinids also make a good composition in the catch.

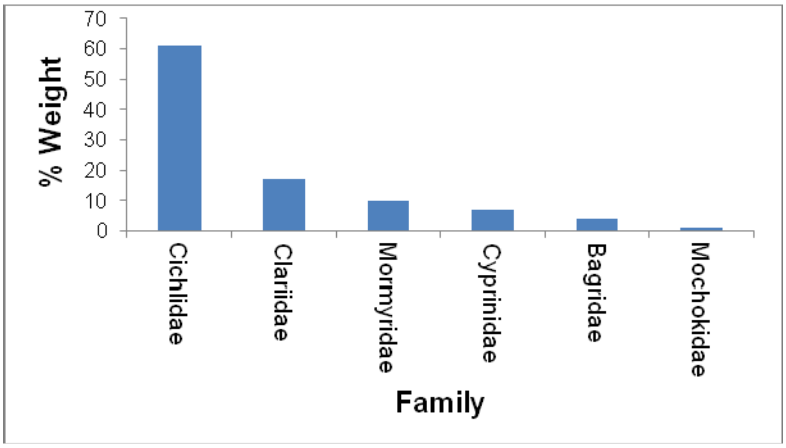


Figure 29. Distribution of fish families by % weight sampled during the survey

At genus level, the most important in terms of weight were *Clarias* (17%), *Oreochromis* (15%), *Mormyrus* (10%), *Protomelas* (9.8%), *Otopharynx* (9%) and *Astatotilapia* (6%) while the least important were *Corematodus* (0.1%), *Aulonocara* (0.2%), *Engraulicypris* (0.9%) among others. Some of the least commercially important genera like *Corematodus* and *Stigmatochromis* are also quite rare naturally.

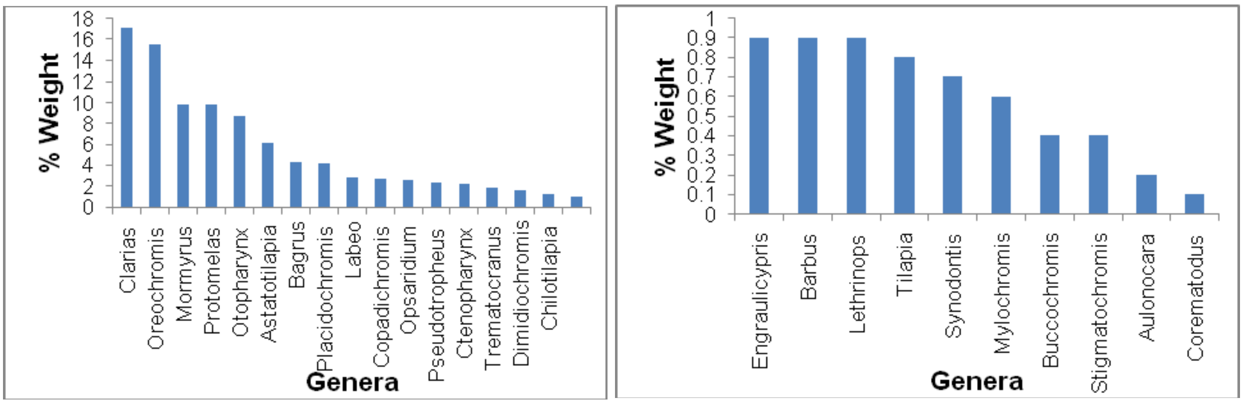


Figure 30. Most abundant (L) and least abundant (R) fish genera sampled during the survey

It should be emphasised that in Figure 30, the *Oreochromis* species comprise the Shire River tilapia (*Oreochromis shiranus*) and the three variants of tilapia – *Oreochromis karongae*, *Oreochromis squamipinnis* and *Oreochromis lidole* found both in Lakes Malawi and Malombe as well as some parts of the Upper and Middle Shire River.

In terms of fishery importance, the majority of the catch in the Shire River System is landed from species like *Clarius gariepinus*, *Oreochromis* spp., *Mormyrus longirostris* and small cichlids such as *Otopharynx argyrosoma*, *Protomelas* spp. and *Astatotilapia calliptera* (Table 2). Some species, like those listed in Table 3, were sampled in low numbers in the River System but their contribution to total landings in Lake Malawi is quite enormous. Species like *Engraulicypris sardella*, *Copadichromis* spp., *Buccochromis lepturus*, *Synodontis njassae* and *Lethrinops species* dominate fish landings in both the large and small scale fisheries of Lake Malawi.

After the collapse of the Chambo (Tilapia) fishery in Lake Malombe and the south-east arm of Lake Malawi due to heavy fishing pressure, the catch is mainly dominated by the small cichlids which are known as kambuzi (Figure 32) hence the versatile kambuzi fishery of Lake Malombe.

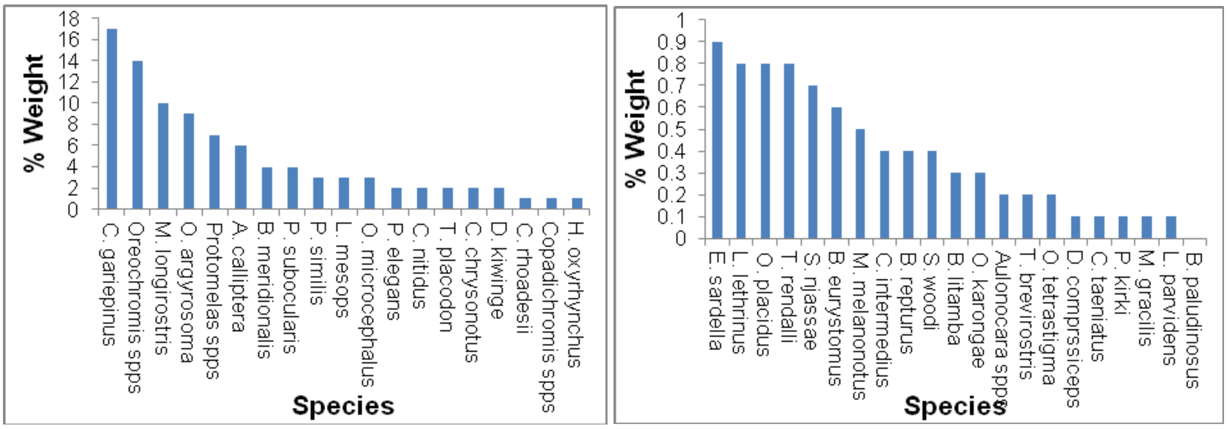


Figure 31. Most abundant (L) and least abundant (R) fish species sampled during the survey

Figure 32. Small cichlid (kambuzi) catch from south east arm of Lake Malawi caught using a small meshed beach seine (Photo: F. Kapute)

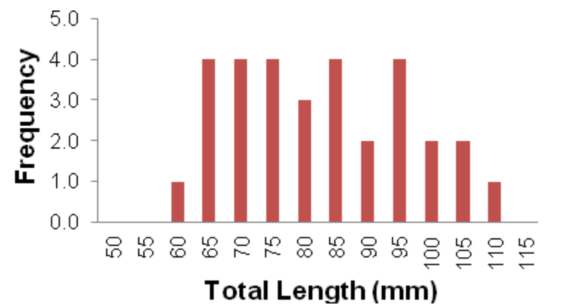
The kambuzi fishery is characterised by use of destructive small meshed gear such as beach seines and mosquito net patched purse seines (chilimira and nkacha) to increase the catch effort.

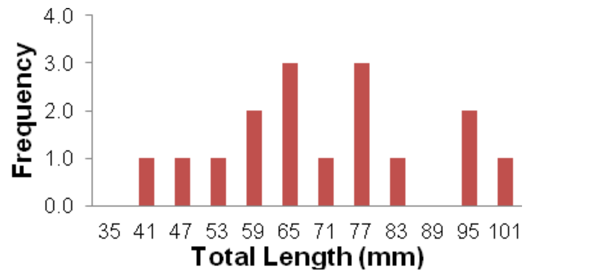
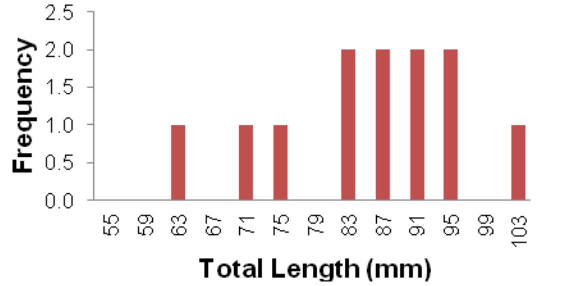
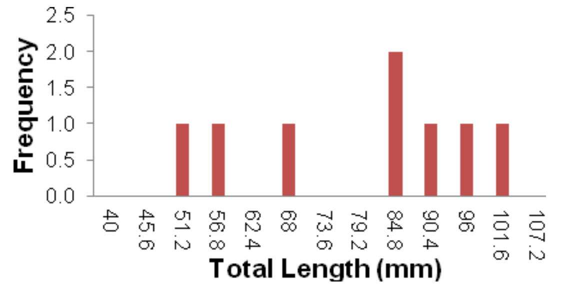
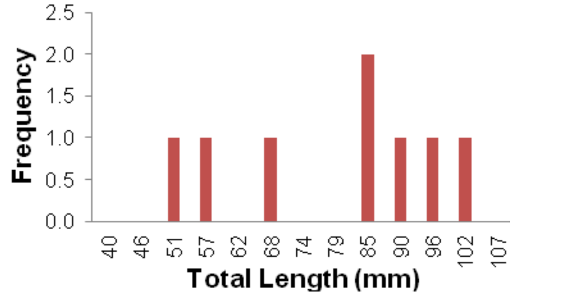
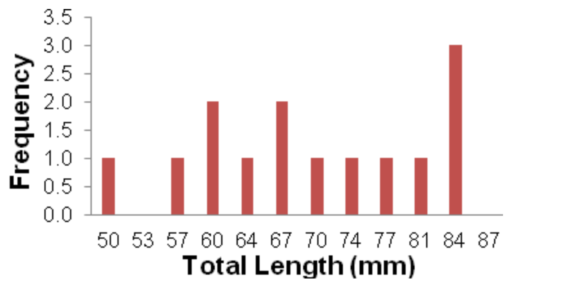
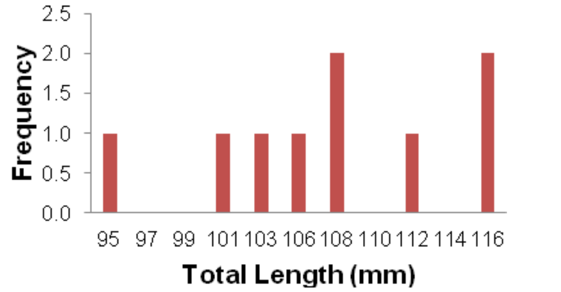
3.16 Size Distribution by Species

An analysis of the figures and length data in Figure 33 demonstrates the fact that nearly all of the cichlids caught in the Shire River system are small sized probably for two reasons: firstly, being an indication of overfishing where small meshed gear such as mosquito nets dominate, resulting in the removal of larger sizes; secondly, is the fact that the species are inherently small sized such as *Pseudotropheus elegans* and *Allistotilapia calliptera*, *Oropharynx argyrosoma*, *Placidochromis subocularis* and many others.

Astatotilapia calliptera

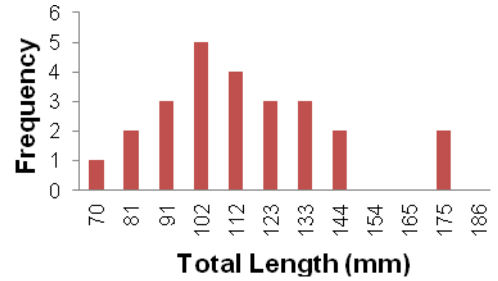
- Size range: 60 – 110 mm TL
- Average 80.6±14.0 mm TL



Copadichromis chrysonotus • Size range: 40 – 100 mm TL • Average: 68.3±17.6 mm TL	
Copadichromis species • Size range: 60 – 100 mm TL • Average: 83.7±11.2 mm TL	
Ctenopharynx intermedius • Size range: 45 - 101 mm TL • Average: 73.8±20.6 mm TL	
Ctenopharynx nitidus • Size range: 35 - 290 mm TL • Average 82.2±63.2 mm TL	
Engraulicypris sardella • Size range: 50 – 84 mm TL • Average: 68.4±11.0 mm TL	
Hemitaeniochromis oxyrhynchus • Size range: 95 - 115 mm TL • Average: 106.2±6.8 mm TL	

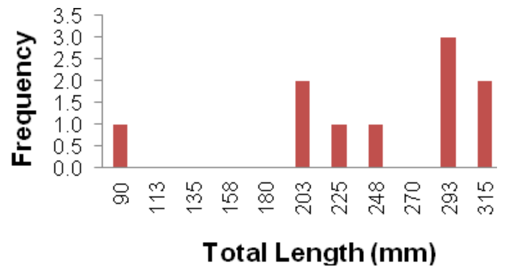
Opsaridium microcephalus

- Size range: 70 - 175 mm TL
- Average: 109.5±26.6 mm TL



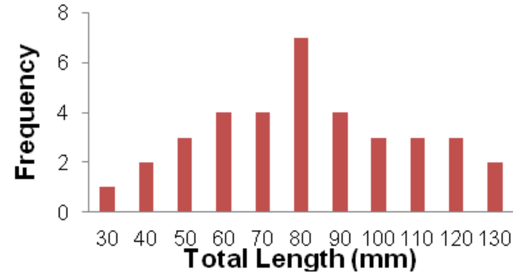
Oreochromis species

- Size range: 90 – 315 mm TL
- Average: 239.2±69.2 mm TL



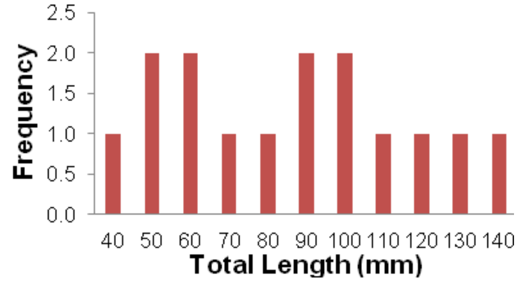
Otopharynx argyrosoma

- Size range: 30 – 130 mm TL
- Average: 78.3±26.7 mm TL



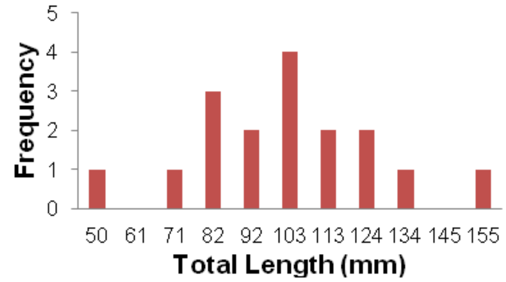
Placidochromis subocularis

- Size range: 40 - 140 mm TL
- Average: 83.4±31.6 mm TL



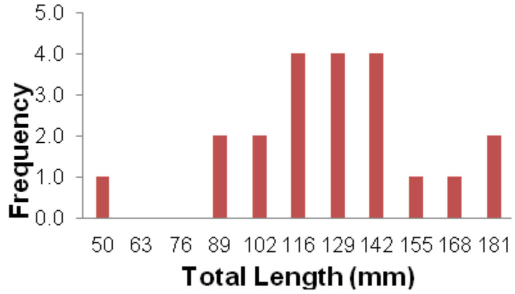
Protomelas similis

- Size range: 50 – 155 mm TL
- Average: 96.8±24.6 mm TL



Protomelas species

- Size range: 50 - 181 mm TL
- Average: 120.9±31.3 mm TL



Pseudotropheus elegans

- Size range: 45 - 67 mm TL
- Average: 55.9±7.7 mm TL

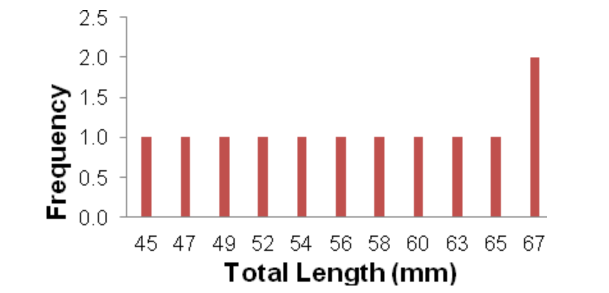


Figure 33. Length frequency histograms of different species

3.17 Distribution and Size at Capture of Major Fish Groups

Although six fish families were sampled during the study, only cichlids occurred in sufficient numbers to warrant analysis of gear selectivity. Therefore the analysis that follows focused on cichlid fishes only.

The size distribution and selectivity pattern of Cichlids are shown in Figure 34. Size distribution for cichlids caught in Scoop nets ranged from 60 mm to 315 mm TL with an average of 114 mm ± 57mm TL. The size-at-capture was estimated at 101 mm ± 57mm TL using the gamma distribution function of selectivity (Figure 34).

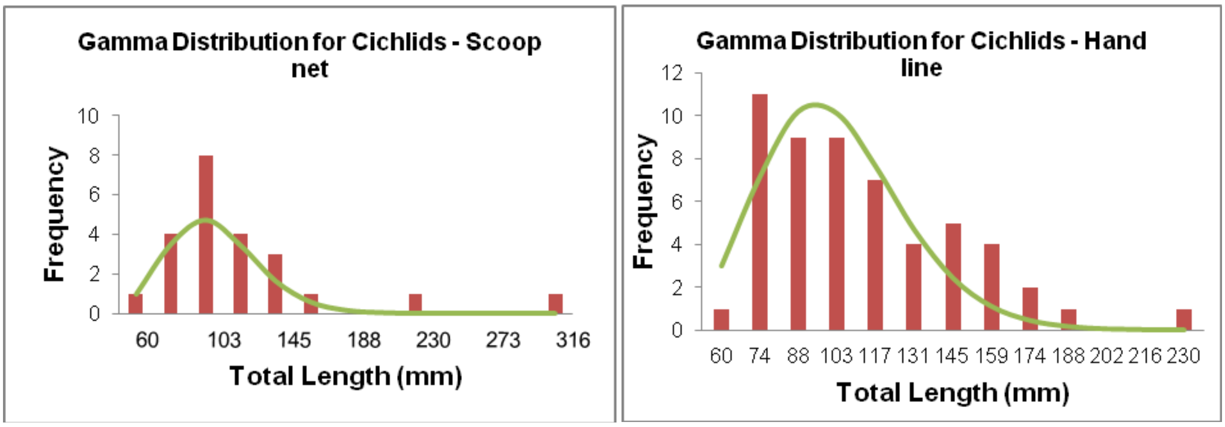


Figure 34. Distribution and size at capture of cichlids caught using scoop nets and hand line respectively

Size distribution of cichlids caught in Hand lines ranged from 60 mm to 230 mm TL with an average of 105 mm ± 36 mm TL. The size-at-capture was estimated at 93.4 mm ± 28 mm TL using the gamma distribution function of selectivity (Figure 34).

4 Discussion

4.1 The Shire River Aquatic Environment

The shoreline for the Shire River system as observed during the field survey is generally covered by vegetation all the way from the outflow point of Lake Malawi (Figure 35L). This is different from Lake Malawi, where the shoreline has clear and sometimes wide sandy beaches (Figure 35R). Breeding of the cichlid fishes that make nests and spawn their eggs along the sandy beaches is therefore more pronounced in Lake Malawi than in the Shire River. The latter favours riverine species more than all cichlids in general.

Figure 35. Shire River (L) and Lake Malawi (R) marshy and sandy shorelines respectively (Photos: F. Kapute)

It should also be emphasised that the sand bar at the start of the Shire River at the south east arm of Lake Malawi plays a key role on how much water moves into the River from the Lake. There have always been fears of the Shire River and Lake Malombe drying up due to the cessation of flows from Lake Malawi in an event of extreme low water levels in the lake as occurred from 1908 to 1935 when outflow was near zero for about 27 years (Parry *et al*., 2009).

The abundant presence of vegetation along the banks of the Shire River influences fishing in that it limits the operation of beach seines commonly used in clear sandy beaches of Lake Malawi and Lake Malombe. Gill nets and other smaller traditional fishing gear such as hand line, scoop nets etc. are therefore used extensively in the Shire River.

4.2 Fish and Fisheries in the Shire River System

The fish community of the Shire River including Lake Malombe is typical of that of Lake Malawi comprising key genera such as Lethrinops, Otopharynx, Copadichromis, Oreochromis, Engraulicypris, Clarias, Synodontis, Opsaridium, Barbus among many others (Table 3). The list in Table 3 is comprehensive and covers the entire Shire River system fish species above and/or below the Kapichira and other falls that serve as a bio-geographic divide between the Lake Malawi and the Zambezi River system fish fauna.

Most of the fish species in Table 3 are demersal (bottom feeders) and feeding high in the trophic level - a niche that is unlikely to be significantly affected by water levels. Also, most of the species are Cyprinids hence increasing water levels may not affect breeding.

TABLE 3. SHIRE RIVER FISH SPECIES COMPOSITION

Species	Family	Local name	Habitat	Status
Amphilius platychir	Amphiliidae	?	Demersal	Native
Anguilla nebulosa	Anguillidae	Mkunga	Demersal	Native
Aplocheilichthys johnstoni	Poeciliidae	?	Benthopelagic	Native
Aplocheilichthys katangae	Poeciliidae	?	Benthopelagic	Native
Astatotilapia calliptera	Cichlidae	?	Benthopelagic	Native
Barbus afrohamiltoni	Cyprinidae	Matemba	Benthopelagic	Native
Barbus arcislongae	Cyprinidae	Matemba	Benthopelagic	Native
Barbus atkinsoni	Cyprinidae	Matemba	Benthopelagic	Native
Barbus johnstonii	Cyprinidae	Ngumbo	Benthopelagic	Native
Barbus kerstenii kerstenii	Cyprinidae	Matemba	Benthopelagic	Native
Barbus lineomaculatus	Cyprinidae	Matemba	Benthopelagic	Native
Barbus macrotaenia	Cyprinidae	Matemba	Benthopelagic	Native
Barbus microcephalus	Cyprinidae	Matemba	Benthopelagic	Native
Barbus paludinosus	Cyprinidae	Matemba	Benthopelagic	Native
Barbus radiatus aurantiacus	Cyprinidae	Matemba	Benthopelagic	Native
Barbus trimaculatus	Cyprinidae	Matemba	Benthopelagic	Native
Barbus viviparus	Cyprinidae	Matemba	Benthopelagic	Native
Brycinus imberi	Alestiidae	Nkhalala	Demersal	Native
Chiloglanis neumanni	Mochokidae	?	Benthopelagic	Native
Chilotilapia rhoadesii	Cichlidae	Gundamwala	Benthopelagic	Native
Clarias gariepinus	Clariidae	Mlamba	Benthopelagic	Native
Clarias ngamensis	Clariidae	Mlamba	Demersal	Native
Clarias theodorae	Clariidae	Mlamba	Demersal	Native
Cyathochromis obliquidens	Cichlidae	?	Benthopelagic	Native
Dimidiochromis kiwinge	Cichlidae	Mbaba	Benthopelagic	Native
Dimidiochromis strigatus	Cichlidae	Mbaba	Benthopelagic	Native
Hemigrammopetersius barnardi	Alestiidae	?	Pelagic	Native
Hemitilapia oxyrhyncha	Cichlidae	Mbaba	Benthopelagic	Endemic
Hippopotamyrus discorhynchus	Mormyridae	Mphuta	Demersal	Native
Hydrocynus vittatus	Alestiidae	?	Demersal	Native
Irvineia orientalis	Schilbeidae	?	Demersal	Native
Labeo altivelis	Cyprinidae	?	Benthopelagic	Native
Labeo cylindricus	Cyprinidae	Ningwi	Benthopelagic	Native
Leptoglanis rotundiceps	Amphiliidae	?	Demersal	Native
Malapterurus shirensis	Malapteruridae	?	Benthopelagic	Native
Marcusenius macrolepidotus	Mormyridae	?	Demersal	Native
Marcusenius nyasensis	Mormyridae	?	Demersal	Native
Micralestes acutidens	Alestiidae	?	Pelagic	Native
Mormyrops anguilloides	Mormyridae	?	Demersal	Native
Mormyrus longirostris	Mormyridae	Samwamowa	Demersal	Native
Opsaridium ubangiensis	Cyprinidae	?	Benthopelagic	Native
Opsaridium zambezense	Cyprinidae	?	Benthopelagic	Native

Species	Family	Local name	Habitat	Status
Oreochromis mossambicus	Cichlidae	Makakana	Benthopelagic	Native
Oreochromis placidus placidus	Cichlidae	Chambo	Benthopelagic	Native
Oreochromis shiranus chilwae	Cichlidae	Chambo	Benthopelagic	Native
Oreochromis shiranus shiranus	Cichlidae	Makumba	Benthopelagic	Native
Otopharynx tetraspilus	Cichlidae	?	Demersal	Native
Otopharynx tetrastigma	Cichlidae	Kambuzi	Demersal	Native
Protomelas kirkii	Cichlidae	Kambuzi	Benthopelagic	Native
Protomelas triaenodon	Cichlidae	Kambuzi	Benthopelagic	Native
Protopterus annectensbrieni	Protopteridae	?	Demersal	Native
Pseudocrenilabrus philander dispersus	Cichlidae	?	Benthopelagic	Native
Serranochromis robustus jallae	Cichlidae	Tsungwa	Demersal	Native
Synodontis nebulosus	Mochokidae	?	Benthopelagic	Native
Synodontis njassae	Mochokidae	Nkholokolo	Benthopelagic	Native
Tilapia rendalli	Cichlidae	Chilunguni	Benthopelagic	Native
Trematocranus placodon	Cichlidae	Mbaba	Demersal	Native

Source: http://fish.mongabay.com/data/ecosystems/Shire.htm

Most of the Cyprinid fishes are free spawners, that discharge eggs into the open water rather than building nests as is the case with Cichlids. Later the eggs will adhere to whatever substrate they happen to land on. Therefore, though higher water levels upstream of Kamuzu Barrage would have an impact of inundation of riparian vegetation and river sandbars within Liwonde National Park, this will not impact on the breeding of most fish species in the Park. This is not surprising considering that the Shire River is the only outlet of Lake Malawi and it is therefore essentially one system implying that the fish community is also expected to be homogenous. Information gathered through literature search and results from the field survey support the fact that the fishery in the Shire River aquatic system like Lake Malawi is multi-species.

While literature suggests that more than 50 fish species are found in the Shire River system (www.fish.mongabay.com), about 40 species were recorded during the field survey, a majority of these being cichlids (mouth brooders). Conspicuously missing were riverine species (Cyprinids) save a few specimens of *Opsaridium microcephalus*, *Barbus paludinosus* and *Barbus litamba* identified at the Barrage from fishers and believed to be illegally caught from the protected Liwonde National Park. No specimen of *Opsaridium microlepis* (Mpasa) was recorded from the Shire River explaining the ever increasing scarcity of this commercial IUCN Red Listed species. However it is likely that some fish species were under-sampled or entirely missed out because of limitations in efficiency and selectivity inherent in fishing gears from which fish were sampled.

The Shire River's beaches are generally covered with more vegetation from Lake Malombe where more cichlids than riverine species are found. While riverine species favour such aquatic environment, presence of more cichlids is due to fish migration from the south east arm of Lake Malawi to Lake Malombe (which is part of the Shire River system) through the Upper Shire River. Catches from the southern part of the over-exploited Lake Malombe appear better than the rest of the areas of the Lake suggesting yet more migration of fish from the Liwonde National Park that borders the southern part of Lake Malombe (FAO, 2005).

It was clear from the findings that enforcement of fisheries management by the Malawi Department of Fisheries is facing challenges because, despite there being a closed season for Lake Malombe, illegal fishing was still commonly observed.

The study concluded that the Liwonde National Park is an important breeding area for fish that migrate and are caught by fishers in the southern part of Lake Malombe around Mvera area (also as reported earlier by FAO, 2005) and the stretch of the Shire River down to the Barrage at Liwonde. Protecting the fishery in the Park would therefore have far reaching advantages to the fisheries especially in the Middle Shire River and southern part of Lake Malombe.

4.3 Possible Impacts of the Upgraded Kamuzu Barrage at Liwonde on Fish and Fisheries in Lakes Malawi and Malombe and the Shire River

4.3.1 Impediment to Fish Migration

Riverine fish species are generally migratory species (Welcomme 1985) mainly for breeding purposes. In the Shire River, important and commercially valuable migratory species include *Opsaridium microlepis* (Mpasa) and several Barbus species found in the Upper and Middle Shire (www.anglingmalawi.org). Mpasa has been included under the IUCN 'Red List' of endangered species. Physical barriers eliminate diadromous or obligate migrating fish species by preventing movement to upstream breeding sites by adults but also slowing down-stream movements of juveniles.

The fish fauna of the Upper and Lower Shire River are separated by natural barriers (waterfalls) downstream of the existing Barrage at Liwonde. As a result, fish species are very distinct and endemic to each geographical area. Most of the species in the Upper Shire are also found in the south east arm of Lake Malawi and Lake Malombe probably due to migration. In the Lower Shire, the fish fauna is essentially of Zambezi River Basin eco-region as more than 60 species are caught in this fishery. Out of the 60 species, only three species are of commercial importance namely, Mlamba (*Clarias gariepinus*), Chikano (*Clarias ngamensis*) and Mphende (*Oreochromis mossambicus*) (Willoughby and Tweddle, 1978). From the outflow of Lake Malawi near Mangochi downstream to Lake Malombe, the Shire River flows through a relatively flat area without any obstruction. The natural barriers to fish migration in the River are the water falls at Nkula downstream to Kapichira Falls. The distance between the Barrage (Liwonde) to the first natural barrier (falls) at Nkula is about 80km. The gates at the Barrage at Liwonde when fully open are not an impediment to migration of fish. That is why fishermen catch a lot of migrating fish at the Barrage using Scoop and Cast nets when the gates are open.

As explained earlier, the Liwonde National Park is an important refuge and breeding area for fish in the Shire River and Lake Malombe since the rest of the areas are subjected to intensive and uncontrolled fishing. Since the Kamuzu Barrage is located downstream of Liwonde National Park, it does not interfere with any fish migrations in the Shire River between the Park and Lake Malawi. Further, the upgraded Kamuzu Barrage would pose essentially the same type of physical barrier to fish movements as the existing one; hence no change from the status quo is expected with respect to fish migrations. The existing natural impediment (falls) at Nkula and Kapichira downstream will continue to block migration of fish from the Lower Shire to the Upper Shire. It is important to note nevertheless that downstream migration of the fish will still occur as the gates are often fully open under low flow and high flow conditions. Upstream migration may also be possible during these times since by their nature, fish prefer to swim against the water current.

One way of facilitating migration of fish in the Shire River past the Barrage is construction of fish passes also known as fish ladders. However, any benefit from providing fish passage is limited to the 80km stretch of the Shire River between the Barrage and Nkula falls. The following section provides a discussion on existing fish passage experience in Malawi.

Fish passes in Malawi

Unpublished information sourced from the Malawi Department of Fisheries indicates that fish passes in Malawi have previously been constructed in several places though only limited data is available. In Bua River (Central Malawi), fish passes were constructed within the context of an environmental impact assessment (EIA) requirement for rice cultivation along the lower reaches of the River. The fish of interest here was the Lake Salmon – *Opsaridium microlepis* (Mpasa). Other fish passes have been constructed at Mulunguzi Dam (on Zomba Mountain) for trout species. It is also reported that fish passes were constructed at Kapichira Falls down the Shire River by ESCOM. However, in all these reported cases there was not a detailed assessment of the effectiveness of the fish passes and information remains scanty (personal communication from the Malawi Department of Fisheries).

Also one of the major disadvantages of existing fish passes is that they expose fish to being easily captured. The experience of uncontrolled blocking of rivers to catch breeding riverine fish in Malawi which has resulted in the elimination particularly of Mpasa (*Opsaridium microlepis* – Lake Salmon), presents a great challenge of the effectiveness of fish passes. Linthipe River in the Central Region of Malawi which used to support large stocks of Mpasa is a good example. Fishers have been uncontrollably blocking the river catching migrating breeding Mpasa resulting in collapse of the Mpasa fishery there. Therefore, unless followed by a strong fisheries management and enforcement mechanism, fish passes would create a more conducive environment for complete exploitation of already declining riverine fish stocks and mostly the IUCN Red Listed *Opsaridium microlepis* (Mpasa).

The Food and Agriculture Organization (ftp://ftp.fao.org/docrep/fao/010/y4454e/y4454e01.pdf) has previously demonstrated use of the following fish passes outside of Malawi.

i) Bottom ramp and slope
A sill having a rough surface and extending over the entire river width with as shallow a slope as possible, to overcome a level difference of the river bottom. This category also includes stabilizing structures (e.g. stabilizing weirs), if the body of the weir has a shallow slope similar to the slope of a ramp or slide and is of loose construction

ii) Bypass channel
A fish pass with features similar to those of a natural stream, bypassing a dam. The whole impounded section of the river can thus be bypassed.

iii) Fish ramp
A construction that is integrated into the weir and covers only a part of the river width, with as gentle a slope as possible to ensure that fish can ascend. Independently of their slope, they are all called ramps; in general the incorporation of perturbation boulders or boulder sills is required to reduce flow velocity.

4.3.2 Destruction of Fish Breeding Aquatic Habitats through Flooding and Siltation

Physical infrastructure such as barrages have been reported to cause habitat loss (Welcomme, 1985). Turbidity and siltation of the water increases after the water passes through the barrage gates (www.africanwater.org, 2011). Sedimentation could entail burying already made nests for spawning of the cichlids such as the Tilapine family found in the river course. Increase in silt load also accelerates the natural evolutionary processes of the river system resulting in choking of the substrate rendering it unsuitable for spawning by species requiring well aerated flows and clear pebble or gravel bottoms (Welcomme 1985). *Opsaridium microlepis* (Mpasa) appears to be one of such species (www.Cbi.org, 2011). Heavy siltation could also affect the breeding of fish by destroying breeding nests for the spawning cichlids such as *Oreochromis shiranus* along the shoreline of the Shire River. Siltation is also a problem to reproductive success of fish species such as *O. microlepis* which requires silt free water to reproduce (www.Cbi.org).

However, water released from a dam or weir is usually low in sediment because sedimentation in the reservoir is dependent on residence time and flow rates within the reservoir. Therefore, the problem of destruction of fish breeding aquatic habitats through flooding and siltation due to the upgraded Barrage is unlikely.

Further, riverine fishes generally migrate upstream to breed during the rainy season when water levels are already high. This is a time when the Barrage's influence at Liwonde on the water flow is least. Also, most fish species in the Shire River (Table 2 and 3) are riverine which do not build breeding nests but eggs that attach to substrates such as grass, rocks etc. Inundation of breeding areas as a result of the Barrage is therefore unlikely to be an issue.

The upgraded Barrage will also not release higher regulated flows than the existing situation. In any case, the Barrage has no influence over natural flood flows in the Shire River system – they are beyond the operating level of the Barrage. Also any impact such as siltation will be short-lived and minor due to the potential dilution properties of the Shire River.

4.3.3 Changes in Water Flow Downstream

Operation of the Barrage gates at Liwonde has a direct effect on the flow of water in the Shire River downstream. In the Lower Shire, the River has numerous meanders hence reduced water flow may result in the progressive restriction of the stream to a smaller bed within the original channel leading to loss of habitats for fish.

Riverine aquatic organisms are usually adapted to particular water flow patterns (Welcomme, 1985) explaining why riverine fish species usually breed during flooding regimes which are also associated with more food availability and when most of the fish become sexually ripe. Sudden or periodic increased flow of water as a result of opening of the gates at the upgraded Barrage may trigger sexual maturity and consequently spawning of fish downstream especially the Lower Shire. This may eventually change the breeding pattern (timing) for other species of fish.

Water release patterns from the upgraded Kamuzu Barrage that would be generally favourable to downstream fish and fisheries include:

i) allowing some natural flooding to occur during the wet season, to stimulate natural fish reproduction and to maintain the vitality of the Elephant Marsh and other areas with important fish populations;

ii) avoiding significant daily fluctuations in flow rates, such as for peaking power (which can upset the natural cycles of fish and other aquatic life); and

iii) avoiding very sudden decreases in flows due to rapid gate closures at the Barrage since such sudden drops can cause large-scale fish stranding.

However, as explained earlier, the upgraded Barrage will not result in a reduction of flow volume downstream but only a change in the flow pattern. Also, likely downstream impacts of the upgraded Kamuzu Barrage will depend on how water releases at the Barrage are managed, and whether there will be any appreciable difference from the status quo water release regime for the existing Barrage. The Barrage also acts as a facility to regulate flow in the Shire River so that there is no change in the total volume of water but a change in the timing of flows, i.e. there will be slightly less flow during the high flow season as more water is stored behind the Barrage and then slightly more flow during the low flow season as more water is released from the Barrage. There will therefore be no change in the total volume of water released downstream by the Barrage, only a change in the timing and magnitude of the releases. Similarly, fishing activities will also to that effect not be affected in the Lower Shire River since water levels will not be significantly affected.

4.3.4 Impacts on Fish of Lake Malawi Particularly the Rock Dwelling Cichlids (Mbuna)

In Lake Malawi, Mbuna (beautifully coloured aquarium) fish species (Figure 36) are very common in Cape MaClear near Monkey Bay, the area between the south-east and south-west arms of Lake Malawi (Figure 2).

Figure 36. Beautifully coloured rock dwelling Cichlids (Mbuna)

(http://www.tropicalfishandaquariums.com/AfricanCichlids/index.asp)

This area of the Lake is part of the protected Lake Malawi National Park. The Mbuna are more dominant in Cape MaClear where the Lake is deep and has a rocky bottom – which favour Mbuna's feeding on the rocky substrates. Though Mbuna have varied depth differences extending from the surface to more than 40 m (Lewis, Reinthal and Trendall, 1986), its population in the south east arm of Lake Malawi is insignificant. During the field survey, not even one was found (Table 2 and figure 33) in south east arm of Lake Malawi, Lake Malombe and the Shire River. Therefore, as far as the south east arm of Lake Malawi (Area A) is concerned, the threat of the Mbuna species being impacted by the upgraded Barrage is not valid.

4.3.5 Impacts of Construction Activities on Fish and Fisheries Resources

Clearing of vegetation and earth moving works during the upgrading of the Barrage is likely to cause accelerated erosion in the project area with sediments contaminating water in the Shire River and silting up spawning grounds on the river bed. Solid wastes and oils from construction plant and sites may spill into the Shire River thereby contaminating its waters and likely kill some aquatic organisms including fish. These impacts are expected to be short term and minor given the potential dilution properties of the Shire River. Thus such water pollution in the River will be localised and not affect the entire Shire River system.

Table 4 presents a summary of the potential environmental impacts, their sources, areas of impact, potential mitigation measures and brief description of the occurrence of the impact and mitigation. This summary is a synthesis of the results from both the desk study and the field surveys (Appendix 1).

TABLE 4. SUMMARY OF IMPACTS AND SUGGESTED MITIGATION MEASURES/PLANS

Impact	Type of Impact	Source of Impact	Impact Area	Mitigation Measure / Comments
Impediment/blocking of fish migration	Negative	The Barrage and the action of closing the gates at the Barrage could eliminate diadromous or obligate migrants by preventing movement to upstream breeding sites by adults and slowing down- stream movements of juveniles. However, the gates when fully open are not an impediment to migration of fish. That is why fishermen catch a lot of fish at the Barrage using Cast nets when the gates are open.	*At the Barrage, *Upstream breeding areas, *Immediate downstream as far as Nkula (80km) where there is a natural barrier to fish movement upstream	Constructing fish passes Fish passes or ladders have satisfactorily worked for salmon in northern temperate rivers. In the tropics, fish passes have successfully demonstrated to be useful. Fish ways at dams on the Tigris and Euphrates rivers have also been used successfully by many of the migratory cyprinid species in these rivers. Information about fish passes in Malawi is scanty, However, fish passes expose fish to easy way of being captured. The experience of uncontrolled blocking of rivers to catch breeding fish in Malawi which has resulted in wiping out of riverine species presents a great challenge of the effectiveness of the fish passes.
Destruction of fish breeding aquatic habitats through siltation	Negative	Increase in turbidity and siltation of the water after passing through the Barrage gates. Sedimentation thus means burying already made nests for spawning of the cichlids. Increase in silt load accelerates the natural evolutionary processes of the river system resulting into choking of the substrate rendering it unsuitable for spawning by species requiring well aerated flows and clear gravel bottoms. Siltation is also a problem to reproductive success of fish such as *O. Microlepis* (Mpasa) which requires silt free water to reproduce.	Upstream fish breeding areas Downstream potential fish breeding areas	Riverine fishes generally migrate upstream to breed during rainy season when water levels are already high. However, this is when the Barrage has the least influence on water flow. Thus, increased water levels cannot affect breeding. But fish are sensitive to habitat changes, therefore proper gate control and enforcement of fishing regulations especially for breeding sanctuaries (e.g. Liwonde National Park) would to protect the “Red listed species”. The section of the Shire River at Liwonde does not have sandy beaches that favour breeding of cichlids. Thus, the area does not naturally favour the breeding of cichlids suggesting why the Chambo (tilapia) fishery is not vibrant in the Shire

Impact	Type of Impact	Source of Impact	Impact Area	Mitigation Measure / Comments
				River. Another mitigation measure (though it is high cost) is improvement of the Spawning areas such as making artificial breeding beaches for fish. This is improvement of bottom texture for fish which spawn over gravel, particularly where siltation has resulted in the loss of the normal substrate. However, most fish species are riverine which do not build breeding nests but eggs attach to substrates such as grass, rocks etc. hence the issue of inundation of breeding areas is not valid.
Changes in flow of water downstream	Negative / Positive	There will be no change in the total volume of water released downstream by the Barrage, only a change in the timing and magnitude of the releases	Barrage downstream and the Lower Shire Zone	Operation of the gates at Kamuzu Barrage to maintain downstream aquatic environment. Closing and opening of gates should be monitored and balanced i.e. releasing sufficient water downstream to meet hydropower, town water supply and irrigation needs as well as meeting environmental requirements. This could be a positive impact in a way that less or too much water tends to favour different species of fish. In fact, flooding may trigger spawning among some riverine species including catfish (*Clarias* spp.)
Disappearance of fish spawning habitats through flooding	Negative / Positive	The upgraded Barrage will not release higher flows than the existing situation. In any case, the Barrage has no influence over natural flood flows in the Shire River system – they are beyond the operating level of the Barrage	Both downstream and upstream	Most fish species are riverine which do not build breeding nests but eggs attach to substrates such as grass, rocks etc. hence the issue of inundation of breeding areas is not valid. Flooding would create new breeding areas for the fish hence may also be a positive impact. Only siltation is a problem not flooding as far as breeding of riverine species and cichlids is concerned. Increased water levels would actually make

Impact	Type of Impact	Source of Impact	Impact Area	Mitigation Measure / Comments
				breeding of riverine species much easier i.e. by facilitating migration up stream.
Loss of fish landing beaches and fish drying areas upstream due increased water levels	Negative	Some beaches may be inundated for a slightly longer time because of the Barrage.	Barrage upstream and Upper Shire	Lake Malawi water levels fluctuate naturally much greater than the operating level of the Barrage and the proposed 40cm increase in maximum regulated height. Sandy beaches are inundated by natural flows irrespective of Barrage operation.
Reduced fish activities downstream due to low water levels	Negative		Barrage downstream	The total amount of water going down the system will not change as a result of upgrading the Barrage.
Changes in water quality	Negative	Downstream flooding, upstream water retention, construction may affect the physical and chemical properties of water e.g. pH, conductivity etc which may eventually affect the physiology of fishes	Both upstream and downstream	Constant flushing of the system i.e. the opening and closing of Barrage gates. As regards construction, this is not a long term problem as the system would stabilise sometime after construction is completed.

4.4 Mitigation of Adverse Impacts

Analysis of these findings suggests that potential impacts will be impediment of migration, siltation, destruction of aquatic habitats-reproductive and schooling habitats, destruction of fish processing/drying areas upstream, reduced catches especially of riverine and Red-listed species such as the Mpasa especially downstream due to reduced water levels, flooding and water quality deterioration. However, these potential impacts from the upgraded Kamuzu Barrage at Liwonde are not anticipated to occur, or if they do occur will only be minor in nature for the reasons listed below:

i) The upgraded Kamuzu Barrage would pose essentially the same type of physical impediment to fish movements as the existing one; hence no change from the status quo is expected with respect to fish migrations.

ii) Downstream migration of the fish will still occur as the gates are fully open under extreme low flow and high flow conditions.

iii) Upstream migration may also be possible during opening of gates since by their nature, fish prefer to swim against the water current.

iv) One suggested way of facilitating migration of fish in the Shire River passed the Barrage apart from the opening of the gates would be construction of a fish pass. However, success of a fish passage facility at the Barrage is questionable because fish passes expose fish to easily being captured. Its effectiveness can only be guaranteed with strict fisheries management and enforcement. Also, riverine fishes generally migrate upstream to breed during rainy season when water levels are already high. This is a time when the Barrage's influence at Liwonde on the water flow is least.

v) On destruction and inundation of fish breeding grounds: Most fish species in the Shire River are riverine which do not build breeding nests but eggs that attach to substrates such as grass, rocks etc. The issue of inundation of breeding areas is therefore not valid.

vi) Any impact from increased siltation arising from construction activities will be short-lived and minor due to the potential dilution properties of the Shire River.

vii) On changes in water flow in the Shire River: The upgraded Barrage will also not release higher flows than the existing situation. The Barrage has no influence over natural flood flows in the Shire River system – they are beyond the operating level of the Barrage.

viii) Water release patterns from the upgraded Kamuzu Barrage should be managed so they are generally favourable to downstream fish and fisheries such as: (i) allowing some natural flooding to occur during the wet season, to stimulate natural fish reproduction and to maintain the vitality of the Elephant Marsh and other areas with important fish populations; (ii) avoiding significant daily fluctuations in flow rates which can upset the natural cycles of fish and other aquatic life; and (iii) avoiding very sudden decreases in flows due to rapid gate closures at the Barrage. Such sudden drops can cause large-scale fish stranding.

ix) The Barrage acts as a facility to regulate flow in the Shire River so that there is no change in the total volume of water but a change in the timing of flows, i.e. there will be slightly less flow during the high flow season as more water is stored behind the Barrage and then slightly more flow during the low flow season as more water is released from the Barrage. There will therefore be no change in the total volume of water released downstream by the Barrage, only a change in the timing and magnitude of the releases.

x) Similarly, fishing activities will also to that effect not be affected in the Lower Shire River since water levels will not be significantly affected.

xi) This area of the Lake is part of the protected Lake Malawi National Park. The Mbuna are more dominant in Cape MaClear where the Lake is deep and has a rocky bottom – which favour Mbuna's feeding on the rocky substrates. Though Mbuna have varied depth differences extending from the surface to more than 40 m, its population in the south east arm of Lake Malawi is insignificant. During the field survey, not even one was found in south east arm of Lake Malawi, Lake Malombe and the Shire River. Therefore, as far as the south east arm of Lake Malawi (Area A) is concerned, the threat of the Mbuna species being impacted by the upgraded Barrage is not valid.

xii) Construction impacts such as clearing of the area, water pollution and siltation are expected to be short term and minor given the potential dilution properties of the Shire River. Thus such water pollution in the River will be localized and not affect the entire Shire River system.

5 Conclusion and Recommendation

It is concluded, based on careful analysis of findings from this Report, that the project of upgrading the Kamuzu Barrage which may likely result in rising water levels upstream (but within the natural fluctuating water levels) does not pose significant danger to the fish and fisheries of the Shire River System if mitigation measures which are proposed in this report are adopted and implemented. Key observations and recommendations made are as follows:

- The upstream area between the Barrage, Lake Malombe and the Liwonde National Park, where fish migration takes place is sensitive to water level rise likely to be affected by the upgrading of the Kamuzu Barrage. However, the upgraded Barrage will not cause any significant changes in water levels but rather have the same operation as the present Barrage.
- Lowering water levels downstream may not prohibit fish breeding but rather reduce the breeding area and hence limit fish catches. On the other hand, increased water levels will simply trigger breeding which is an advantage.
- Most of the fish caught from areas of the Shire River around the Liwonde National Park appear to migrate from the Park which appears to be an important breeding area.
- Most fish found in the Shire River especially upstream from the Barrage breed in the Liwonde National Park which is a protected area hence reduced threat to breeding of fish.
- As long as migration of fish between Lake Malawi and Lake Malombe through the 15 km Upper Shire stretch continues, threats to breeding of the fish upstream will be minimal.
- Except for the part of the Shire River within Liwonde National Park, elsewhere, management of fish exploitation is very minimal if not non-existent at all.
- The fisheries for the Shire River except for the Lower Shire and small parts of the Upper Shire appear to be uncoordinated requiring reinforcement of varied participatory monitoring and data collection approaches, owing to its multi-species nature. This will ensure sustenance of fisheries livelihoods while mitigating impacts of the Barrage.
- As an important aquatic habitat for breeding of fish that migrate to the main part of the Shire River and Lake Malombe, there is need to institute sound fisheries management strategies in Liwonde National Park to monitor recruitment of fish stocks.

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Appendix 1: Summary of Key Questions

1. Does the project affect species composition and the fishery of the Shire River? YES and/or NO
    a. Any suggestions/comments proposed to mitigate this impact? YES.
    b. Some fish species would flourish better in high waters (rheophilic) while other wouldn't (limnophilic species)
    c. Also migration would stabilize and/or compensate for any changes or species loss that may occur as a result of increased water levels
2. May the project likely affect fishing in the Shire River? NOT REALLY
    a. If yes, what measures have been put in place, and if no, why?
    b. Most of the fishing gears that are extensively employed in the Shire River fisheries are cast nets, scoop nets, fish traps and gill nets. Beach seines are common in Area A of the south east arm of Lake Malawi). Operation of these gears cannot be hindered by increased water levels.
3. Does the project have any effect in impeding/blocking migration of fish? YES
    a. Has this work provided solutions or suggestions to mitigate this impact? YES
4. Is there likelihood that increasing and/or low water levels upstream and downstream respectively would result into destruction of fish breeding habitats? YES
    a. Are there any mitigation measures for this impact provided by this work? YES
5. Does the potential for flooding downstream present a danger to destruction of fish breeding habitats downstream? YES
    a. Has this work suggested proper mitigation measures for the same? YES
6. Are there any nationally endangered fish species that could be affected as a result of the upgraded Barrage? YES
    a. Has this EIA made any suggestions to mitigating this impact? YES
7. Does the upgraded Barrage pose any challenge to destruction of fish landing beaches and fish drying areas? YES, but for isolated areas only especially Lake Malombe
    a. Are there suggestions for mitigating this impact? Not really, because this is more of a social issue hence to be tackled by other expertise.

Government of the Republic of Malawi

Ministry of Water Development and Irrigation
National Water Development Programme

Independent Environmental Impact Assessment for the Upgraded Kamuzu Barrage

Final Environmental and Social Impact Assessment
Volume 2: Wildlife

December 2013

SMEC

Celebrating 40 years 1970 - 2010

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Abbreviations

AEWA	Agreement on the Conservation of African-Eurasian Migratory Waterbirds
CBD	Convention on Biological Diversity
CITES	Convention on International Trade in Endangered Species of Wild Fauna and Flora
CMS	Convention on Migratory Species
EIA	Environmental Impact Assessment
ESCOM	Electricity Supply Corporation of Malawi (Ltd)
ESIA	Environmental and Social Impact Assessment
ESMP	Environmental and Social Management Plan
HRWL	Highest Regulated Water Level
IFC	International Finance Corporation
IUCN	International Union for Conservation of Nature
km	kilometre
LNP	Liwonde National Park
m	metres
masl	metres above sea level
MNREE	Ministry of Natural Resources, Energy and Environment
MoIWD	Ministry of Water Development and Irrigation
NGO	Non-Governmental Organisation
NP	National Park
NT	Near Threatened
PPP	Public – Private Partnership
SMEC	Snowy Mountains Engineering Corporation Ltd.
USD	United States Dollar
UTM	Universal Transverse Mercator
WESM	Wildlife and Environment Society of Malawi

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Executive Summary

The Government of Malawi through the Ministry of Water Development and Irrigation is implementing an integrated water development plan for the Shire River Basin. One of the major activities at this stage is the upgrading of the Kamuzu Barrage at Liwonde along the Shire River. In this second phase the rehabilitation is expected to increase the regulating capacity of the Barrage by raising the highest regulated water level (HRWL) by 20 – 40cm compared to the existing HRWL of 475.32 masl. However, the Barrage control capacity does not include situations of severe floods or drought. The Government of Malawi contracted SMEC to undertake an ESIA which involved interdisciplinary fields including the wildlife component.

The specific objectives for the wildlife component in the ESIA included:

- Collecting wildlife baseline data for the area of project impact.
- Identifying environmentally sensitive areas/habitats (e.g. wetlands, ecologically important areas) which may be impacted by the Project.
- Identifying any locally/regionally/nationally rare/endangered species of wildlife potentially impacted by the Project.
- Assisting in the identification of potential environmental impacts and mitigation measures.
- Working with other Team members in the identification and assessment of Project alternatives to minimise adverse environmental impacts.
- Providing technical support to Team members on wildlife aspects
- Providing written input into the ESIA and ESMP reports including sections/chapters on methodology, description of wildlife, impacts, mitigation and monitoring measures

A combination of techniques including secondary sources and primary data were used to collect wildlife information used in assessing potential impacts of the project to wildlife. Primary data was collected from a site visit and included direct observation, transects, interviews and discussions. During the field visit all wildlife encountered was recorded. The field survey also involved interviews and discussions.

Risk analysis suggested possible negative impacts to wildlife arising from flooding and changes in water flow and presence of barriers to wildlife movement and migration.

Modelling of flooding regimes from the planned upgraded Barrage suggests that there will be little or insignificant deviation in areas to be covered by water as a result of enhanced impoundment. While species like crocodiles, the African Skimmer and terrapins may experience limited effects from the temporary flooding of sand bars and beaches, other species of conservation importance such as hippopotamus, Lillian’s Lovebird, migratory birds, rhinoceros and elephants will not be affected. Also the upgraded Barrage is anticipated to have little effect to the critical habitats in the project area. The Barrage will continue to be a physical barrier for hippopotamuses and crocodiles to cross from upstream to downstream.

On the positive side, the Barrage will continue to be a reliable source of water for the Shire River through regulation of flows and will ensure there is constant water availability for wildlife and other aquatic organisms. This is important given the unreliable water flow due to the erratic weather of Lake Malawi and the Shire River Basin. However, the anticipated effect of the upgraded Barrage to wildlife will also very much depend on how the Barrage gates will be opened to regulate water flow downstream.

Monitoring of species diversity, recruitment, abundance, distribution and movement of species of interest and critical habitats is recommended to determine if there will be any significant impacts from the changed flooding regimes. Human wildlife interactions will also need to be monitored to assess whether the flooding regimes will result in any new or increased occurrence of human wildlife conflicts.

1 Introduction

This report covers the activities of the wildlife expert following a field visit to Malawi from 10th to 23rd October 2011 and evaluation of the wildlife data and information collected.

1.1 Objectives of the ESIA

The objectives are as stipulated in the terms of employment covering activities to be undertaken by the expert and advisory role on wildlife matters to other members of the ESIA team.

The specific objectives for the wildlife component in the ESIA included:

- Collecting wildlife baseline data for the area of project impact.
- Identifying environmentally sensitive areas/habitats (e.g. wetlands, ecologically important areas) which may be impacted by the Project.
- Identifying any locally/regionally/nationally rare/endangered species of wildlife potentially impacted by the Project.
- Assisting in the identification of potential environmental impacts and mitigation measures.
- Working with other Team members in the identification and assessment of Project alternatives to minimise adverse environmental impacts.
- Providing technical support to Team members on wildlife aspects
- Providing written input into the ESIA and ESMP reports including sections/chapters on methodology, description of wildlife, impacts, mitigation and monitoring measures

1.2 Methods

A combination of techniques including secondary sources and primary data were used to collect wildlife information used in assessing potential impacts of the project on wildlife. Considerable secondary information on wildlife was available from Liwonde National Park, Department of National Parks and Wildlife, SMEC office in Lilongwe, Majete Wildlife Reserve, published/unpublished literature and Malawi Government website. Primary data was collected from site visit and included direct observation, transects, interviews and discussions. During the field visit all wildlife encountered was recorded. For the interviews and discussions some guiding questions were prepared to guide the conversation and included:

- Which animals are found in the area.
- What animals are rare in the area or have unique significance (of any kind)?
- Are there any human – wildlife conflicts in the area?
- Are there any wildlife movements experienced here?
- Are there places where some animals breed in this area?
- What is the effect of the existing Kamuzu Barrage to wildlife?
- Are you aware that there are plans to upgrade the Kamuzu Barrage at Liwonde?
- What will happen if water levels rise due to the upgrading of the Barrage?
- What will be the effect to wildlife?
- Do you have any suggestions on what could be done?

For some people and institutions there were additional questions that included:

- What was the situation before the Barrage was commissioned in 1965?
- What was the effect to wildlife soon after the Barrage was commissioned?

- What is the institutional position on the upgrading of the Barrage in respect to environmental issues?

Most of the key areas that cover the project area were visited (Table 1). Starting from the point where the mouth of the Shire leaves Lake Malawi we followed the river down to the Elephant Marsh to the south. Some of the areas surveyed were Mtongole village located at the mouth of Shire River as it leaves Lake Malawi, Chipeta, Mpanganjila, Chimwala, Kausi all located to the west of Lake Malombe and Kadewele village to the east of Lake Malombe. The survey also included the Shire River at Mangochi, Kamuzu Barrage at Liwonde, Liwonde National Park and Mvuu Camp. Further south we visited the Shire River at Chikhwawa, the Elephant Marsh, Majete Wildlife Reserve and Kapichira Power Station.

TABLE 1. PLACES VISITED BY THE WILDLIFE EXPERT IN THE PROJECT AREA IN OCTOBER 2011

District	Village/Area	Remarks
Mangochi	Mtongole, Chipeta, Mpinganjila, Kadewele (Mpondas), Chimwala, Kausi	These villages except Kadewele appear to the west of Lake Malombe. Kadewele is on the eastern shores of Lake Malombe
Machinga	Liwonde National Park, Mvuu Camp	These include some of the prime wildlife areas, key wildlife habitats and tourism
Balaka/Machinga	Kamuzu Barrage at Liwonde	This is the actual site of the project and Shire River is the boundary between the two districts
Chikhwawa	Slopes of Shire plateau overlooking the rift valley near Chikhwawa	This is a catchment area that has been seriously affected by destruction of vegetation and wildlife habitat
Chikhwawa	Kamuzu Bridge at Chikhwawa	Borders SUCOMA sugar cane plantation
Chikhwawa/Nsanje	Elephant Marsh	A vast wilderness area currently threatened by human encroachment and cultivation
Chikhwawa	Majete Wildlife Reserve and Kapichira Power Station	This is a reserve that is rapidly improving in conservation and tourism. The power station is located inside the reserve.

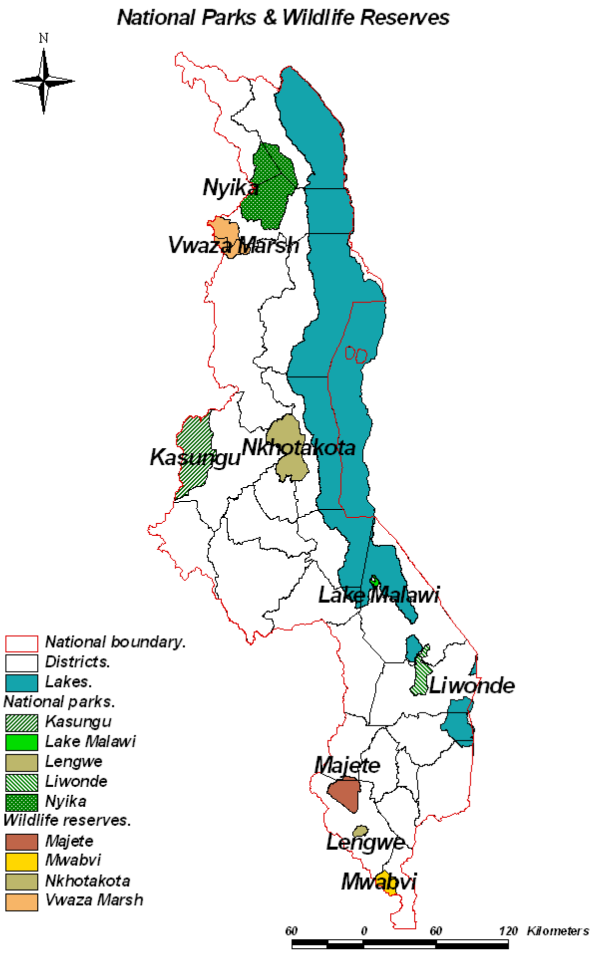
At least 56 people were interviewed and provided information on wildlife related to the project area. They include villagers, chiefs, village headmen, fishers, wildlife managers, NGOs and government officials (Appendix 1).

Potential impacts to wildlife anticipated from the changed flow conditions downstream of the Barrage and changed water levels upstream have been predicted based on the ecology and sensitivity of the individual species found in the impacted areas. It involved the assessment of species habitat utilisation of the flooded area and potential risks when the species is denied use of the habitat due to inundation. For other groups including migratory birds and animals a community ecology approach was used based on the collective ecological requirements of the species utilising the project area particularly the wetlands as a refuge area. The impacts were therefore ranked depending on the possible severity of the impact if the species or community is denied access to the habitat or the habitat is destroyed or degraded by inundation due to the refurbished Barrage or from floods. Experiences gained from what happened to the wildlife from the impacts of the Barrage commissioning in 1965 have been taken into account.

2 Description of the Existing Environment

2.1 Wildlife Habitats

The project area spans over a variety of habitats from open water, floating meadows, lagoons and reeds, floodplain grassland, woodland and mixed woodlands. The immediate (riparian) habitats along the Shire River and Lake Malombe include wetlands, open grasslands and mixed woodlands. Wetlands and open short grasslands occupy most of the floodplains. The extent of coverage varies from place to place but the project area being generally flat allows water stagnation during flooding and rain. There are also a number of protected areas within the project area including Liwonde National Park and Majete Wildlife Reserve (Figure 1).



(Source: Department of National Parks and Wildlife)

Figure 1. National Parks and Wildlife Reserves within the Project area

2.2 Critical Habitats

In the World Bank's Natural Habitats Policy (OP 4.04), critical natural habitats are defined to include most types of protected areas, as well as other areas of known high conservation value. Critical habitat can also be construed as habitat that is essential for maintaining the integrity of an ecosystem, species or assemblages of species. Evaluation of the habitats in the project area with the associated species which utilise the habitats and taking into consideration the ecology of the species and community ecology the habitats shown in Table 2 can be considered as critical habitats responsible for the survival of a number of species in the project area.

TABLE 2. CRITICAL HABITATS IN THE PROJECT AREA

Type	Significance	Remarks
Open water	Important habitat for hippopotamus, crocodiles, terrapins, amphibians, fresh water invertebrates and other species	Open water habitat will increase upstream of the Barrage so these species will benefit from predicted changes
Sand banks (beaches) along Lakes Malawi and Malombe and along Shire River	Nesting areas for crocodiles and terrapins	Lack of these habitats or being inundated will prevent these species from breeding affecting their recruitment and population growth
River sandbars	Serve as roosting and nesting areas for African Skimmers and other birds including waterfowl	Inundation of river sandbars from regulated flows downstream and from higher water levels upstream will reduce the habitat for African Skimmers
Emergent boulders in middle Shire River channel	Habitat for the highly localised Rock Pratincole (*Glareola nuchalis*)	Inundation of boulders from higher regulated flows will reduce habitat for the Rock Pratincole
Reeds	Breeding areas for some birds including weavers	Loss or degradation of these habitats through destruction or inundation will affect recruitment of a number avian species
Riparian short grasslands on river or lake banks	Important grazing area for many herbivores especially during the dry season when most other areas are dry and void of grass and water.	Inundation of short grasslands along river and/or lake banks will negatively impact many herbivore species in the project area
Mopane woodland	Prime habitat and breeding area for the threatened Lillian's Lovebird and also important habitat for many herbivores	Destruction of mopane woodland will affect the lovebird and other species. However, 70% of Liwonde National Park is covered by mopane woodland and inundation may likely affect a very small portion of the woodland. As such flooding is not really an immediate threat to the survival of Lillian's Lovebird.
Riverine vegetation including *Brachystegia* wooded grassland in Majete Wildlife Reserve	Habitat for the reintroduced black rhinoceros in the reserve.	This is a critically endangered species which has been recently reintroduced into the reserve and is progressing well. The riverine habitat is affected by flooding from the Shire River which will impact on the rhinos. The Barrage does not exacerbate natural flooding in the Shire River.
Marshes and wetlands	Critical habitat for migratory birds	Palaearctic and intra African migratory birds utilise the marshes and wetlands in the project area as winter refuge and breeding areas. The marshes and mud flats harbour invertebrates and other small vertebrates that are food for the birds. Wetland vegetation is susceptible to a change in flood regime which may result in a change in the habitat and ecology of the affected area.

The Shire River system which includes the project area from Lake Malawi down to the Zambezi River comprises of various habit types described earlier including sand bars, sand beaches and emergent boulders. The occurrence of these habitats in the system depends on various factors such as geomorphology, nature of parent rock and soils, terrain and volume of flowing water. Sand bars, beaches and emergent boulders are important habitats for various fauna species depending on where the habitat is located, human influence and season of the year.

2.2.1 Sand Bars

A sand bar may be described as "a long mass or low ridge of submerged or partially exposed sand built up in the water along a shore or beach by the action of waves or currents". Usually these are found in mature river systems or beaches with gentle or flat gradient and where the water flow is not very fast. Most are formed from deposition of sand and alluvium or may be formed following water recession due to reduced water flow. Sand bar presence depends on the amount of water flowing and may be covered under water or even disappear during floods.

In the project area sand bars were observed in a number of places visited. They appear from where the Shire River leaves Lake Malawi to Lake Malombe and downstream to locations such as Mvuu Camp in Liwonde National Park (Figure 2) and Elephant Marsh. No attempt was made to document all sand bars in the project area but those encountered during the field work were noted. Nevertheless local people report of presence of sand bars in many parts of the Shire River. In some locations such as Kausi village some vegetation patches were observed in the middle of the river which later due to water currents and erosion the vegetation may die away and remain with emerged sand bars.

African Skimmers (*Rynchops flavirostris*), waders and other water birds are some of the major users of the sand bars along the Shire River. AEWA (1998) reports that the skimmer is an intra-African or Afrotropical migrant associated with the Zambezi river system and it appears in both the Bonn Convention and AEWA appendices of migratory species. It is usually present in the area between April and December. The species migrates up and down larger rivers, and to and from inland lakes, dispersing widely after the breeding season. Migration is driven by the need for calm weather. African skimmers require a 'predictable' river level that neither floods out of season nor drops so much that the birds are exposed to terrestrial predators. AEWA (1998) further reports that the species has an unfavourable conservation status due to the dam activities in the Zambezi basin, and the need for unseasonal river flow for the production of hydroelectricity. This makes the sandbars no longer safe from floods, and rocks emerge too far out of the river and banks are undercut by unseasonable flow (and also by speed-boat activity) all with a potential risk to the survival of the species. The African Skimmer is "ecologically dependent on wetlands" specifically rivers. In addition, the Skimmer is very vulnerable to tourists' activities.

According to the IUCN red list (2012) the African Skimmer is near threatened (NT) and it requires expanses of calm water for feeding. Breeding takes place during the dry season when rivers are at their lowest and sandbars most exposed. This generally occurs from July to November south of the equator. Breeding takes place along broad rivers on large, dry sandbars that are largely free from vegetation (IUCN red list 2012). In Malawi the Shire River is the main habitat and breeding area for the African Skimmer. Pairs nest in loose colonies and lay clutches of one to four eggs in a large usually unlined scrape in the sand. Scrapes occur within 30 m of water but receding water levels may increase the distance. The incubation period is about 21 days.

2.2.2 Sand Beaches

A sand beach may be described as a gently sloping zone where deposits of unconsolidated sediments are subject to wave action at the shore of an ocean, lake or river. Most of the sediment making up a beach is supplied by rivers or by the erosion of highlands adjacent to the coast. Beaches extend from a low waterline landward to a definite change in material or physiographic form, such as the presence of a cliff or dune complex marking a clear demarcation of the edge of a coast or beach. In the project area sand beaches occur along parts of the Shire River and Lake Malombe (Figure 3). Beaches are only found in places where there is very gentle or almost flat gradient to the water level. Rocky banks or cliffs do not allow formation of beaches.

Sand beaches are important habitats for crocodiles and in most cases crocodile conservation is in direct competition with other forms of land use such as agriculture and fisheries (Figure 4). Crocodiles need sand banks as nesting sites but the same sites are required as boat yards by fishers and as recreation areas. In marshy areas crocodiles need the islands as nesting sites but these are required for "dimba" cultivation (dry season cropping). For example in the Lower Shire Valley dimba land supplies a considerable proportion of total food production and it appears that dimba production is increasing in importance (Mphande, 1987). On the other hand young crocodiles tend to hide in the reeds and bask in isolated areas which are not easily accessible making these habitats also vital for the recruitment and survival of crocodile populations.

One of the threats reported previously to the crocodile population has been the closing of Kamuzu Barrage gates on the nesting crocodiles in Liwonde National Park. The Barrage is opened and closed to regulate the flow of water in the middle Shire for hydroelectric power generation. The closure of the Barrage causes a rise in the water level in the Liwonde National Park. The Barrage is normally closed after the crocodiles have laid their eggs (i.e. October) hence submerging the eggs. The Barrage in such years is a major mortality factor for the crocodiles. Ways and means have to be found to alleviate this problem. A compromise solution between the Ministry of Forestry and Natural Resources and ESCOM was proposed to be worked out and if possible the Barrage should be closed before crocodiles start nesting i.e. August (Mphande 1987). The average incubation period for crocodiles is about 80 days and by laying their eggs in October hatching would take place at the beginning of the long rainy season which starts in November and runs up to April.

Terrapins (turtles living in fresh or brackish water) are reported to occur in the project area occupying logs, rocks and mud banks while in the rainy season they are common in isolated pans and waterholes. Nesting takes place in October – November at the beginning of the rainy season and hatchlings emerge in November to January. Nests are vulnerable to predation by water monitors and mongoose (Broadley and Boycott 2009).

2.2.3 Emergent Boulders

These are rock outcrops found along river valleys above water level. They are formed in areas where the geomorphology comprise of hard rock not easily eroded by water current or other erosion agents. Rock outcrops are common in the middle Shire for about 80 km from Matope to Chikhwawa and south wards to the Majete Wildlife Reserve. On this stretch the river is characterised by rock bars and outcrops. Some areas of the Shire River, like parts of Mvuu Camp, are characterised by steep rocky banks. Series of rapids were observed along the Shire River at Kapichira power station located within Majete Wildlife Reserve but photos could not be taken due to security restrictions covering the area. The rocky islands of the Shire River in the Majete Wildlife Reserve provide habitat for breeding populations of the Rock Pratincole (*Glareola nuchalis*).

The Rock Pratincole is another intra-African or Afrotropical migrant in the Zambezi River system, appearing in July and leaving sometime in December or January though it is reported to be endemic in the Majete area. It also requires a 'predictable' river level that neither floods out of season nor drops so much that the birds are exposed to terrestrial predators. This little bird nests on the emergent rocks in white water areas, often near waterfalls. It is classified as "Least Vulnerable" on the IUCN Red Data List, the Rock Pratincole is widely distributed in Africa.

2.3 Fauna Biodiversity (species diversity/richness, distribution, movements)

The project area is rich in biodiversity particularly the Liwonde National park (Table 3). Wildlife is found in almost all villages surrounding the project. However the eastern banks of Shire River record more species than the western banks possibly due to having greater wilderness areas and easy mobility of wildlife in the areas. The western parts are more populated with increased human activities that include farming, settlements and infrastructure development.

TABLE 3. SUMMARY OF WILDLIFE POPULATION TRENDS IN LIWONDE NP AND SURROUNDING FROM 2004 TO 2009

Species	Population Estimate					
	2004	2005	2006	2007	2008	2009
Elephant	604	1064	751	857	805	928
Waterbuck	1,522	2,524	2,451	2,517	2,566	3,539
Impala	983	3,656	2,356	3,187	2,652	4,163
Sable	457	869	800	508	527	736
Warthog	1,323	1,246	1,655	1,618	1,547	3,156
Bushbuck	260	374	399	297	449	604
Kudu	70	200	207	314	187	409
Common duiker	71	184	111	156	146	325
Bush pig	19	40	NR	NR	NR	NR
Reedbuck	72	86	39	76	89	72
Klipspringer	6	8	NR	NR	NR	NR
Grysbok	14	50	NR	NR	NR	NR

Species	Population Estimate					
	2004	2005	2006	2007	2008	2009
Suni	4	2	NR	NR	NR	NR
Buffalo	425	388	553	657	781	864
Eland	76	53	63	71	62	79
Zebra	58	66	110	65	74	78
Hartebeest	54	56	100	89	70	118
Roan	38	42	45	40	43	43
Black rhino	NR	8	8	8	10	11
Oribi	NR	4	NR	NR	NR	NR
Hippopotami	NR	926	NR	NR	1,136	NR
Crocodile	NR	534	NR	NR	3,105	NR

(Source: Liwonde National Park 2004, 2005, 2006, 2007, 2008, 2009a, 2009b); NR: No records available

2.4 Species of Conservation Interest

There are many species of conservation interest. Records show that a number of protected areas in the project area now harbour reintroduced species after the previous populations became locally extinct mainly due to hunting or habitat loss. Of key interest are rhinos, roan antelopes, leopards, buffaloes, eland and zebra. There are also species translocated to Liwonde National Park from Kasungu National Park in the north in order save them from local extinction. However, wildlife population trends from the annual census conducted by Liwonde National Park suggest that the populations of most large game species are stable. There also other species of birds, reptiles, amphibians and selected invertebrates of conservation interest. For example, the globally near-threatened African Skimmer is dependent on river sandbars (surrounded by water) for roosting and nesting, so it only occurs along the Shire River when water levels are low enough for the sandbars to be exposed. Three turtles classified as Least Concern (LC) on the IUCN Red List occur within Malawi. The Yellow-bellied Turtle (*Pelusios castanoides*) is the most common while the East African Black Mud Turtle (*Pelusios subniger*) and African Helmeted Turtle (*Pelomedusa subrufa*) are rarely mentioned though their range of distribution includes Malawi.

Yellow-bellied Turtles are semi-aquatic and are found in rivers, marshes and swamps. This is the turtle which is commonly reported in Malawi and appears among the fairly common reptiles found in the marshes and swamps. It feeds mainly on large pulmonate snails and floating water lettuce. The Yellow-bellied Mud Turtles in captivity from Malawi are reported to lay about 25 eggs towards the end of September. It is also reported that during the dry season, this species may aestivate in the mud.

The East African Black Mud Turtle eats insects, worms, snails, small fish, amphibians, crabs and aquatic plants that grow in water such as water grasses. These turtles are generally nocturnal but will bask in the sun or wander about on land during the rainy season. East African Mud Turtles tend to like a watery habitat and if their river or pond dries up during the dry season they may 'aestivate' in underground burrows when the temperatures become too warm, too cold, or conditions become too dry, re-emerging again when conditions return to a suitable level when water returns. In captivity, the East African Black Mud Turtle has been recorded laying its eggs in February and March, with hatchlings emerging around 58 days later (when incubated at 28 to 30°C), although this may vary with location. Three to twelve eggs are produced per clutch by the female and buried in a flask-shaped nest cavity.

African Helmeted Turtle also known as the Marsh Terrapin or Crocodile Turtle are semi-aquatic, living in rivers, lakes, and marshes, and they also like rain pools and places that are fertilised. The species is omnivorous and will eat almost anything including insects, small crustaceans, fish, earthworms, and snails. They may also feed on carrion. The fine claws on its feet help it tear its prey apart. Groups of these turtles have been observed capturing and drowning larger prey such as doves when they come to drink, the commotion caused by these group attacks is often mistaken for crocodiles. The female will lay 2 to 10 eggs on average, normally during late spring and early summer. The eggs are placed in a flask shaped nest that is about 10-18 cm deep. The eggs hatch in 75– 90 days.

3 Environmental Impacts

3.1 Identification of Key Impacts to Wildlife

Rapid assessment of the situation suggest that some of the immediate impacts that may arise from changed flow regime downstream and changed water levels upstream of the Barrage include loss of habitat for some species due to inundation, loss of breeding areas for crocodiles and terrapins and loss of habitat for migratory birds. A summary of impacts is provided in Tables 4 and 5. Second level impacts may involve increased competition for resources between species and human wildlife conflicts. However flooding will have a dual effect on some wildlife species depending on the ecology of the species. One of the key species of conservation interest the Lillian's Lovebird is not greatly threatened by the rising water levels because most of its habitat is located upslope from the river channel and floodplains.

There may be some impacts to tourism again depending on the effect of rising water levels on species as well as tourism infrastructure and navigation systems.

TABLE 4. POTENTIAL IMPACTS ON KEY WILDLIFE HABITATS

Type	Significance	Potential Impacts
Open water	Important habitat for hippopotamus, crocodiles, terrapins, amphibians, fresh water invertebrates and other species	Open water habitat will increase upstream of the Barrage so these species will benefit from predicted changes
Sand banks	Nesting areas for crocodiles and terrapins	Loss of these habitats will prevent these species from breeding affecting their recruitment and population growth
Sand bars	Essential roosting and nesting habitat of the globally near-threatened African Skimmer.	Loss of these habitats will prevent these species from breeding affecting their recruitment and population growth
Reeds	Breeding areas for some birds including weavers	Loss or degradation of these habitats will affect recruitment of a number of avian species
Seasonal Floodplains	Important grazing area for many herbivores especially during the dry season when most other areas are dry and void of grass and water.	Increased inundation of short grasslands will negatively impact many herbivore species in the project area
Mopane woodland	Prime habitat and breeding area for the threatened Lillian's Lovebird and also important habitat for many herbivores	Loss of Mopane woodland would affect the lovebird and other species. However, 70% of Liwonde National Park is covered by Mopane woodland and inundation is likely to affect only a very small portion of the woodland. As such flooding is not really a threat to the survival of Lillian's Lovebird
Emergent boulders in Shire River channel	Habitat for a localised bird species rare in Malawi, the Rock Pratincole	This is a riverine habitat found in Majete Wildlife Reserve and can be significantly affected by flooding in the Lower Shire River. The Rock Pratincole is confined to this type of habitat and is rare in Malawi.
Riverine vegetation in Majete Wildlife Reserve	Habitat for the reintroduced black rhinoceros in the reserve.	This is a critically endangered species which has been recently reintroduced into the reserve and is progressing well. The riverine habitat can be affected by flooding and hence threaten the survival of the rhinos.
Marshes and wetlands	Critical habitat for migratory birds	Palaearctic and intra African migratory birds utilize the marshes and wetlands in the project area as winter refuge and breeding areas. The marshes and mud flats harbour invertebrates and other small vertebrates that are food to the birds. Some wetland vegetation cannot withstand long term/permanent inundation and would immediately rot changing the habitat and ecology of the affected area

TABLE 5. WILDLIFE IMPACT CORRELATION MATRIX FOR THE PROPOSED UPGRADING OF KAMUZU BARRAGE

Environmental parameters/impacts	Activities				
		Mobilization phase	Construction phase	Operation phase	Remarks
Species diversity	Large mammals	-1	-1	-1	Human activities often have a tendency of displacing large mammals even if the activities do not directly affect them but the associated disturbances do.
	Birds	-1	-1	-1	Human disturbances will displace some bird species
	Reptiles	0	-1	0	Construction activities may keep away some reptiles but would return after construction.
	Amphibians	-1	-1	0	Construction activities will chase away some amphibians.
	Invertebrates	-1	-1	-1	Many invertebrates including insects will possibly be affected at all stages of the project construction and operation.
	All groups downstream	0	0	+2	Ensuring minimum adequate regular water flow downstream will enhance survival of a number of wildlife species.
Species recruitment	Crocodiles	0	0	-2	Inundated sand banks with nests will affect recruitment.
	Terrapins African Skimmer	0	0	-2	Inundated sand banks with nests will affect recruitment.
	Lillian's Lovebird	0	0	-1	Most of the Mopane woodland which is the breeding ground for Lillian's Lovebird is found in uplands and will not be affected by flooding.
	Rock Pratincole	0	0	-2	This bird breeds and roosts on emergent boulders in the Shire River in the Majete Wildlife Reserve. Flooding has already been reported to reduce its habitat.
	Other birds	0	0	-1	Many birds especially weavers breed in the reeds and other vegetation in marshes/wetlands which rot easily when submerged for long periods of time.

Environmental parameters/impacts	Activities				Remarks
		Mobilization phase	Construction phase	Operation phase	
Wildlife movement	Hippos	0	0	-1	Barrage is a partial barrier for hippos to move upstream or downstream
	Crocodiles	0	0	-1	Barrage is a partial barrier for crocodiles to move upstream or downstream
Seasonal Floodplains		0	0	-2	Critical habitat for herbivores during dry season
Riparian wooded habitats		0	0	-1	Important habitats for black rhino and elephants. The refurbished Barrage will only have a minor impact on riparian woodlands.
Water availability for wildlife		0	0	+3	Barrage has ensured water is available to wildlife both upstream and downstream

Key: -1=Mild Adverse; -2=Adverse; -3=Highly Adverse; +1=Mild Beneficial; +2=Beneficial; +3=Highly Beneficial; 0=No impact.

4 Environmental Mitigation Measures

Table 6 provides some mitigation measures proposed to be included in the environmental management plan for the Project for the purpose of minimising adverse impacts arising from Project activities. These mitigation measures are supported by the suggested monitoring outlined in Table 7.

Mitigation measures for restriction of wildlife movement (crocodiles and hippopotamus) are considered unnecessary since the Barrage acts as a partial barrier only and habitat immediately downstream is not favourable to these animals. Barrage gates are normally fully open during extreme low and high flows in the Shire River allowing some movement of animals. The Middle Shire River system is characterised by a narrow rocky channel and fast flowing water with the presence of several rapids and waterfalls (e.g. Kapichira Falls) which are not favoured habitat for crocodiles or hippopotamus. Crocodiles and hippopotamus are also found in abundance in the Lower Shire, particularly in the floodplain wetlands of the Elephant Marsh suggesting wildlife movement is not an issue since the Barrage has been operating since 1965.

Construction works and associated site clearing and vehicle movements may cause minor environmental impacts which can be mitigated by avoiding construction works in the rainy season as well as keeping vegetation clearance to a minimum. Construction teams should be provided with adequate food rations to avoid poaching of wild animals as well as coking fuel to avoid cutting of trees or use of charcoal.

Following the approval and implementation of the project there is a demand for continuous improvement and follow up of the environmental performance within the project system. Environmental monitoring is a process which, when being carried out in a participatory way, can constitute a powerful instrument to raise awareness, to train people and to improve insights in ecological processes and environmental impacts (Kessler 1998). Table 7 provides some of the initial monitoring attributes, indicators and protocols for identified issues in the current project.

TABLE 6. SUMMARY OF PROPOSED MITIGATION MEASURES FOR THE ADVERSE EFFECTS ARISING FROM UPGRADING OF KAMUZU BARRAGE

Impact	Cause	Affected Fauna	Effect	Status	Proposed Mitigation
Species diversity	Change in inundation patterns upstream of Barrage	Large mammals and other species	Flooded areas scare animals away	Short and long term	Controlled flooding upstream is practised to ensure only the necessary water rise is effected to allow limited flooding of wildlife habitat
Habitat destruction, degradation	Flooding of riparian vegetation in Majete	Rock Pratincole	Habitat destroyed by flooding	Short and long term	Barrage operation to regulate water flow downstream to avoid/minimise inundation of river boulders during the breeding season.
Flooding of riparian short grasslands	Change in inundation patterns upstream of Barrage	Herbivores including hippopotamus, impala, waterbucks, warthogs and many other species	Loss of existing Grassland habitat	Short term	This is an important dry season grazing refuge for herbivores in the project area. Limiting water rise will help to reduce the grassland area that will be covered by water
Flooding of reeds, marshes and other wetland vegetation	Change in flow pattern downstream of Barrage	Migratory bird communities	Habitat affected by changing water levels due to new regulated flow regime	Short term	Regulate water levels to maintain the marshes and mud flats supporting migrating birds
Impaired breeding of wildlife species	Inundation of sand banks and bars used as nesting areas	Crocodiles and terrapins	Destruction of the nests and eggs	Short to long term	Barrage operation to limit water rise upstream during critical breeding periods

Note: National Parks staff should be involved in the institutional structures for managing Barrage operation.

TABLE 7. WILDLIFE MONITORING IN UPGRADED KAMUZU BARRAGE PROJECT AREA

Monitoring attribute	Monitoring indicators	Protocols	Cost (USD)
Species diversity	Number of species in areas affected by flooding as a result of Kamuzu Barrage operation	Estimating species diversity/richness on annual basis	30,000
Species performance	Performance of Rock Pratincole (in Majete), elephants and Lillian's Lovebird	Population abundance, structure and distribution evaluated periodically	20,000
Recruitment of species of interest	Population growth of crocodiles and terrapins	Census of crocodiles and terrapins and studying population structure conducted periodically	30,000
Migratory bird communities	Presence and number of migratory birds in marshes and wetlands in the project affected area	Observation of migrating birds based on number of species/individuals, timing, duration of stay on annual basis	15,000
Riparian short grasslands within Liwonde National Park and Majete Wildlife Reserve	Expanse and utilisation	Measuring the size and spatial distribution of the grasslands and level of utilisation including number of species utilising the grasslands conducted periodically	50,000

Note: Coverage of studies is considered to include the whole Shire River catchment from the source at Lake Malawi to the point it enters the Zambezi River. National Parks staff should play an important part in monitoring programs especially within Liwonde National Park and Majete Wildlife Reserve.

5 Conclusion

The construction works and associated vegetation clearance (including quarry site and sand/gravel borrow areas) cover a small area and the impacts will be minor and temporary.

The proposed monitoring to collect data on the health and distribution of riparian habitats within Liwonde National Park and Majete National Park, as well as monitoring of specific wildlife species (elephant, hippopotamus, crocodile, African Skimmer) will lead to better operation of the Barrage. This in turn will result in the long term preservation of habitats and improved biodiversity.

Careful adherence to mitigation measures such as those outlined in Table 6 will be taken to avoid/minimise negative impacts from the Project. Consequently, increasing the regulating capacity of Kamuzu Barrage by raising the highest regulated water level by 20-40 cm by upgrading the Barrage is not expected to have significant adverse effects on wildlife populations in the project area.

The combined ecological impacts from the project are expected to result in a minor negative overall balance.

6 Reference Material

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Figure 2. Sand bars in the middle of the Shire River and floodplain in Liwonde National Park close to Mvuu Camp.

Figure 3. Sand beach at Namakazo area of Mpiganjila village on the western shores of Lake Malombe. Note water birds utilising the sand beach.

Figure 4. A beach at Mwalija or Chimwala village is used by residents for domestic chores (washing, bathing, fetching water) and as fish landing site.

Figure 5. Sand beach at the Elephant Marsh

Figure 6. Shire River at Chipeta village looking across the river. Open water habitat is one of the critical habitats for a number of fauna species including Hippopotamuses (14.10.2011).

Figure 7. Namakazo beach at Mpiganjila village. Note goats grazing on grass on the lake beach. Flooding of the beach will also affect livestock grazing areas. Beaches like this are important for crocodile and terrapin nesting (15.10.2011).

Figure 8. Impala and waterbuck grazing on the floodplain in Liwonde National Park. Flooding from the Barrage could temporarily inundate some low lying grassland areas and reduce the wildlife grazing area. Note the Shire River on the horizon (16.10.2011).

Figure 9. Mopane woodland in Liwonde National Park. Lillian's Lovebird is reported to use crevices of the mopane trees for breeding. Such woodlands are critical for the survival of this threatened species. Over 70% of Liwonde National Park is covered by mopane and most is not at risk of being flooded by Barrage operation (16.10.2011).

Appendix 1: People Met During Field Work in the Project Area (October 2011)

SN	Name	Title	Affiliation	Contacts
1	Felix Kalowekamo	Lecturer	Bunda College of Agriculture	
2	Mariam Binali	Ag. Chief	Mtongole Village	
2	Daniel Wayson	Villager	Mtongole Village	
3	Emily Chipeta	Village Headman	Chipeta Village	
4	Kawile Susa	Villager	Chipeta Village	
5	Metrina Khan	Villager	Mpiganjila Village	0995518996
6	Kondani Sekambwa	Fisherman	Mpiganjila Village	
7	Emmanuel Chilungamo	Fisherman	Mpiganjila Village	
8	Rajabu Samuel	Fisherman	Mpiganjila Village	
9	Paul John Namakasu	Village Headman	Mpiganjila Village	
10	Rashid Moses Khan	Villager	Mpiganjila Village	0994353375 0881740411
11	Margreth Anton	Villager	Chimwala/Mwalija Village	
12	Idrissa Ali Abdul	Fisherman	Chimwala/Mwalija Village	
13	Augustine Michael	Fisherman	Chimwala/Mwalija Village	
14	Biriad Bwanali	Fisherman	Chimwala/Mwalija Village	
15	Frank Chalo	Fisherman	Chimwala/Mwalija Village	
16	Sifa Denson	Fisherman	Chimwala/Mwalija Village	
17	Haji Samson	Fisherman	Chimwala/Mwalija Village	
18	Yusuph Sunje	Fisherman	Chimwala/Mwalija Village	
19	Omaa Augustine	Fisherman	Chimwala/Mwalija Village	
20	Jaffari Dickson	Fisherman	Chimwala/Mwalija Village	
21	Kassin Dayton	Fisherman	Chimwala/Mwalija Village	
22	Fatina Augustine	Fisherman	Chimwala/Mwalija Village	
23	Tole Manyozo	Fisherman	Chimwala/Mwalija Village	
24	Askot Danken	Fisherman	Chimwala/Mwalija Village	
25	Maumbo Mmadi	Fisherman	Chimwala/Mwalija Village	
26	Michael Thomas	Fisherman	Chimwala/Mwalija Village	
27	Michael Thomas	Fisherman	Chimwala/Mwalija Village	
28	Rome Sindi	Fisherman	Chimwala/Mwalija Village	
29	Hamilton Wailess	Fisherman	Chimwala/Mwalija Village	
30	Lucy Kaluwa	Villager	Kadewele Village	
31	Loveness Kadewele	Villager	Kadewele Village	
32	Loveness Masanga	Villager	Kadewele Village	
33	Lucy Bula	Villager	Kadewele Village	
34	Wetu Edward	Villager	Kadewele Village	
35	Leonard N'gisi	Villager	Kadewele Village	
36	Nsaku Kawina	Village Headman	Kadewele Village	
37	Machinga Dayton	Chairman, Village Beach Committee	Kadewele Village	
38	Manyozo John	Villager	Kadewele Village	

SN	Name	Title	Affiliation	Contacts
39	Daton Mustapha	Villager	Kadewele Village	
40	Wilson German	Villager	Kadewele Village	
41	Hauvi James	Villager	Kadewele Village	
42	Musa Lesta	Chief	Kausi Village	
43	Yunus Yusuph	Villager	Kausi Village	
44	Eneress Mustapha	Villager	Kausi Village	
45	Esnath Jasten	Villager	Kausi Village	
46	Mariam Akim	Villager	Kausi Village	
47	Fatma Alaton	Villager	Kausi Village	
48	Angel Gondwe	Safari Guide	Mvuu Lodge	
49	Dinara Kankhuni	Camp Manager	Mvuu Lodge	
50	Charlington Banda	Parks Assistant	Liwonde National Park	
51	Benson Kandyero	Wildlife Scout	Liwonde National Park	
52	Sam Nyanyale	Divisional Manager	Liwonde National Park	0888876743 01570007
53	McPhillip Mwithokona	Head, Wildlife Management Unit	Liwonde National Park	0881055430
54	Blessings Msikuwanga	Research Officer	Liwonde National Park	0884445756 0999930931
55	Mavuto Kulinji	Parks Assistant	Liwonde National Park	
56	Michael Holics	Team Leader	SMEC, Lilongwe	+265992159192 +265 1 927261
57	Dr. Mrityunjay M. Jha	Team member	SMEC, Dar es Salaam	+255689555512
58	Murphy Kajumi	Sociologist	SMEC, Lilongwe	0999897423 0888897423
59	Sulemani Shuvah	Boatman (Elephant Marsh)	Tambo Village	
60	Nicholaus Finta	Boatman (Elephant Marsh)	Nyang'a Village	
61	Ronick Hale	Fisher (Elephant Marsh)	Sabora Village	
62	Patricio Ndadzela	Project Manager	Majete Wildlife Reserve	9999 65027
63	Shadrack Chado	Senior Operations & Electrical Maintenance Engineer	Kapichira Power Station	1 429 006/007 012 09 427 600
64	Clement Mbota	Deputy Director (Wildlife Management)	Department of National Parks and Wildlife - Lilongwe	09 297 903
65	Chiza Manda	Assistant Director (CS)	Department of National Parks and Wildlife - Lilongwe	0991 332 533 0888 351 320
66	Vicent Kaitano	Manager	Wildlife and Environmental Society of Malawi - Lilongwe	
67	Wilfred Ndovi	Project Coordinator (Sustainable Management of Wildlife through CBRM)	Department of National Parks and Wildlife - Lilongwe	08203771 01751402 01762332
68	Sosten Lingwalanya	Deputy Director	Department of Tourism	1775499 999933679
69	Kasizo Chirambo	Assistant Director	Department of Forestry	01771761 888879271 999274110

Appendix 2: Description of Field Activities in the Project Area by the Wildlife Expert in October 2011

Date	Day	Description of duties
8	Saturday	Review of inception project report and other documents submitted by SMEC. Literature search on Liwonde National Park, Species of conservation importance at the project area including Hippopotamus, Elephants, Crocodiles and Lillian's Lovebird.
10	Monday	Travel from Dar es Salaam to Lilongwe. Arrive at SMEC country office at Lilongwe meet with Team Leader Michael Holics, SMEC Country Manager Stayford Phiri, another team member Dr Mrityunjay Jha and local counterpart Mr Felix Kalowekamo. Received project briefing from Team Leader, had orientation of the SMEC offices and started project document review.
11	Tuesday	Working meeting with local counterpart Mr Felix Kalowekamo, held discussions of the wildlife issues in the project area and the existing field situation. In collaboration with the Team Leader Mr Michael Holics we planned the field visit to Liwonde and surrounding areas, logistics and key areas and people to meet in the field. Continued with document review at SMEC offices in Lilongwe.
12	Wednesday	Worked from the SMEC offices in Lilongwe. Continued with documents review of previous studies in the project area. Reviewing the field visit plan with team leader Michael Holics and Local counterpart Mr Felix Kalowekamo following fuel shortage at Lilongwe.
13	Thursday	Worked from SMEC offices in Lilongwe. Continued with documents review and planned for a revised field visit itinerary with the team leader, local counterpart Mr Felix and secretary Ms. Evelyn. Finalised transport hire for the field trip and other logistical arrangements. Confirmed to leave for field work on the next day i.e. Friday 14th October 2011.
14	Friday	Travelled from Bridge View Hotel in Lilongwe with local counterpart Mr Felix Kalowekamo to the project area in Mangochi District. Heading southwards from Lilongwe we branched eastwards at Masasa junction and descended into the rift valley. First we visited Mtongole village in the afternoon where the source of Shire River is located. We met the Acting Chief Mariam Binali and other villagers. We visited the source of Shire river from Lake Malawi and discussed with the Chief about the wildlife issues and possible impact of the improved Kamuzu Barrage to the area. We later moved to Chipeta village where we met the Village Headman Emily Chipeta. We discussed with her again the wildlife issues and later visited the Shire river at the village. At his point we could see across the river the marshes to the south east end of Lake Malawi which are believed could be inundated during floods or by water flow control at the barrage. The marshes are reported to have sand bars where crocodiles put their nests. Later we proceeded to Mangochi where we visited again the Shire River at Mangochi and the Bakili Muluzi Bridge. We spent the night at Mangochi.
15	Saturday	Started off at around 8am in the morning and managed to visit four villages surrounding Lake Malombe, one village on the eastern shores and three villages on the western shores. At Kadewele village on the eastern side of Lake Malombe we managed to meet the Village Headman Kadewele, Beach Village Committee Chairman Machinga Dayton and other villagers and fishermen. We also visited the Chantoji beach and Nkuju crocodile nesting site. At Mpinganjlila village we met the village Headman Paul John Namakasu and other villagers and fishermen. We visited Namakazo area a fish landing site and sand bars. At Chimwala village we managed to speak to a number of fishermen and visit the Mwalija beach, also a fish landing area. The last village to visit was Kausi where we met the Chief Mussa Lesta and other villagers. The Chief took the liberty of taking the team to Tenesi beach and provided information on wildlife in the village and human wildlife conflicts they experience. As dusk was drawing in we started off to Liwonde and arrived at around 8pm and retired for the day.
16	Sunday	Started off at 8am to Liwonde National Park. Met the Scout guard on duty at the gate Mr Benson Kandyero who provided us with an escort scout Mr Charlington Banda who escorted us to Mvuu camp. On the way we managed to see many herds of wildlife suggesting that the Park is relatively rich in wildlife resources. At Mvuu camp we met with Camp Manager Mr Dinara Kankhuni and Tour Guide Mr Angel Gondwe. We discussed with them the issues of upgrading the Kamuzu barrage and its possible consequences on wildlife. The manager offered us a boat ride to see the effect of water currents and waves on the Shire River banks around the lodge, and he commented that rising water levels would exacerbate the problem hence affecting the camp

		infrastructure and consequently tourism. In the afternoon we came back and had a meeting with the Manager of Liwonde National Park Mr Sam Nyanyale.
17	Monday	In Malawi it is a public Holiday – Mother's Day but the top management of Liwonde National Park agreed to meet us for a discussion. We started off from Hippo View Lodge at about 8.30am and arrived at the LNP Headquarters in the Park. We had a discussion with the Division Manager Mr Sam Nyanyale, Research Officer Mr Blessings Msikuwanga and Head of Wildlife Management Mr McPhillip Mwithokona. After a two and a half hour meeting we proceeded to see the Lillian's Lovebird habitat and breeding site at Namisundu area, located within the Park. On our way back we visited the Kamuzu Barrage at Liwonde township. We returned to Liwonde after midday and spent the afternoon reviewing reports obtained from LNP.
18	Tuesday	Set off from Liwonde at around 8.30am and travelled through Zomba, Blantyre, Shire plateau to Kamuzu Bridge at road block Chikhwawa. Observed the Shire River. From the slopes of Shire plateau we could see the Shire meandering as it flows lazily towards the Zambezi and with a number of ox bow lakes and branched streams. We proceeded to the Elephant Marsh at Chilomo where we arrived late afternoon. Observed the marshes through navigating by canoe until late evening. Retuned to Chikhwawa where we spent the night.
19	Wednesday	Started off from Chikhwawa at about 8.30am after fixing a flat tyre, we proceeded to Majete Wildlife Reserve. At Majete we met the Project Manager Mr Patricio Ndadzela and discussed with him a number of wildlife issues. We proceeded to Kapichira Power Station and had a discussion with the Senior Operations and Electrical Maintenance Engineer Mr Shadreck Chado. We then started a long journey back to Lilongwe via Blantyre and Kamuzu Bridge at Zalewa. We arrived in Lilongwe at about 1900 hours.
20	Thursday	Reported back at the SMEC offices at Lilongwe and briefed the team leader on the field trip to the project area. Then in the company of the local counterpart we visited key people and offices in Lilongwe including National Parks and Wildlife, Lilongwe Sanctuary, Danish Hunters Association and the Environment. At the National Parks and Wildlife we met Mr Clement Mbota the Deputy Director (Wildlife Management), and Mr Chiza Manda, the Assistant Director (CS). At WESM we met the Manager Mr Vicent Kaitano and Project Coordinator (Sustainable Management of Wildlife through CBRM) Mr Wilfred Ndovi. We were not lucky to find any person at the Environment office as all of them had gone for a climate change symposium. We returned to SMEC offices and continued with review of various reports and documents availed to the team related to the ongoing assignment.
21	Friday	The day stated by visiting other key personnel who are stakeholders in the project. We managed to visit the Ministry of Tourism, Wildlife and Culture where we met the Deputy Director of Tourism (Marketing) Mr Sosten Lingwalanya and later we went to the Department of Forestry where we were able to meet the Assistant Director Mr Kasizo Z. S. Chirambo. We returned to the office and continued with review of documents and reports and also discussed with team leader issues related to report writing.
22	Saturday	Continued with review of documents and other literature and started initial stages of designing the report format and preparations for a return journey back to Tanzania the next day.
23	Sunday	Spent the morning hours working on the draft report and later at around 10.30am left for the Kamuzu International Airport in Lilongwe and flew to Dar es Salaam.

Government of the Republic of Malawi

Ministry of Water Development and Irrigation
National Water Development Programme

Independent Environmental Impact Assessment for the Upgraded Kamuzu Barrage

Final Environmental and Social Impact Assessment
Volume 2: Vegetation

December 2013

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Abbreviations

cm	centimetre
EIA	Environmental Impact Assessment
ESIA	Environmental and Social Impact Assessment
ESRI	Mapping software
GPS	Global Positioning System
ha	hectare
HRWL	Highest Regulated Water Level
km	kilometre
LRWL	Lowest Regulated Water Level
m	metre
masl	metres above sea level
mm	millimetre
UNDP	United Nations Development Programme
UNESCO	United Nations Educational, Scientific and Cultural Organization

Acknowledgements

Invaluable assistance and advice was provided to the study team by rangers and staff from the Liwonde National Park; rangers and staff from the Majete National Park; and Dr Montford Mwanyambo, and staff from the National Herbarium of Malawi at Zomba.

Executive Summary

The Ministry of Irrigation and Water Development commissioned the Snowy Mountains Engineering Corporation (SMEC International) to undertake a detailed Environmental Impact Assessment (EIA) for the upgrade (including raising the height) of Kamuzu Barrage in accordance with the requirements of Malawi's EIA process and World Bank Safeguard Policies.

This Ecological Technical Report has been prepared as an appendix to the main Environmental and Social Impact Assessment (ESIA) report. The objective the study is to inform the ESIA process by collating baseline data on the ecology of the project area, identifying ecological risks associated with the project, and developing appropriate management measures to minimise or mitigate risks to an acceptable level.

The study focuses primarily on the impacts to the biotic communities immediately adjacent to the areas of Lake Malawi and the Shire River that may experience fluctuations in water levels and inundation periods as a result of the proposed barrage upgrade. Impacts to terrestrial and aquatic flora and fauna are addressed in the Wildlife Technical Report and the Aquatic Ecology Technical Report respectively.

The study characterised the biotic communities at 30 different sites adjacent to the Shire River, Lake Malombe and Lake Malawi. Each site was within 50 m of the high water level; the location of each was largely determined by its accessibility from the road network. At each site the survey team characterised the biotic community according to a predetermined descriptor of the vegetative communities that were represented. A 'patch' of the dominant vegetation type was captured within a GPS polygon to act as a 'training site' for spectral imagery analysis of the entire project area. Each site was described in terms of topography and distinguishing features and photographed with a GPS enabled camera.

In order to quantify the extent of impacts from arising from different inundation models, biotic communities were characterised within the predicted inundation area for a range of water levels. A combination of manual delineation and unsupervised spectral classification was used delineate the boundaries between the biotic communities within the inundation area. Using this technique, the following biotic communities were found to be represented within the inundation area:

- Perennial Marshes
- Seasonal Marshes – Uncultivated
- Seasonal Marshes - Under Cultivation (dambos)
- Seasonal Flood Plains
- Riverine Woodlands
- Dry Bush Savannah
- Cleared Woodland

In order to quantify the impact of each inundation model on each biotic community type, the total area within each inundation model was calculated using geometry and summary tools in ArcGIS (ESRI). A separate map showing the results of each calculation was developed for visual comparison.

The results of the modelling show that there will be a minimal change in the area of habitat inundated and inundation period associated with a 20 cm increase in Barrage height (corresponding to a new Highest Regulated Water Level (HRWL) of 475.52 masl). However, a potentially significant increase in the area of inundation and inundation period is possible upstream of the Barrage if the height is raised by 40 cm (corresponding to a new HRWL of 475.72 masl). This may significantly impact important Perennial Marsh habitat located along the boundary between the Shire River and Liwonde National Park. It is recommended that if the Barrage is raised by 40 cm that a Perennial Marsh habitat monitoring program is implemented within the boundaries of the Park and an adaptive management program is adopted whereby the operation of the Barrage is regulated in response to the findings of the monitoring program. No such monitoring program is deemed necessary if the Barrage is raised by only 20 cm.

It is also recommended If levels do need to be increased above 475.5 masl then the Barrage should be operated to mimic the seasonal flooding patterns of system i.e. levels of 475.5+ masl permitted during the wet season only (i.e. Dec – April); maintain levels below 475.5 during the dry season (May – Oct).

This operational regime will also minimise the incidences of prolonged (i.e. greater than existing levels) inundation of Seasonal Floodplain and Marshland habitats downstream of the Barrage. This is significant as this habitat type may support crocodile (and turtle) nesting during the critical incubation period lasting from October to December.

1 Introduction

1.1 Project Background

Over the last century Lake Malawi has experienced severe periodic water level fluctuations which in turn have caused social, economic and environmental changes, mostly of a negative nature. For instance, in the period 1915 to 1937 the water level of the Lake was so low that the outflow from the Lake more or less stopped, leaving the Shire River dry.

Different ways of securing and stabilising the water flow have been suggested and studied. The most resent of these studies is the Lake Malawi Level Control Study – Phase I and II which analysed different types of interventions to stabilise the flow in the Shire River, including the no-action alternative. The preferred option identified by this study was to upgrade the existing Kamuzu Barrage at Liwonde so that flow in the River could be regulated in response to prevailing environmental conditions.

The Ministry of Irrigation and Water Development contracted the Snowy Mountains Engineering Corporation (SMEC International) to undertake a detailed Environmental Impact Assessment (EIA) for the upgrade of Kamuzu Barrage in accordance with the requirements of Malawi's EIA process and World Bank Safeguard Policies.

This Ecological Technical Report has been prepared as a technical appendix to the main Environmental and Social Impact Assessment (ESIA) Report. The objective of this technical report is to inform the EIA process by collating baseline data on the ecology of the project area, identify ecological risks associated with the proposed project, and develop appropriate management measures to minimise or mitigate risks to an acceptable level.

This Ecological Technical Report is focused primarily on the impacts to the biotic communities immediately adjacent to the areas of Lake Malawi and the Shire River that may experience fluctuations in water levels as a result of the proposed Barrage upgrade (Figure 1). Impacts to terrestrial and aquatic flora and fauna are addressed in the Wildlife Technical Report.

1.2 Ecological Setting

The water bodies and catchment area influenced by the project include Lake Malawi and the Shire River water systems (Figure 2). Lake Malawi has a catchment area at the Lake outlet of about 126,500 km^2, consisting of:

- 64,372 km^2 drainage area in Malawi
- 26,600 km^2 drainage area in Tanzania
- 6,768 km^2 drainage area in Mozambique, and
- 28,740 km^2 of Lake surface

The Shire River forms the only outlet of Lake Malawi, running through the southern part of the country. Its lower part – below the junction with Ruo River – forms the border with Mozambique. A few kilometres further downstream of the southern border of Malawi the Shire River discharges into the Zambezi.

The Shire River catchment, below the Lake and excluding the Ruo catchment, covers an area of 18,945 km^2.

Although Malawi lies within the tropics, the topography is varied and the range of altitude so great that climatic conditions are a complex mosaic with many gradations between dry and wet and hot and cold.

The project area has been defined as the reaches/areas of the Shire River, Lake Malombe and Lake Malawi that may experience permanent or temporary changes in water levels as a result of the proposed upgrade of the Kamuzu Barrage at Liwonde. The project area covers a distance of approximately 100 linear kilometres from the lower reaches of Lake Malawi to Chikhwawa on the Shire River (Figure 2).

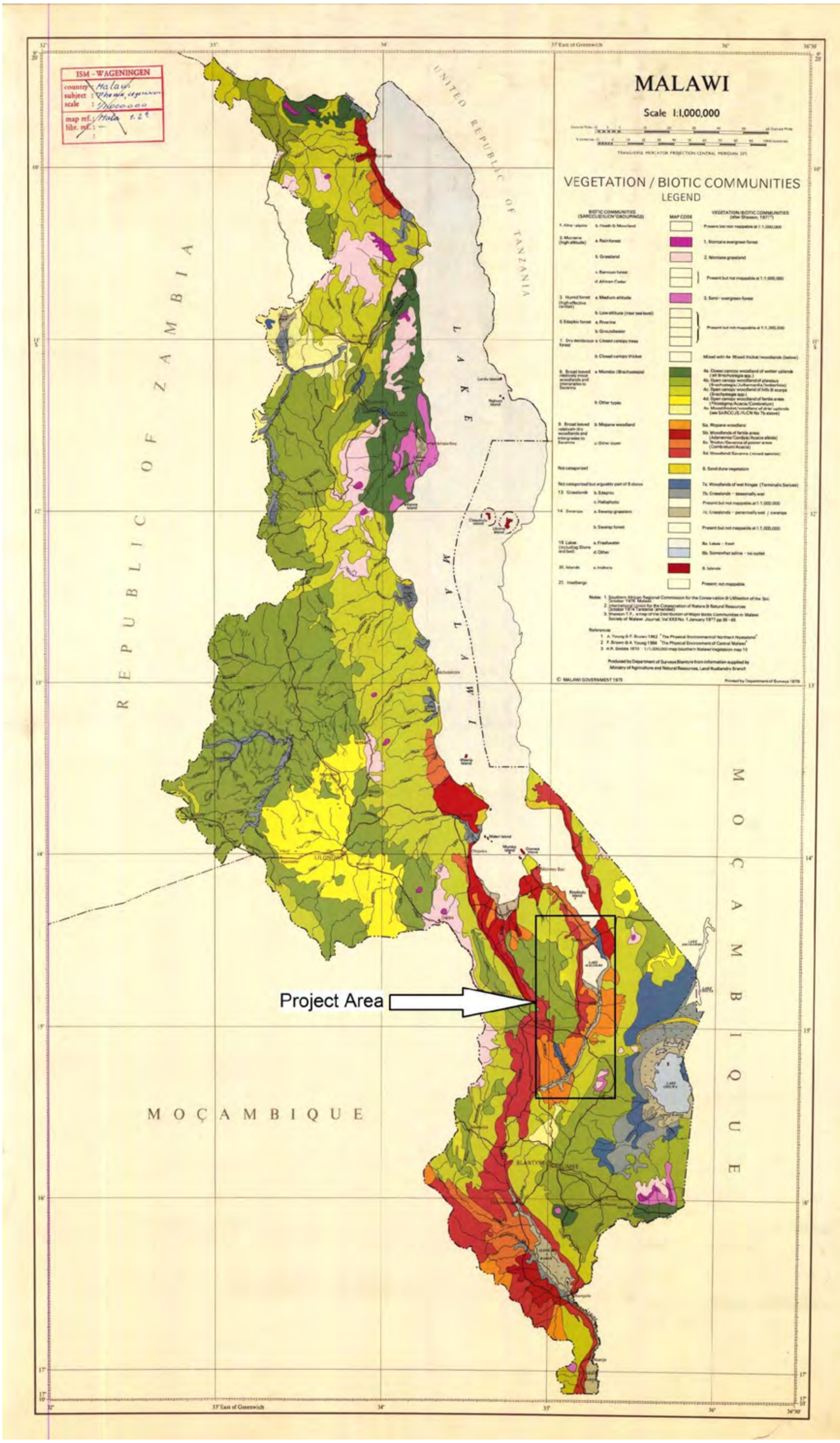


Figure 1. Biotic Communities of Malawi and Project Area

The project area is naturally divided in to four major zones these are:

1. Lake Malawi – Southern arms
2. Upper Shire River – from Samama to Matope
3. Middle Shire River - from Matope to Kapichira
4. Lower Shire River – Kapichira to Mozambique border

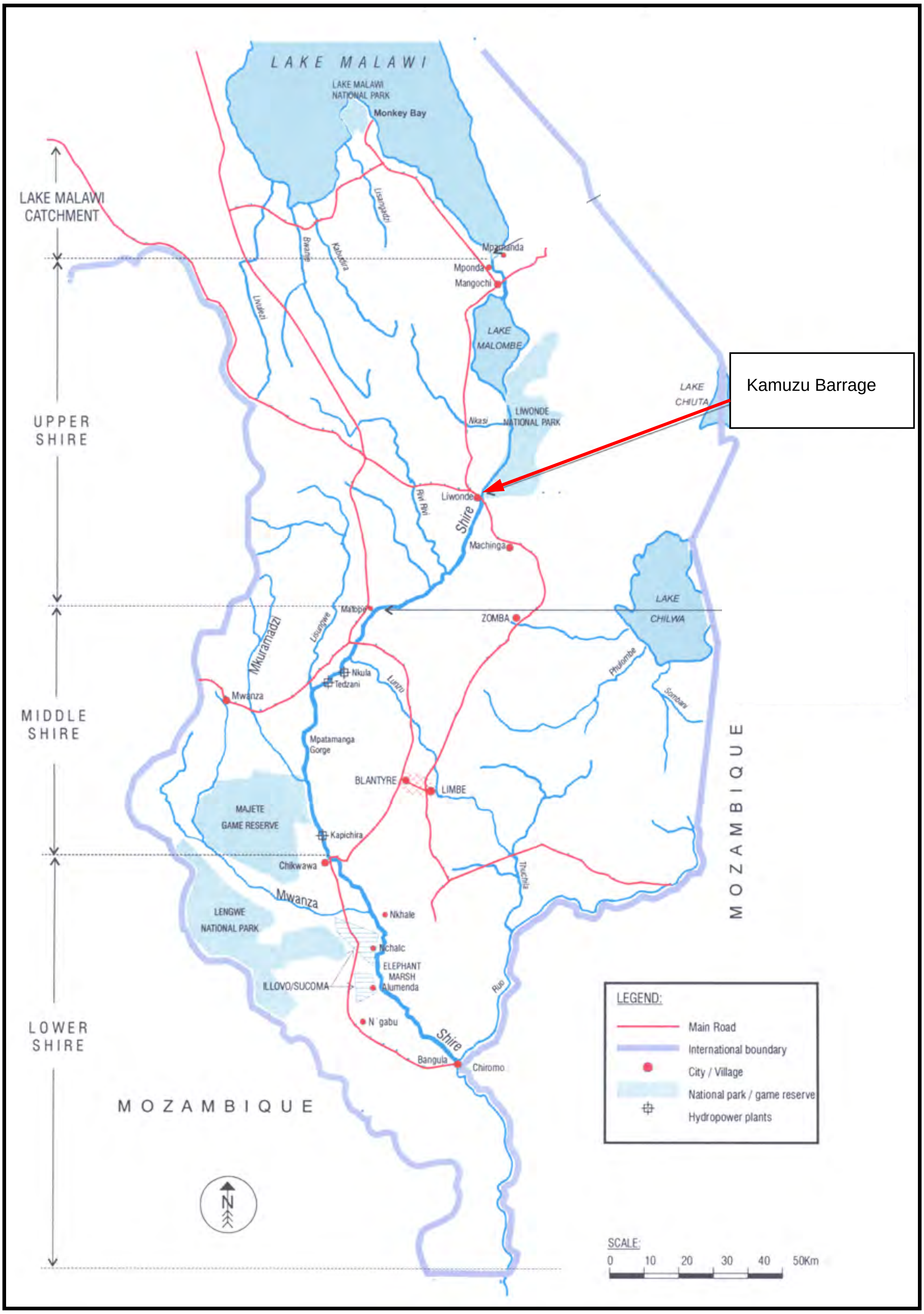


Figure 2. Map of Project area

1.2.1 Lake Malawi

Lake Malawi is the southernmost and third largest of the East African great lakes. It is approximately 560 km long and 75 km across at its widest point. Maximum depth is around 700 m. The Lake is located at an altitude of about 475 m and experiences marked seasonal variations in wind, temperature and precipitation. The depth of the Lake falls off quickly from the shore and depths of more than 200 m are found offshore. In the south-eastern area, where the Lake discharges its excess water in to the Shire River, the fall-off in depth is less striking and large shallow sandy areas occur. The Lake, in particular the southern part, supports important fisheries both artisanal and semi-industrial. The Lake has been included on the United Nations Educational, Scientific and Cultural Organization (UNESCO) World Heritage List due to its unique fish biodiversity, represented by the several hundred different "mbuna" cichlid species. These species are almost exclusively found on stone and rocky bottom and only 2-3 species inhabit sandy substrate.

Figure 3. Lake Malawi

1.2.2 Upper Shire River

The Upper Shire River is defined as the river channel from its outflow from Lake Malawi at Samama down to Matope and includes Kamuzu Barrage (Figure 4). For this 100 km stretch the River flows down an extremely gentle gradient, the water level at Liwonde being only 2 m lower than the Lake exit (the gradient is even less with the Barrage in operation). The flat landscape and reduced stream velocity cause the River to meander creating a network of pools and channels, and to flood adjacent land in the rainy season.

Figure 4. Kamuzu Barrage

The area is relatively dry with mean annual rainfall of around 700 mm (contrasting with over 2,000 mm on the nearby Zomba Mountain). The rainy period is from November to April when more than 90% of the rain falls. May to October constitutes the dry season. Mean annual temperature is around 22°C.

The landscape of the Upper Shire takes its character from the Great African Rift Valley, which runs north-south in a 15-35 km wide trough. The valley consists of plains and gentle foot slopes, which rise to an altitude of approximately 700 m. To the west the Rift Valley merges into uplands and hills around 1,100 m, while an escarpment delimits the eastern boundary several hundred metres high guarding an extensive area of uplands and hills.

The area is underlain by basement complex rocks of pre-Cambrian and Cambrian age. Extensive faulting since Mesozoic times has led to the formation of the Rift Valley, which itself is filled with unconsolidated sediments of lacustrine, fluvial and colluvial origin.

Soils are generally well drained, yellowish brown to reddish brown, medium to fine textured and are deep if developed in alluvium. In the lowest areas soils have been modified by flooding and sedimentation, giving rise to considerable localised variations.

Much of the Upper Shire Valley and the lakeshore plain areas, where soils have reasonable drainage, are dominated by woodland savannahs. Apart from Liwonde National Park, most of the areas of semi-deciduous riverine forest have been cleared for cultivation. Some areas of Mopane (*Colophospermum mopane*) woodland survive, mostly in association with other trees and shrubs.

1.2.3 Middle Shire River

The Middle Shire, from Matope to Kapichira, drops over 370 m in elevation over a distance of about 90 km. The gradient is gentle but gradually increases. Beginning around Matope, the River falls below the surrounding land and is flanked by alluvial terraces. This section also contains a series of cataracts (Kholombidzo, Nkula, Tedzani, Hamilton and Kapichira). Additional River characteristics include: meanders, rapids flanked by islets, and abandoned river channels. Several tributaries join the main channel, the most important being the perennial Lisungwe and Mkurumadzi Rivers.

The Middle Shire Valley is relatively dry with annual rainfall in the order of 700-800 mm. Mean annual temperature is approximately 24°C.

The Middle Shire Valley forms the floor of the Great African Rift Valley and consists of undulating but rugged and densely dissected country. The area is largely underlain by Precambian metamorphic rocks (basement complex) consisting of gneisses and granulite. Soils in general are moderately deep, well drained, brown, and medium textured with weathered rock in the subsoil and gravel and stones throughout the profile.

Population pressure in the Middle Shire Valley has resulted in the natural vegetation only appearing in areas deemed unsuitable or very marginal for cultivation. The remnants of the natural vegetation may be classed as woodlands and savannahs.

1.2.4 Lower Shire River

Downstream of Kapichira, the Shire River Valley widens in to a flat alluvial plain. For about 150 km the Shire meanders over this plain.

The area is relatively dry, recording rainfall of 700-1,000 mm annually. Dry spells lasting several weeks are not uncommon during the period of the rainy season. Highest mean monthly temperatures fall into the range of 27-30°C during the rainfed crop growing season.

The Lower Shire Valley is a continuation of the Rift Valley, as noted in the preceding sections. The floor of the Rift Valley is flanked by escarpments associated with the major fault lines which follow a south-east to north-west trend. Relief is dominated by the Chikwawa-Thyolo Escarpment to the east, the Majete Escarpment to the north-west, the Nsanje Hills to the south-west and the Lower Shire uplands to the west. Altitude in the Lower Shire Valley ranges from 50 m to 200 m, while to the north-west and south-west the land rises to nearly 1,000m.

The hills and uplands surrounding the Lower Shire Valley predominantly consist of basement complex rocks, gneisses and granulite. The Valley itself is characterised by Tertiary unconsolidated sediments. Soils in the

Valley are deep, medium to fine texture, brown to very dark in colour and have a drainage ability, which varies from good to very poor.

The upper reaches of this section host large areas of commercial sugar cane agriculture, whilst the lower reaches are dominated by the seasonally flooded Elephant Marsh with its attendant market garden agriculture and artisanal fisheries. The natural vegetation of the Valley has been largely removed or extensively disturbed by cultivation. Seasonally waterlogged areas adjacent to the Shire River support productive grass vegetation.

1.2.5 Hydrology of Lake Malawi and the Shire River

1.2.5.1 Lake Malawi

The level of Lake Malawi normally exhibits an annual fluctuation of about one metre between the low dry season and the high level at the end of the rainy season. In addition, the Lake has historically exhibited a pattern of temporal cyclical fluctuation. From the evidence of writings of early travellers it is inferred that the Lake level was very low in 1830, very high in 1857-63, falling in 1875-78, high in 1882, very low in 1890, but rising in 1892-95.

The factors determining the fluctuations in water level are the runoff from the lakes large catchment (half of which originates in the high rainfall areas of southern Tanzania), the rainfall directly on the Lake surface, and loss through evaporation. The residual water, the so called freewater, is either used to change the volume of the lake or is released into the Shire River. The evaporation is the conservative factor, leaving the water level to be heavily dependent on changes in rainfall pattern – in particular on the rainfall directly on the Lake. Representative data on Lake rainfall and evaporation are not available. An indicative water balance for the Lake, based on hydrological and meteorological data from the period 1953/54 to 1973/74, has been presented in a Government of Malawi – UNDP/WMP project report; calculated into average annual flow figures the balance showed:

- Inflow from catchment: 595 m^3/sec
- Rainfall on the Lake: 1230 m^3/sec
- Lake evaporation: 1467m^3/sec
- Free water (combined Lake outflow and change in Lake volume); 358 m^3/sec

Lake Malawi is a nutrient poor (oligotrophic) clear lake. The production of phytoplankton which forms the base of the food chain, and consequently influences the total fish production, is limited by the storage of nutrients. The influx of nutrients from the catchment runoff is mostly lost into a stratified anoxic layer originating at a depth of approximately 250 m. Some mixing and mobilisation of nutrients occurs in the cool winter season (May – August), due to south-easterly trade winds. In the shallower south-eastern part of the Lake, the entire water column is mixed in the cold season and nutrients sedimented to the bottom are returned to the water column. The existence of internal upwelling under the influence of the strong southerly winds also helps in mixing the water and hence maintaining the productivity of the south east arm of the Lake. This leads to a much higher annual biological production in this part of the Lake compared to the northern segment.

1.2.5.2 Lake Outflow and Upper Shire

The flow of the Shire River is primarily determined by two components: the outflow from Lake Malawi; and the inflow from the drainage basin downstream of the Lake. Of these, the outflow from the Lake is the dominant component. In the dry season, Lake outflow accounts for virtually all the water entering the Shire River. Evaporation from Lake Malombe accounts for an average annual loss of about 20 m^3/sec. The Kamuzu Barrage provides some flow regulation capacity and is used to secure the base flow needed for hydropower generation.

The long term variations in Lake levels, and thus the outflow, have caused periodic changes in the flow characteristics of the Shire on a historical time-scale. The River ceased to flow altogether in 1915 and only gradually regained its regular flow in 1934-37 when the water level in Lake Malawi rose to the height whereby it was able to break through the sand and sediment bars that the tributaries had built up in the Upper Shire. From the early 1950s until mid 1970s, the River flow at Liwonde was maintained at annual average levels fluctuating between 200 m^3/sec and 600 m^3/sec. The Kamuzu Barrage was completed in 1965 for the purposes of storing water in the upper part of the River to maintain a minimum flow of at least 170 m^3/sec downstream. In the period from the mid-1970s and through the 1980s the Lake level increased and the average annual flow was recorded at between 400-800 m^3/sec. In the early 1990s, however, the whole of south-eastern Africa experienced serious droughts and a dramatic fall in the Lake level and a reduction in Shire flow resulted.

The lowest water level in 40 years was recorded in December 1995, when the lake level reached 473.0 masl (meters above sea level) with a resulting downstream water flow (measured at Liwonde) of 129 m^3/sec. This flow was well below that required for maintaining hydropower production at the plants in the Middle Shire.

An additional factor that affects the outflow is the status of silt and sand deposits in the river bed of the Upper Shire River. As a result of the modest slope of the whole upper course, sand bars are able to form, preventing some of the water from flowing downstream. A reduced initial outflow from the Lake, due to low water levels, will further exacerbate the problem. A high river flow enables the silt barriers to be broken through and the flushing of sediment downstream.

Some of the siltation changes are a result of the dynamics of the main River, but the major problems are caused by the seasonal tributaries and their discharge points in to the Shire. Silt transport by the tributaries has increased in recent times due to poor land-management and the intensification of agriculture in the catchment area.

The relatively nutrient rich water exiting the Lake is further enriched as it flows downstream. The erosive force of the River and tributaries add to the concentration of nitrogen and phosphorus available for plant growth. Some of these nutrients will be used by planktonic algae in the River; others will be used to promote the growth of reed and wetland species, including floating or submerged plants. The water hyacinth (*Eichhornia crassipes*), a noxious floating plant, has recently established itself in the area and is benefiting from the nutrient rich water in some of the more sheltered parts of the Shire River.

1.2.5.3 Lake Malombe

Lake Malombe is effectively an extension of the Upper Shire, located approximately mid-way between the outflow and Liwonde. Typically, the length of the Lake is about 30 km with a maximum width of about 15 km. The depth averages about 7 m, with a maximum of around 17 m. It is claimed that the depth has decreased in recent years. The existence and dimensions of the Lake are totally dependent on the discharge of the Shire River. Large seasonal fluctuations in Lake area are common and records exist of a total dry-out in the years the Shire ceased to flow in its upper course.

Due to its shallow depth, the water in Lake Malombe is comprehensively mixed at all times of the year; the nutrients are efficiently recycled and the productive zone extends right to the bottom of the water column. Additionally, the Lake profits from the inflowing nutrient rich water, and surface runoff entering the Lake from adjacent land further contributes to the productivity levels. Readily observable indicators of the nutrient rich (eutrophic) character of the Lake are high levels of chlorophyll“a”, and the low transparency of the water.

1.2.5.4 Middle Shire

Moving downstream the River is fed by a number of tributaries, most of them seasonal. The flow regime of the River here, therefore, exhibits greater variations between peak flows and low flows than the upper part. Typically – in normal Lake outflow periods – the rainy season flow is about 1.5 to 3 times the magnitude of the dry season flows. Although flood episodes of local origin are important, a significant proportion of peak average flow is due to higher lake levels towards the end of the rainy season. A comparison of Shire River flow discharge at Liwonde and that at Maganga (2.5 km downstream of Kapichira falls) indicates that the Middle Shire tributaries contribute about 30% of the Shire water in the rainy season, and less than 10% in the dry season.

1.2.5.5 Lower Shire

The Lower Shire is slow flowing over a flat flood plain. During periods of high water level it overflows the area termed Elephant Marsh, creating a large wetland with a multitude of channels and pools. The Elephant Marsh in its downstream portion is also heavily influenced by the Ruo River running from the east at the Malawi – Mozambique border. In some years, the Ruo River might even have a greater impact on the water table in the Marsh than the Shire River itself. Downstream of the Ruo River confluence is another extensive wetland area known as the Ndinde Marsh.

The existing water withdrawal for irrigation purposes is at present only 12 m^3/sec in the peak periods (SUCOMA Sugar Estates). The main water management problem faced by the irrigation interests in the Lower Shire is at present the heavy silt content of the water. Continuous mechanical removal of silt from the intake channel is needed to maintain irrigation operations on the SUCOMA estates.

1.2.6 Biotic Communities

For the purpose of this rapid assessment the biotic communities represented within 100 m of the water edge were included in the assessment; the rationale being that this was the zone of influence of any fluctuation in water levels resulting from the Barrage upgrade. Five distinct biotic communities were identified as being represented within the project area during the field assessment, including:

1. Perennial Marshes
2. Seasonal Marshes – Uncultivated
3. Seasonal Marshes - Under Cultivation (dambos)
4. Seasonal Flood Plains
5. Riverine Woodlands

A brief description of the characteristics of each biotic community type is provided below.

1.2.6.1 Perennial Marshes

Perennial Marshes are found along parts of the river and in certain sections of the lakeshore zone on both Lake Malawi and Lake Malombe. The permanent marsh areas are in relatively shallow water, but the soils are almost permanently inundated. The vegetation consists of tall reeds and aquatic grasses, and various smaller floating and/or submerged plants where the river current is either weak or virtually non-existent (Figure 5). Full descriptions of aquatic macrophytes in the Upper, Middle and Lower Shire are given in Blackmore, Dudly & Osborne (1988). Some common species are given in Table 1 to provide the reader with some detail for the aquatic systems that may be affected by this project.

TABLE 1. COMMON AQUATIC MACROPHYTES FOUND IN PERENNIAL MARSHES OF THE SHIRE RIVER

Reeds, rushes, sedges and grasses	Water lilies and other floating aquatics
Cyperus papyrus	*Azolla pinnata*
Typha capensis	*Commelina benghalensis*
Vossia cuspidate	*Ipomoea aquatica*
Phragmites mauritianus, P australis	*Nymphaea caerula, Nymphaea lotus*
Thelipterys confluens (Pteridophyta)	*Pycreus mundtii*
	Salvinia hastata
Submerged plants	
Ceratophyllum demersum	
Ottelia spp. (e.g. O. exserta., O. scabra)	
Potamogeton pectinatus, P. thunbergia	
Spirodela polyrhiza	

Figure 5. Example of a Perennial Marsh

1.2.6.2 Seasonal Marshes

The lake and river levels rise and fall on average 1 m in a single year. These fluctuations are due to annual rainfall inflow mainly to Lake Malawi. The fluctuations are also affected by the rate of water release at the Kamuzu Barrage, so they are not true seasonal fluctuations, but a combination of natural and managed cycles of water flow.

The species found in seasonal marsh areas are similar to those found in perennial marshes, with die-back of aquatic plants when water levels recede, plus the addition of plants that tolerate wet and dry soils (Figure 6). Water tolerant woody plants occur here, as do water tolerant grasses, sedges and reeds (Table 2). The landscape is generally flat with tall reeds and grasses, with scattered, short trees and shrubs that sometimes form small thickets.

In addition to the species listed for the permanent swamp areas, there are a few emergent woody plants. These tend to be rooted in silt and humus accumulations formed on the tops of reed banks and papyrus suds.

TABLE 2. COMMON EMERGENT WOODY PLANTS

Woody Plants	Reeds, rushes, sedges and grasses
Hibiscus diversifolius	*Cyperus spp. (numerous)*
Mimosa pigra	*Echinochloa haploclada, E. pyramidalis*
Sesbania bispinosa	*Hemarthria altissima*
Syzygium cordatum	

Figure 6. Example of an uncultivated seasonal marsh

1.2.6.3 Seasonal Marshes – Cultivated

Most of the seasonal marshes around Lake Malombe and in the Upper Shire were under some form of 'dambo' cultivation at the time of the assessment. Brinkman and Blokhuis (1986) define dambos as:

"areas that have free water at or on the surface for at least the major part of the growing season. The water is sufficiently shallow to allow the growth of a wetland crop or of natural vegetation rooted in the soil".

The most commonly planted dambo crop is maize (Figure 7); other common crops are beans, peas, sweet potatoes and sugar cane. Vegetables such as cabbage, rape, pumpkin leaves, champiru or mustard are grown to a lesser extent (Klarer 2008).

Figure 7. Example of cultivated seasonal marsh (dambo)

1.2.6.4 Seasonal Floodplains

Seasonal floodplains occur where there are shallow gradients from the lake and river body sides on to dry land. The land is more commonly dry than submerged here, as opposed to seasonal marshlands and/or swamp, which is more commonly submerged, but may dry out from time to time.

Here we see scattered tall trees, predominantly palm species, and tree and scrub thickets, most commonly associated with low lying islands and termite mounds. Table 3 provides a list of typical plant species found in seasonal floodplains.

The flat-lands areas are covered in tall grasses, reeds and sedges and in the lower lying locations, these merge in to seasonal marshlands (Figure 8).

Some seasonal floodplain areas are also under cultivation.

TABLE 3. TYPICAL FLOODPLAIN PLANT SPECIES

Woody plants - Trees	Woody plants - Shrubs
Hyphaene petersiana	*Adina spp.*
Phoenix reclinata	*Carissa spp.*
Kigelia Africana	*Dichrostachys cinerea*
Afzelia quanzensis	*Ficus spp.*
Acacia nilotica	*Garcinia spp.*
Acacia nigrescens	*Grewia spp.*
Dalbergia melanoxylon	*Gymnosporia senegalensis*

Woody plants - Trees	Woody plants - Shrubs
Combretum imberbe	*Maerua triphyllum*
Lonchocarpus capassa	*Ormocarpum kirkii*
Trichilia capitata	*Rhus spp.*
Xanthoxercis zambeziaca	
Ziziphus mucronata	
Reeds, rushes, sedges and grasses	Non-grasses
Cyperus spp. (numerous)	*Asparagus spp.*
Kyllinga spp.	*Hibiscus spp.*
Mariscus spp.	*Leonotis spp.*
Pycreus spp.	*Ocimum canum*
Brachiaria brizantha	*Pluchea spp.*
Echinochloa haploclada, E. pyramidalis	*Sanseveria aethiopica*
Hemarthria altissima	*Sesamum spp.*
Oryza spp.	*Sesbania spp.*
Phragmites australis, P. mauritianus	*Veronia spp.*
Sporobolus festivus, S. robustus	

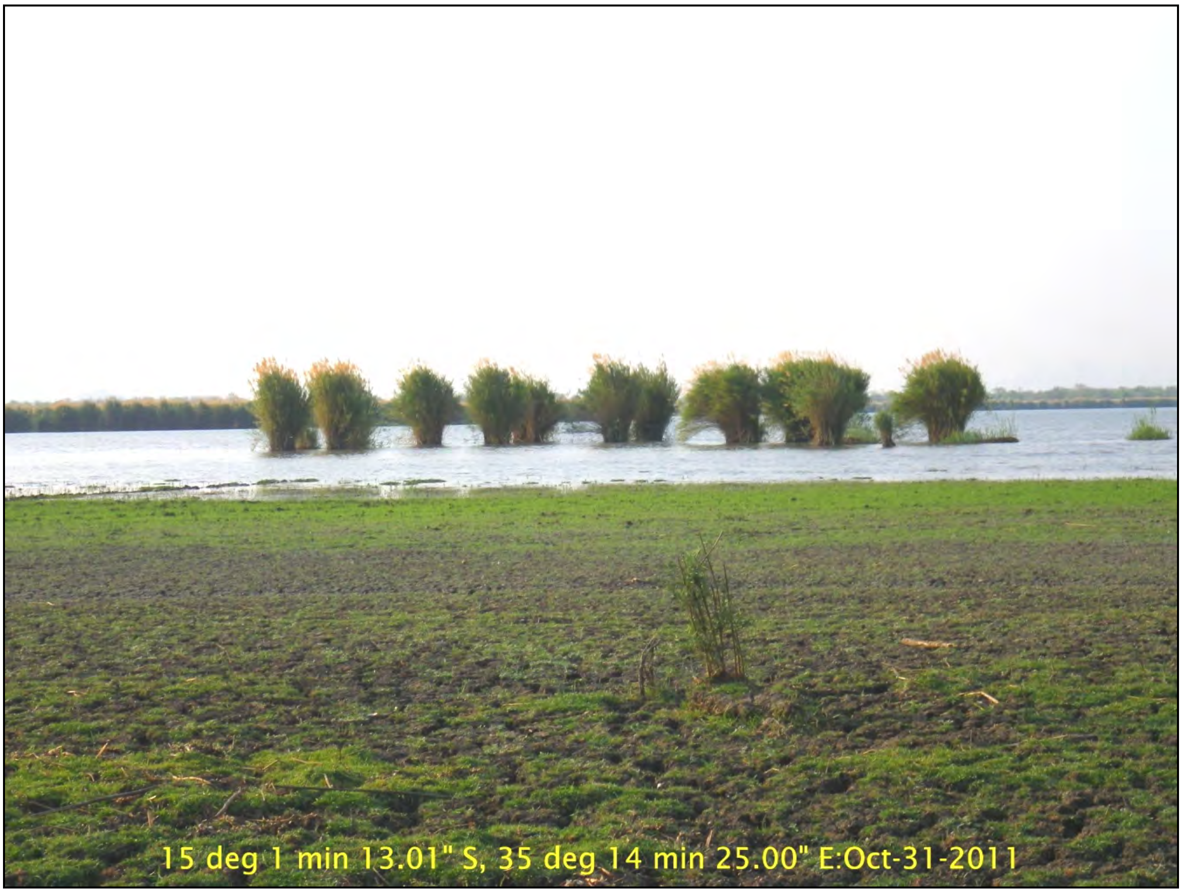


Figure 8. Example of seasonal flood plains

1.2.6.5 Riverine Woodlands

Riverine Woodlands tend to predominate in the steeper areas of the Middle Shire where the river banks are drier, these woodlands tend to be species rich (Table 4). The trees are relatively tall, varying in height from 12 to 30 m, with secondary shrub and emerging tree understory (Figure 9). The tree canopies are relatively close and vary from interlocking to slightly apart (up to about 5 m).

TABLE 4. COMMON PLANTS ASSOCIATED WITH RIVERINE WOODLANDS

Woody plants	Cont.
Acacia xanthophloea	*Dichrostachys cinerea*
Albizia brevifolia	*Diospyros spp.*
Balanites aegyptica	*Faedherbia albida*
Cissus quadrangulifolia	*Strychnos spp.*
Colophospermum mopane	*Tamarindus indicus*
Combretum mossambicensis	*Terminalia sambesiaca*
Commiphora africana	*Thylachium africanum*
Dalbergia spp.	*Xeromphis obovata*

Figure 9. Example of riverine woodland

2 Methods

This study took the form of a rapid ecological assessment of the project area conducted between 30/10/2011 and 4/11/2011.

2.1 Field Studies

The study team assessed the biotic communities at 30 different sites adjacent to the Shire River, Lake Malombe and Lake Malawi. Each site was within 100 m of the high water edge; the location of each site was largely determined by its accessibility from the road network.

Each site was assessed by a team of ecologists specialising in impact assessment and botany, including:

- Dr Michael Clarke – SMEC – Certified Environmental Practitioner in Impact Assessment; and
- Dr Montford Mwanyambo – National Herbarium of Malawi at Zomba.

At each site the survey team characterised the biotic community according to the categories described in Section 1.2.5. A representative 'patch' of the dominant vegetation type was captured within a GPS polygon to act as a 'training site' for spectral imagery analysis of the project area (see Section 2.2). Each site was photographed with a GPS enabled camera.

The botanists then developed a vegetative species list for each site, and collected representative samples of the species present for cataloguing at the national herbarium.

All data was entered in to a site specific data sheet; these are attached in Appendix 1.

2.2 Spectral Analysis

In order to quantify the extent of impacts from different inundation models, vegetation classes were defined within the boundary of each inundation model. Vegetation types can be classed using either supervised or unsupervised classification techniques or manual delineation using control points from a ground survey. Supervised classification generally requires the use of multi-spectral imagery to allow for accurate delineation of vegetation classes. No multi-spectral imagery was available for use in the study area, however high resolution aerial photography (taken in 2010) was obtained to assist with the hydraulic modelling. Based on a review of the aerial photography, the number of vegetation classes required and the ability of unsupervised classification techniques to distinguish between vegetation classes, it was determined that a combination of manual delineation and unsupervised classification would provide the most accurate mapping, using the aerial photography as a guide. By using the same imagery used as a backdrop to the hydraulic modelling we also ensured no variation in the boundary of vegetation classes.

Based on the field survey the following broad vegetation classes were identified within the study area:

- Perennial Marshes
- Seasonal Marshes – Uncultivated
- Seasonal Marshes - Under Cultivation (dambos)
- Seasonal Flood Plains
- Riverine Woodlands
- Dry Bush Savannah
- Cleared Woodland

The distribution of vegetation classes within the study area were initially assessed by reclassing the output of each inundation model (473, 474, 475, 475.5 and 476). This resulted in a broad boundary (unsupervised classification) for the 'Water' and 'Permanent inundation' classes as well as the 'Marsh' and 'Floodplain' areas. To provide a more accurate vegetation map, the rest of the vegetation classes were manually delineated in ArcGIS (ESRI) and each of the 'Marsh' and 'Floodplain' boundaries were re-inspected at a Scale between 1:100 and 1:4000 and divided where obvious errors were present.

By delineating the vegetation class boundaries for the inundation model that covered the greatest area first (model 476) we were able to use Geo-processing tools ArcGIS (ESRI) to reclassify the boundaries of the other (smaller) inundation models. The output of each inundation model was then divided into two sections, the top half from Mponda to the Kamuzu Barrage and the bottom half from the Kamuzu Barrage to Chigaru (the extent of the available aerial photography). In order to quantify the impact of each inundation model on the vegetation classes, the total area within each inundation model (top and bottom halves) was calculated using geometry and summary tools in ArcGIS (ESRI). A separate map showing the results of each calculation was provided for visual comparisons (see Section 3).

2.2.1 Outputs

Two types of output were produced (see Section 3):

i. Mosaic maps showing the distribution of biotic communities within the project area.

ii. The area of each biotic community type within the project area was calculated.

3 Results

The number of each type of biotic community represented in the field studies are shown in Table 5. A data sheet for each site is provided in Appendix 1. This information was used to inform the mapping of biotic community mosaic maps in Section 3.1.

The outputs from the Design Consultant's hydraulic modelling for the upgraded Barrage were overlaid onto the biotic community mapping. These outputs showed the expected upstream and downstream inundation footprints for a range of water release scenarios. By overlaying a range of inundation footprints on top of the biotic community mapping the areas of each biotic community type that will be impacted at various water levels at the Barrage, was calculated for a range of release scenarios.

TABLE 5. BIOTIC COMMUNITIES REPRESENTED IN FIELD STUDIES

Site	Perennial Marshes	Seasonal Marshes – Uncultivated	Seasonal Marshes - Under Cultivation (dambos)	Seasonal Flood Plains	Riverine Woodlands
1				■	
3	■				
4	■				
5	■				
6			■		
7			■		
8					■
9					■
10					■
11					■
14	■				
15	■				
16	■				
17				■	
18				■	
19				■	
20					■
21				■	
22				■	
23	■				
24	■				
25			■		
26			■		
27			■		
28					■
29		■			
30					
31					
32		■			
33		■			

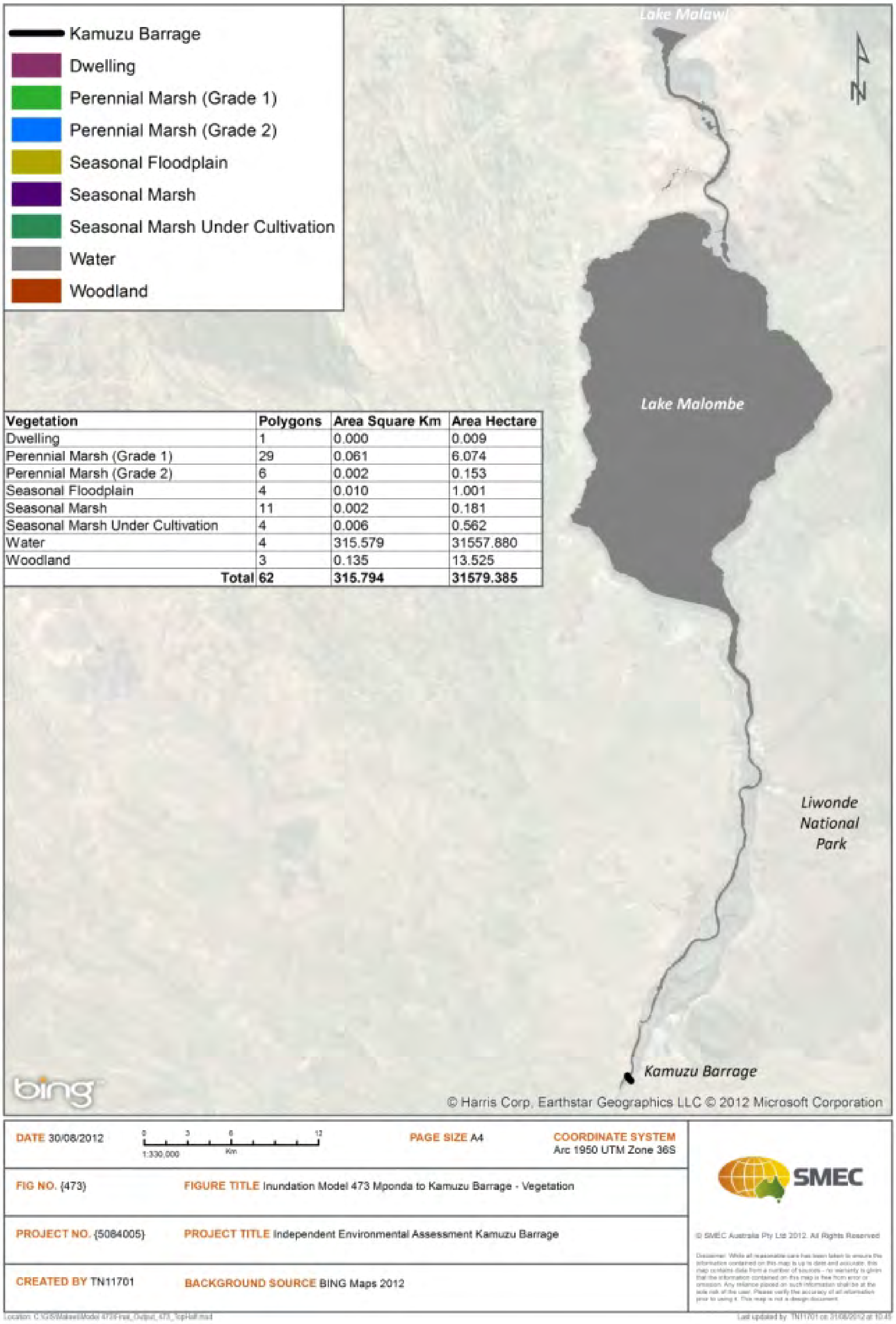
3.1 Modelling

The existing Kamuzu Barrage has the capacity to control water levels in Lake Malawi within a range from 473.5 masl (Lowest Regulated Water Level) to 475.32 masl (Highest Regulated Water Level). The proposed Project to raise the height of the Barrage will increase the HRWL in Lake Malawi by 20-40cm (i.e. from 475.32 to 475.52 – 475.72 masl depending on social/environmental impacts; Norplan, 2011). This is still within the range of historical lake levels, which records show vary from a low of 469.94 masl in 1915 to a high of 477.25 masl in 1980 (a maximum difference of 7.31 m well beyond the influence of the Barrage; Norconsult 2003).

The purpose of this assessment is to provide information on how manipulations of water levels within the operating range of the modified (i.e. raised) Barrage may impact the land and habitats immediately adjacent to the Shire River, Lake Malombe and the southern part of Lake Malawi. It is intended that this information will then be used to inform the development of an operational schedule for the modified Barrage that minimises impacts to fringing habitats that are sensitive to seasonal or temporal modifications in the existing flooding cycles of the system.

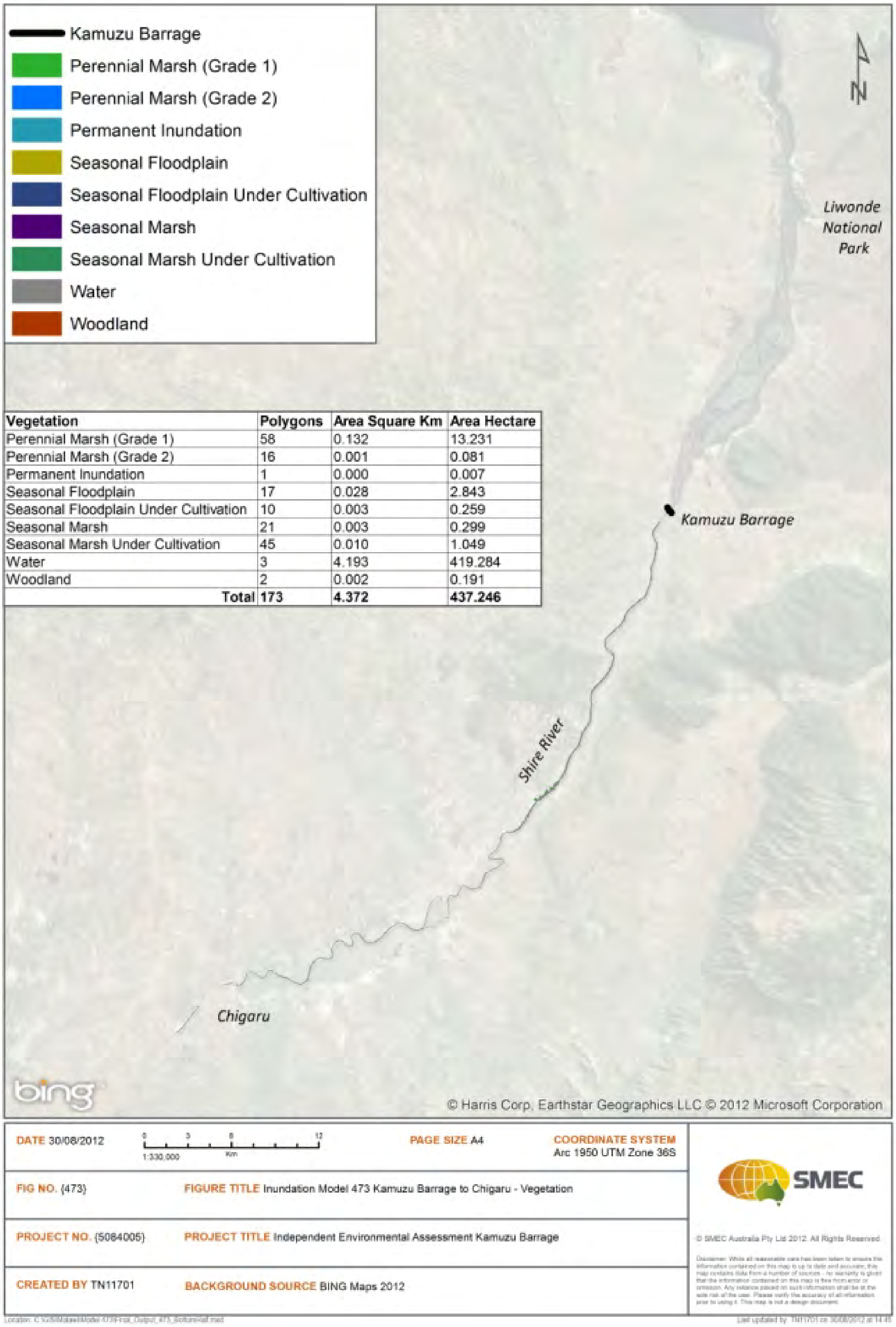
Hydraulic modelling has considered five scenarios ranging from 473 masl (i.e. below the existing LRWL) to 476 (i.e. above the proposed HRWL for the raised Barrage). The levels included in the models are: 473; 474; 475; 475.5 and 476 masl.

Maps showing the inundation of each habitat / land use type upstream and downstream of the Barrage at the various levels are provided in Figures 10 to 19. The area of each habitat type that will be inundated at each water level immediately upstream and downstream of the Barrage is summarised in Figures 20 and 21.



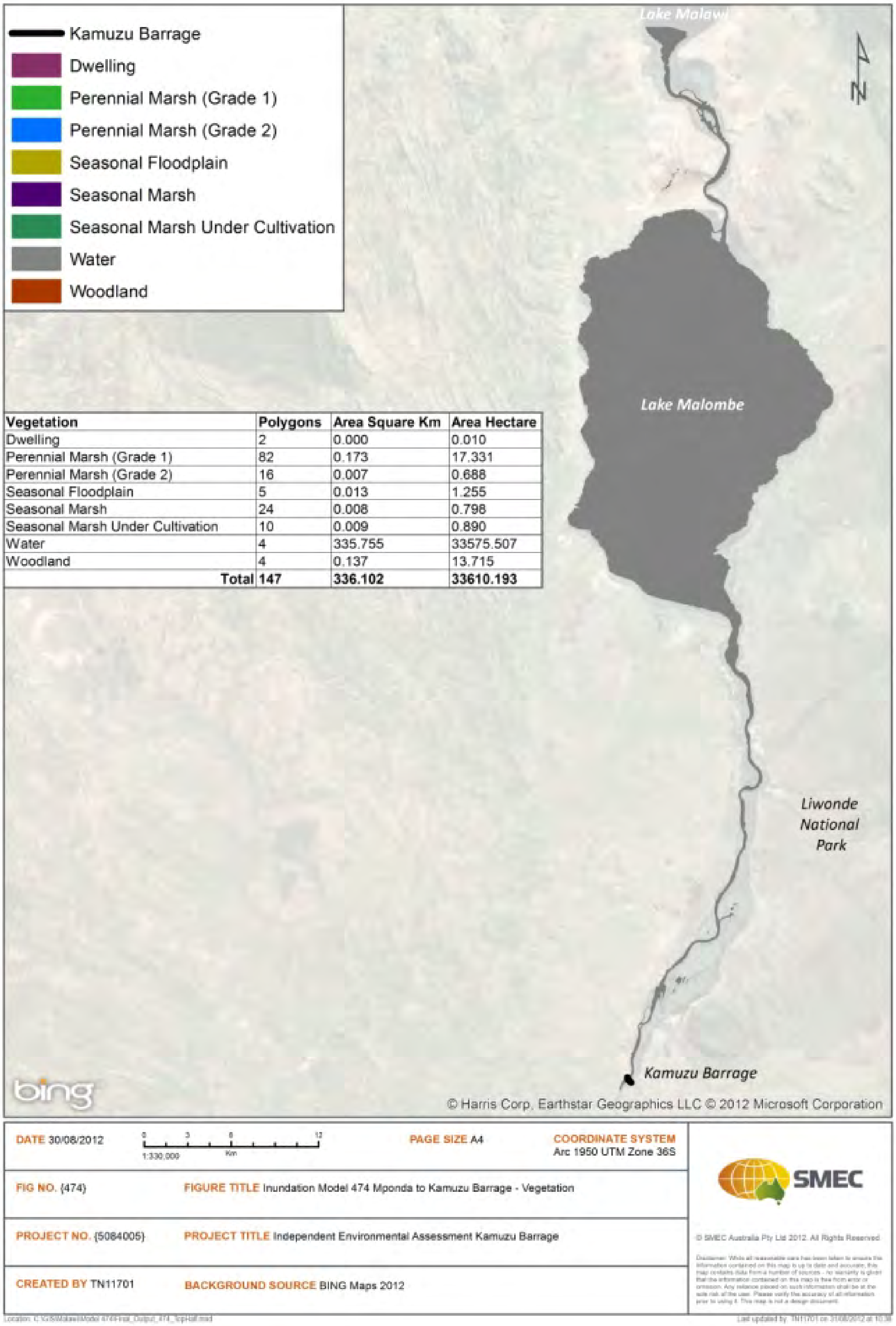
Vegetation	Polygons	Area Square Km	Area Hectare
Dwelling	1	0.000	0.009
Perennial Marsh (Grade 1)	29	0.061	6.074
Perennial Marsh (Grade 2)	6	0.002	0.153
Seasonal Floodplain	4	0.010	1.001
Seasonal Marsh	11	0.002	0.181
Seasonal Marsh Under Cultivation	4	0.006	0.562
Water	4	315.579	31557.880
Woodland	3	0.135	13.525
Total	**62**	**315.794**	**31579.385**

Figure 10. Inundation map 473 masl Lake Malawi to Kamuzu Barrage



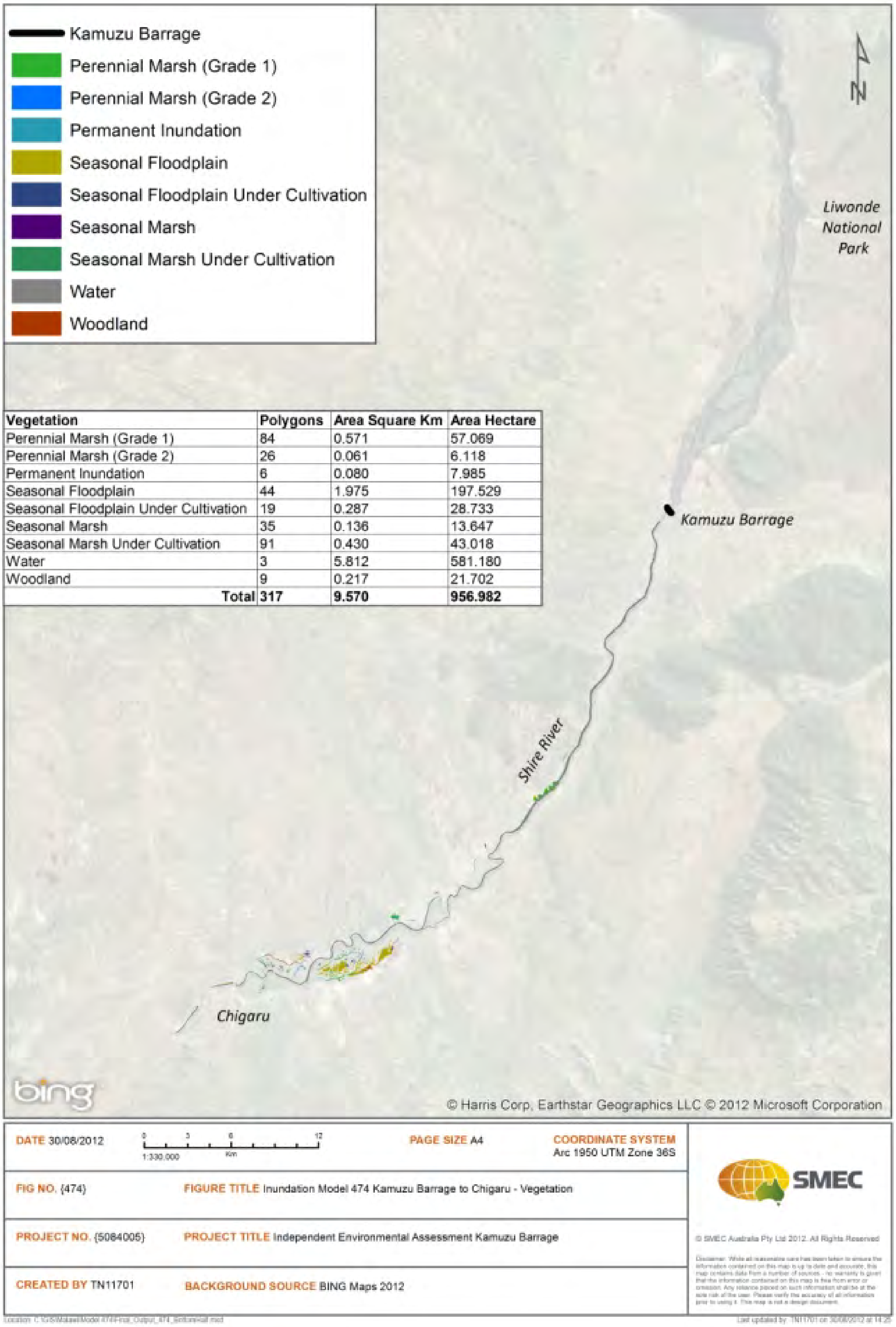
Vegetation	Polygons	Area Square Km	Area Hectare
Perennial Marsh (Grade 1)	58	0.132	13.231
Perennial Marsh (Grade 2)	16	0.001	0.081
Permanent Inundation	1	0.000	0.007
Seasonal Floodplain	17	0.028	2.843
Seasonal Floodplain Under Cultivation	10	0.003	0.259
Seasonal Marsh	21	0.003	0.299
Seasonal Marsh Under Cultivation	45	0.010	1.049
Water	3	4.193	419.284
Woodland	2	0.002	0.191
Total	**173**	**4.372**	**437.246**

Figure 11. Inundation map 473 masl Kamuzu Barrage to Chigaru



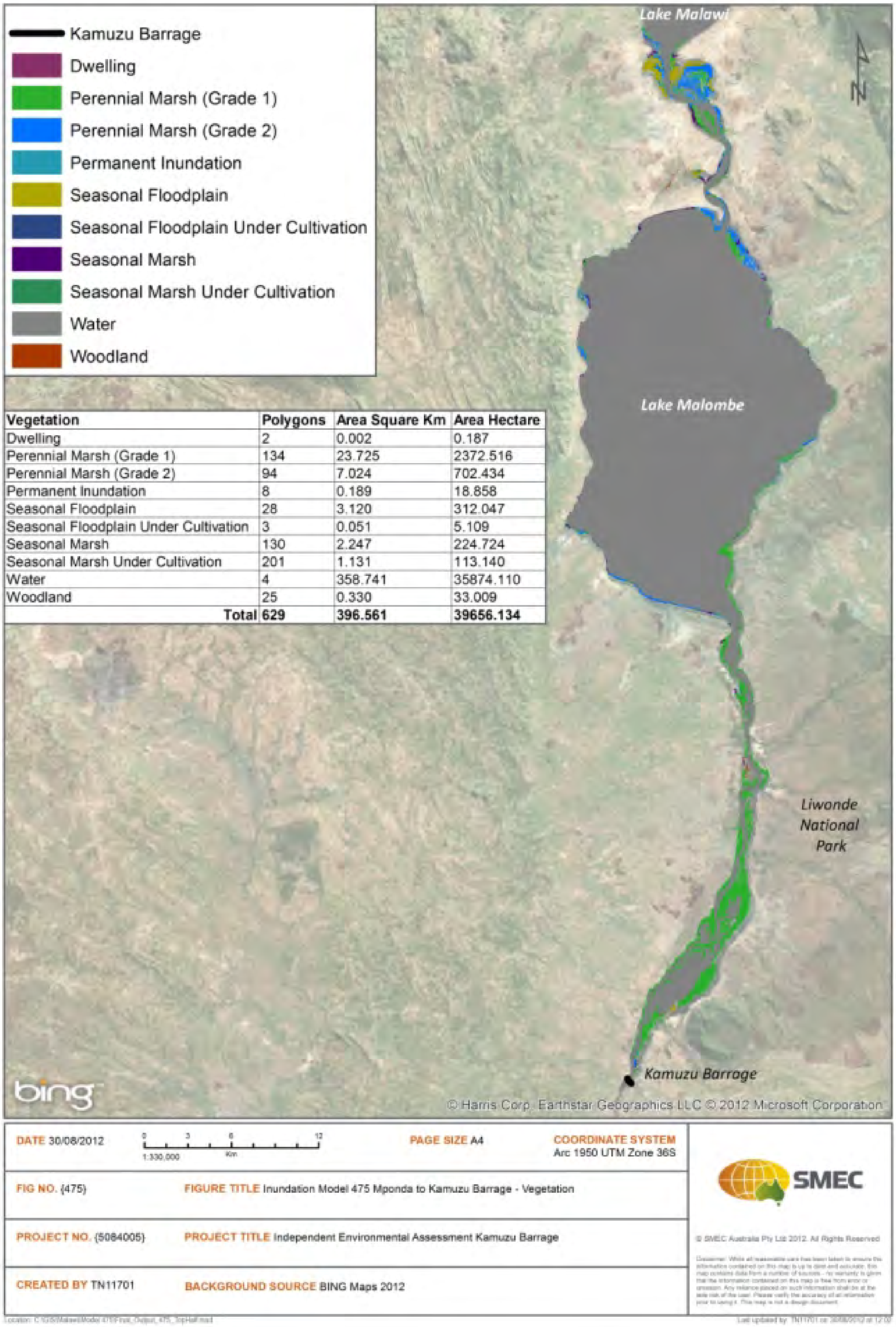
Vegetation	Polygons	Area Square Km	Area Hectare
Dwelling	2	0.000	0.010
Perennial Marsh (Grade 1)	82	0.173	17.331
Perennial Marsh (Grade 2)	16	0.007	0.688
Seasonal Floodplain	5	0.013	1.255
Seasonal Marsh	24	0.008	0.798
Seasonal Marsh Under Cultivation	10	0.009	0.890
Water	4	335.755	33575.507
Woodland	4	0.137	13.715
Total	**147**	**336.102**	**33610.193**

Figure 12. Inundation map 474 masl Lake Malawi to Kamuzu Barrage



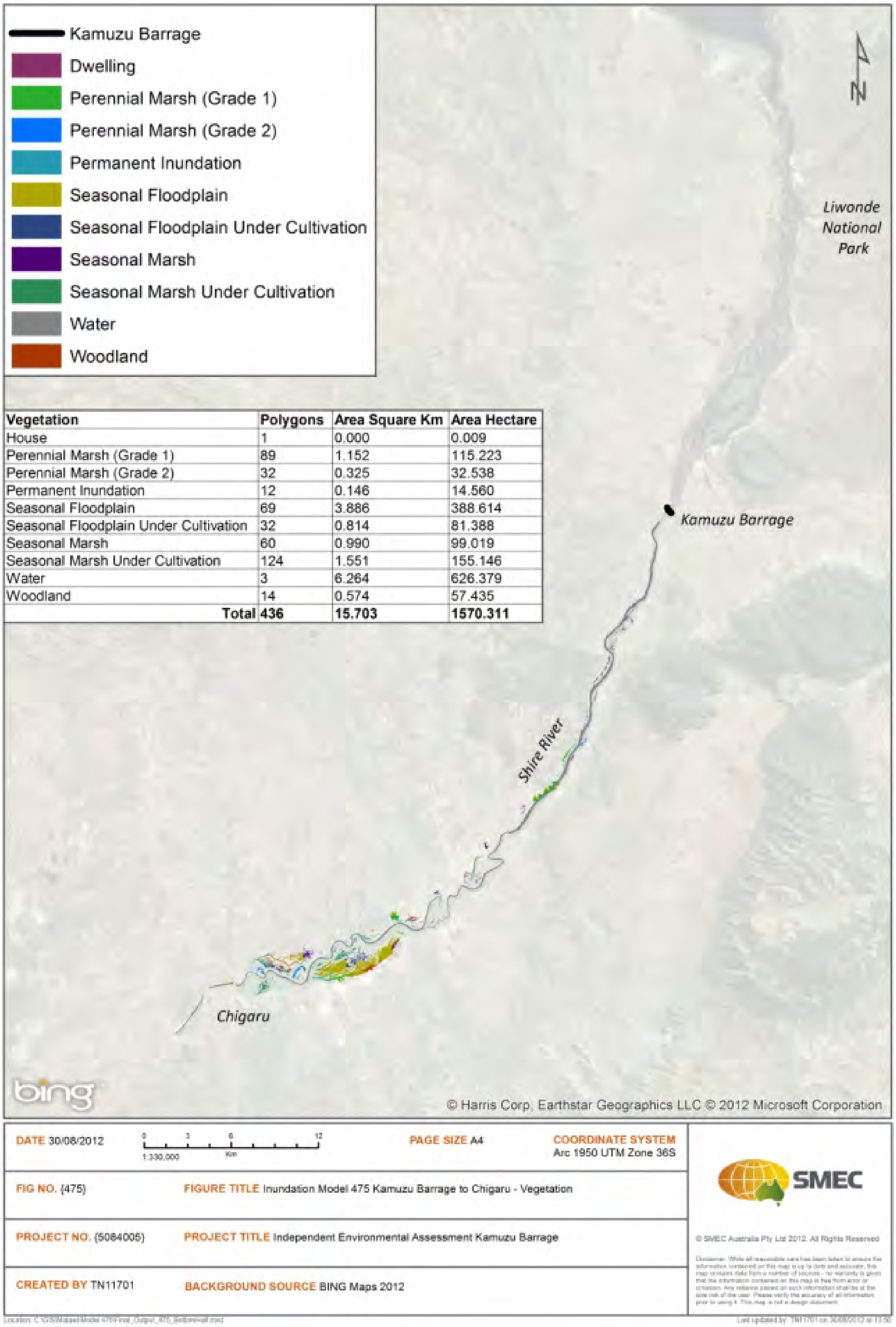
Vegetation	Polygons	Area Square Km	Area Hectare
Perennial Marsh (Grade 1)	84	0.571	57.069
Perennial Marsh (Grade 2)	26	0.061	6.118
Permanent Inundation	6	0.080	7.985
Seasonal Floodplain	44	1.975	197.529
Seasonal Floodplain Under Cultivation	19	0.287	28.733
Seasonal Marsh	35	0.136	13.647
Seasonal Marsh Under Cultivation	91	0.430	43.018
Water	3	5.812	581.180
Woodland	9	0.217	21.702
Total	**317**	**9.570**	**956.982**

Figure 13. Inundation map 474 masl Kamuzu Barrage to Chigaru



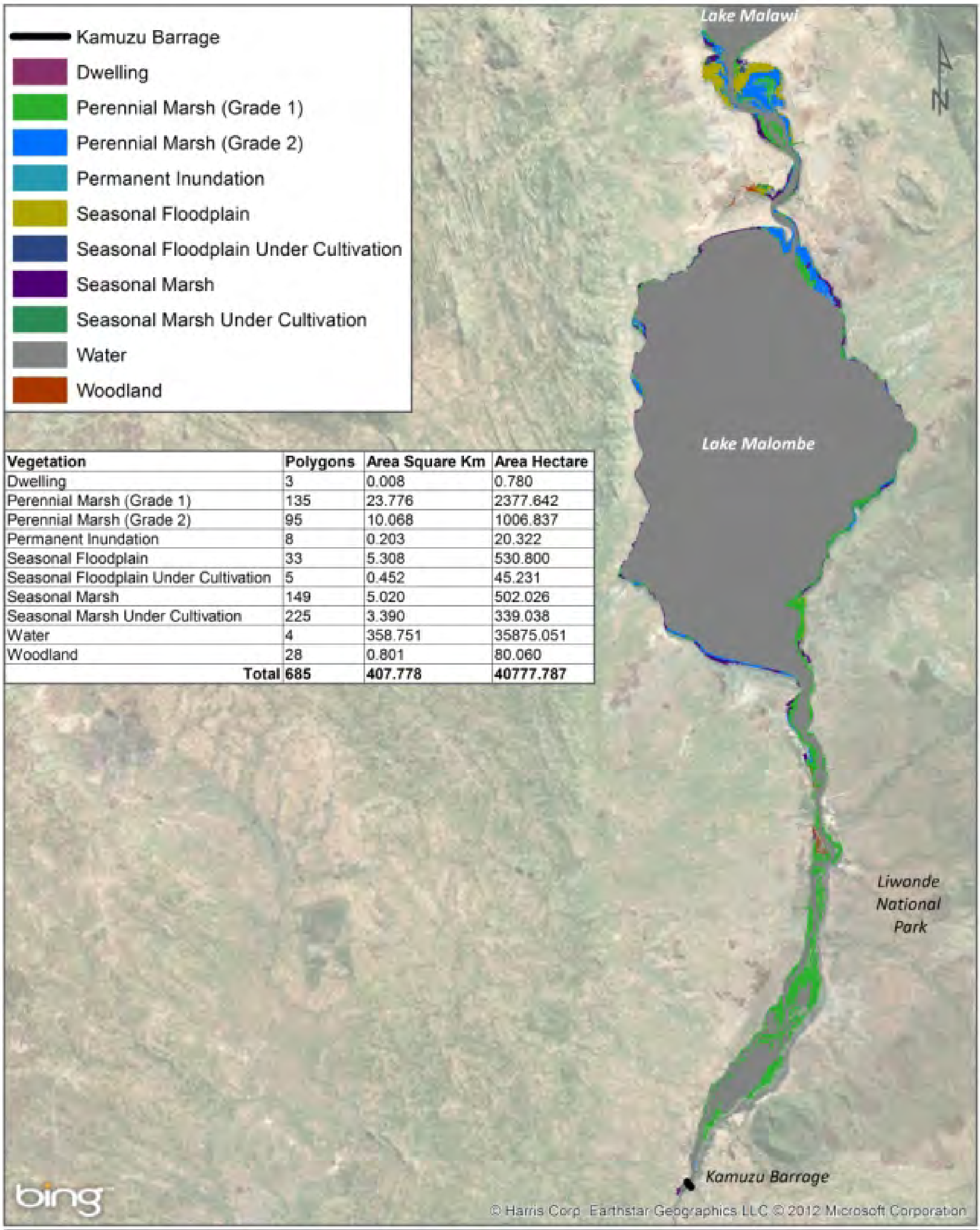
Vegetation	Polygons	Area Square Km	Area Hectare
Dwelling	2	0.002	0.187
Perennial Marsh (Grade 1)	134	23.725	2372.516
Perennial Marsh (Grade 2)	94	7.024	702.434
Permanent Inundation	8	0.189	18.858
Seasonal Floodplain	28	3.120	312.047
Seasonal Floodplain Under Cultivation	3	0.051	5.109
Seasonal Marsh	130	2.247	224.724
Seasonal Marsh Under Cultivation	201	1.131	113.140
Water	4	358.741	35874.110
Woodland	25	0.330	33.009
Total	**629**	**396.561**	**39656.134**

Figure 14. Inundation map 475 masl Lake Malawi to Kamuzu Barrage



Vegetation	Polygons	Area Square Km	Area Hectare
House	1	0.000	0.009
Perennial Marsh (Grade 1)	89	1.152	115.223
Perennial Marsh (Grade 2)	32	0.325	32.538
Permanent Inundation	12	0.146	14.560
Seasonal Floodplain	69	3.886	388.614
Seasonal Floodplain Under Cultivation	32	0.814	81.388
Seasonal Marsh	60	0.990	99.019
Seasonal Marsh Under Cultivation	124	1.551	155.146
Water	3	6.264	626.379
Woodland	14	0.574	57.435
Total	**436**	**15.703**	**1570.311**

Figure 15. Inundation map 475 masl Kamuzu Barrage to Chigaru

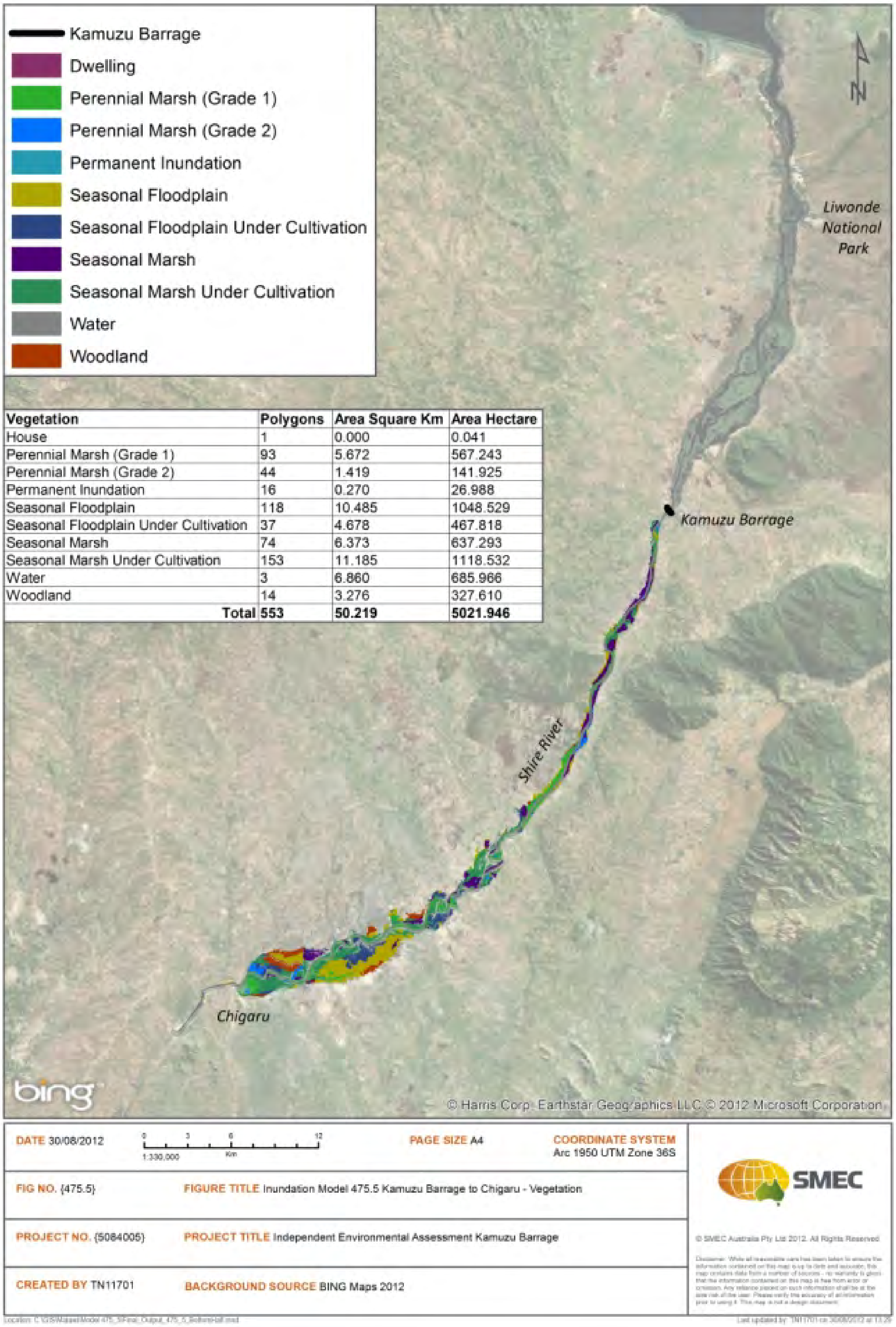


Vegetation	Polygons	Area Square Km	Area Hectare
Dwelling	3	0.008	0.780
Perennial Marsh (Grade 1)	135	23.776	2377.642
Perennial Marsh (Grade 2)	95	10.068	1006.837
Permanent Inundation	8	0.203	20.322
Seasonal Floodplain	33	5.308	530.800
Seasonal Floodplain Under Cultivation	5	0.452	45.231
Seasonal Marsh	149	5.020	502.026
Seasonal Marsh Under Cultivation	225	3.390	339.038
Water	4	358.751	35875.051
Woodland	28	0.801	80.060
Total	**685**	**407.778**	**40777.787**

DATE 30/08/2012	0 3 6 12 Km 1:330,000	PAGE SIZE A4	COORDINATE SYSTEM Arc 1950 UTM Zone 36S
FIG NO. {475.5}	FIGURE TITLE Inundation Model 475.5 Mponda to Kamuzu Barrage - Vegetation		
PROJECT NO. {5084005}	PROJECT TITLE Independent Environmental Assessment Kamuzu Barrage		
CREATED BY TN11701	BACKGROUND SOURCE BING Maps 2012		

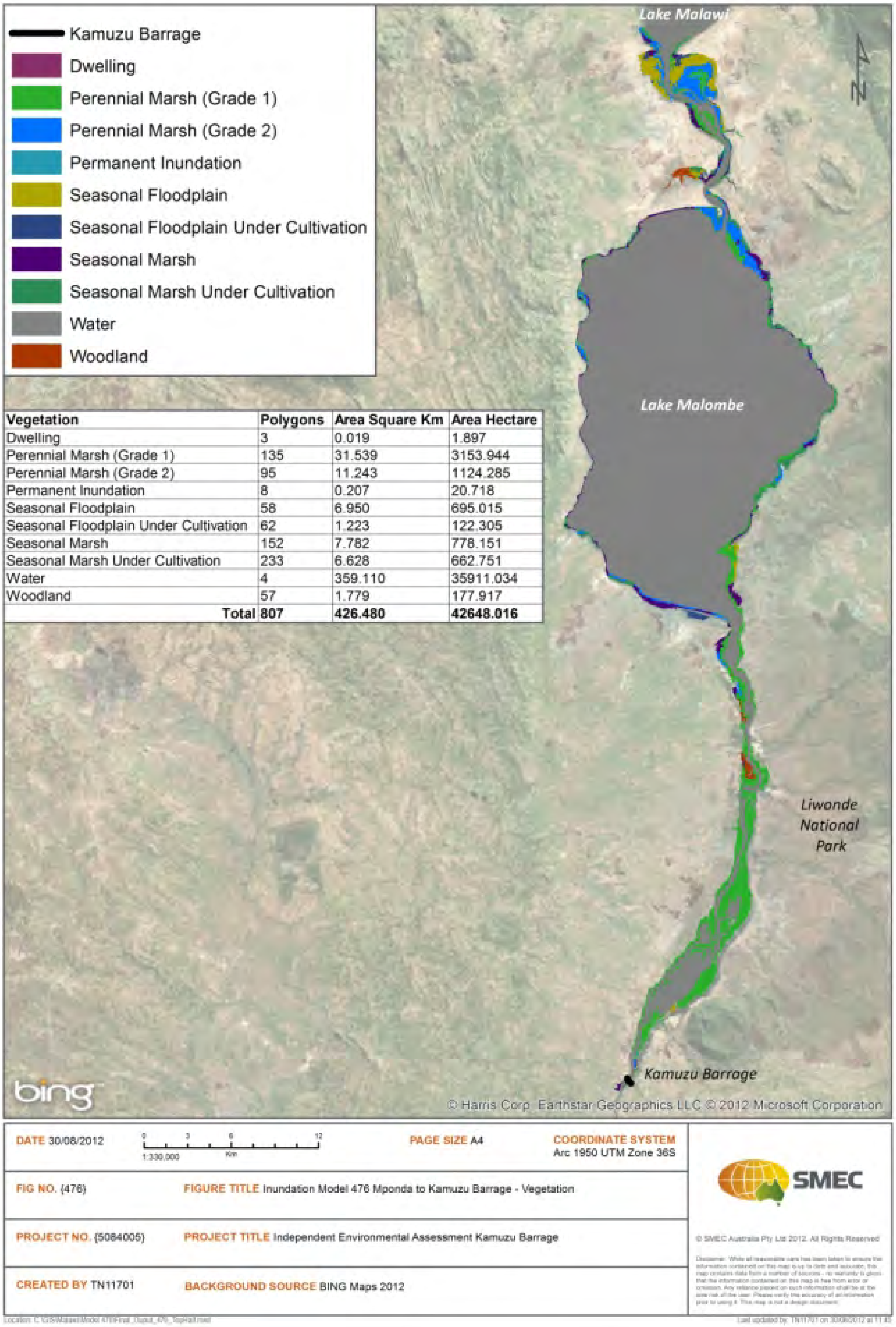
SMEC

Figure 16. Inundation map 475.5 masl Lake Malawi to Kamuzu Barrage



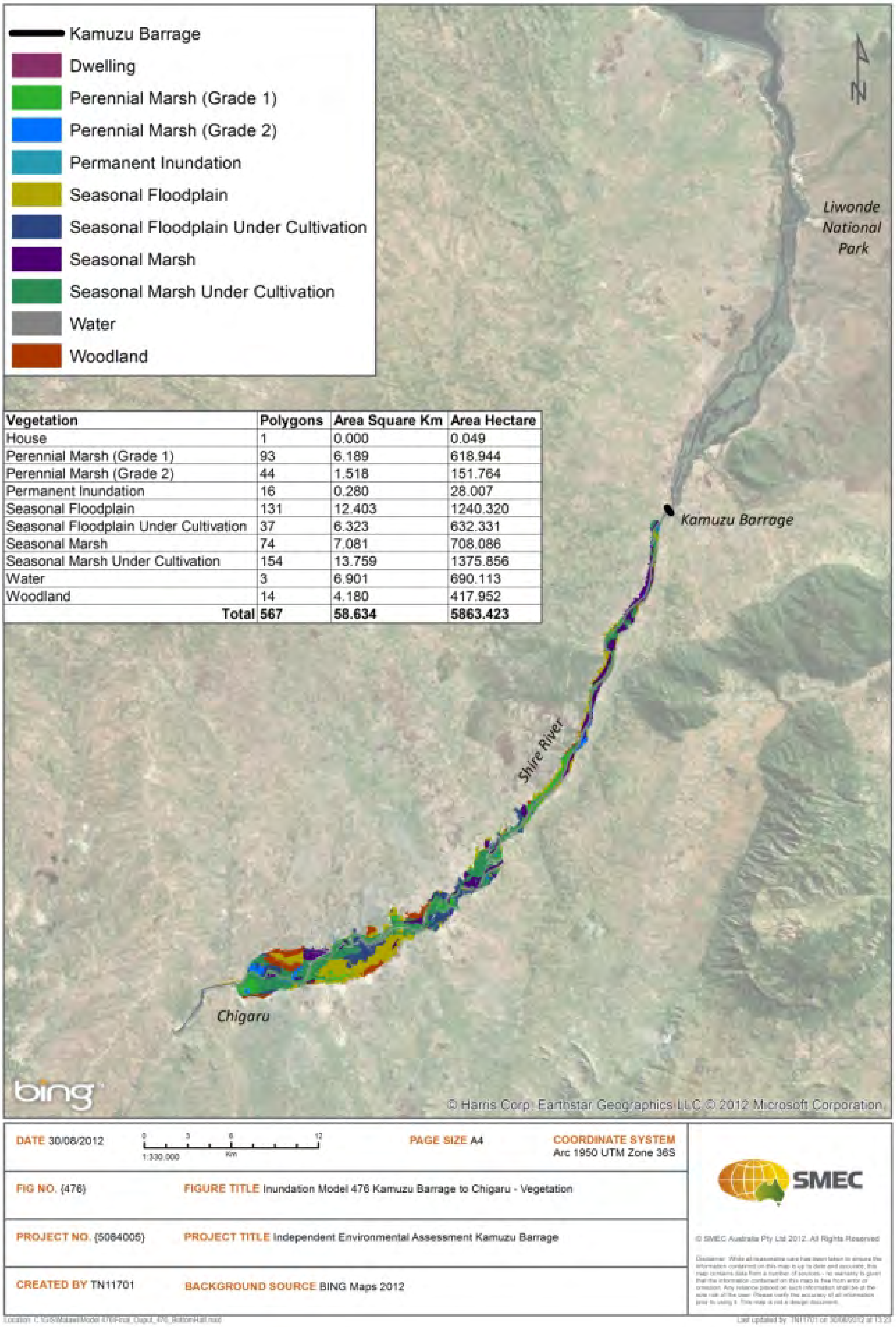
Vegetation	Polygons	Area Square Km	Area Hectare
House	1	0.000	0.041
Perennial Marsh (Grade 1)	93	5.672	567.243
Perennial Marsh (Grade 2)	44	1.419	141.925
Permanent Inundation	16	0.270	26.988
Seasonal Floodplain	118	10.485	1048.529
Seasonal Floodplain Under Cultivation	37	4.678	467.818
Seasonal Marsh	74	6.373	637.293
Seasonal Marsh Under Cultivation	153	11.185	1118.532
Water	3	6.860	685.966
Woodland	14	3.276	327.610
Total	**553**	**50.219**	**5021.946**

Figure 17. Inundation map 475.5 masl Kamuzu Barrage to Chigaru



Vegetation	Polygons	Area Square Km	Area Hectare
Dwelling	3	0.019	1.897
Perennial Marsh (Grade 1)	135	31.539	3153.944
Perennial Marsh (Grade 2)	95	11.243	1124.285
Permanent Inundation	8	0.207	20.718
Seasonal Floodplain	58	6.950	695.015
Seasonal Floodplain Under Cultivation	62	1.223	122.305
Seasonal Marsh	152	7.782	778.151
Seasonal Marsh Under Cultivation	233	6.628	662.751
Water	4	359.110	35911.034
Woodland	57	1.779	177.917
Total	**807**	**426.480**	**42648.016**

Figure 18. Inundation map 476 masl Lake Malawi to Kamuzu Barrage



Vegetation	Polygons	Area Square Km	Area Hectare
House	1	0.000	0.049
Perennial Marsh (Grade 1)	93	6.189	618.944
Perennial Marsh (Grade 2)	44	1.518	151.764
Permanent Inundation	16	0.280	28.007
Seasonal Floodplain	131	12.403	1240.320
Seasonal Floodplain Under Cultivation	37	6.323	632.331
Seasonal Marsh	74	7.081	708.086
Seasonal Marsh Under Cultivation	154	13.759	1375.856
Water	3	6.901	690.113
Woodland	14	4.180	417.952
Total	**567**	**58.634**	**5863.423**

Figure 19. Inundation map 476 masl Kamuzu Barrage to Chigaru

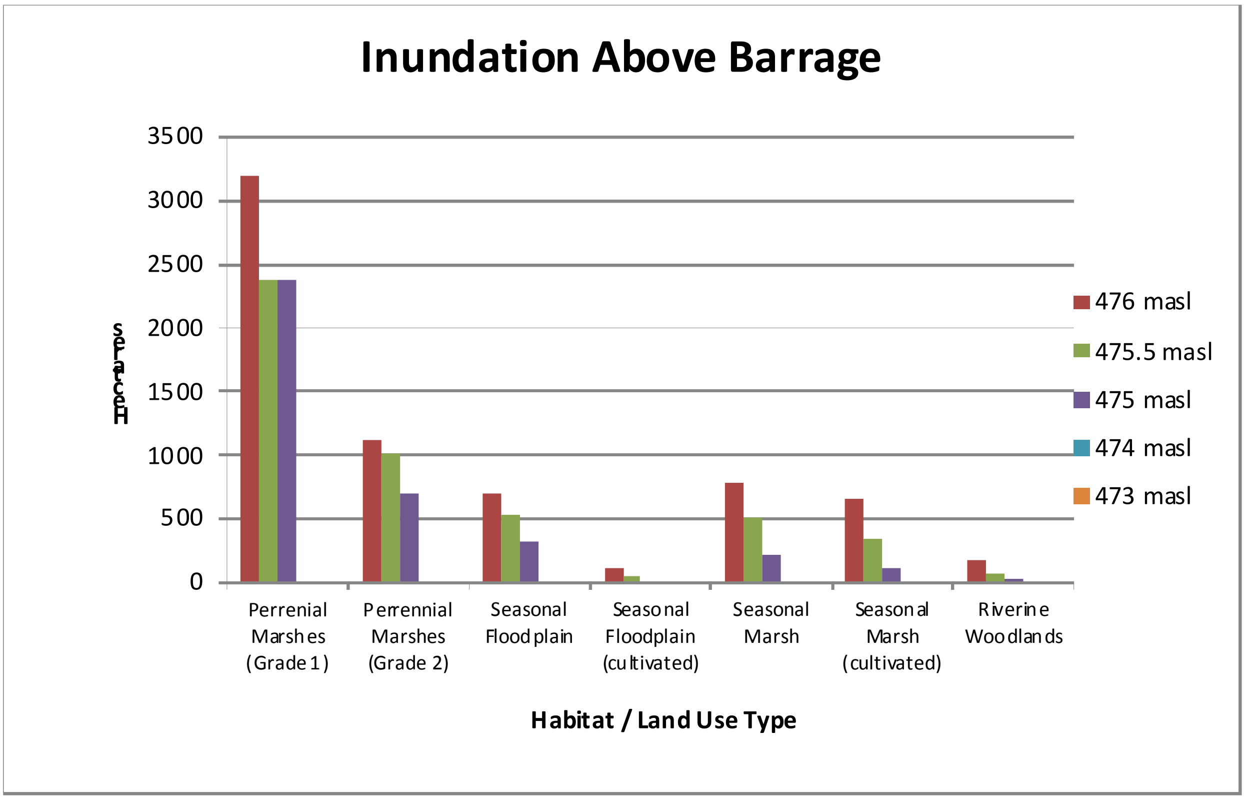


Figure 20. Habitat inundation above Kamuzu Barrage over a range of water levels

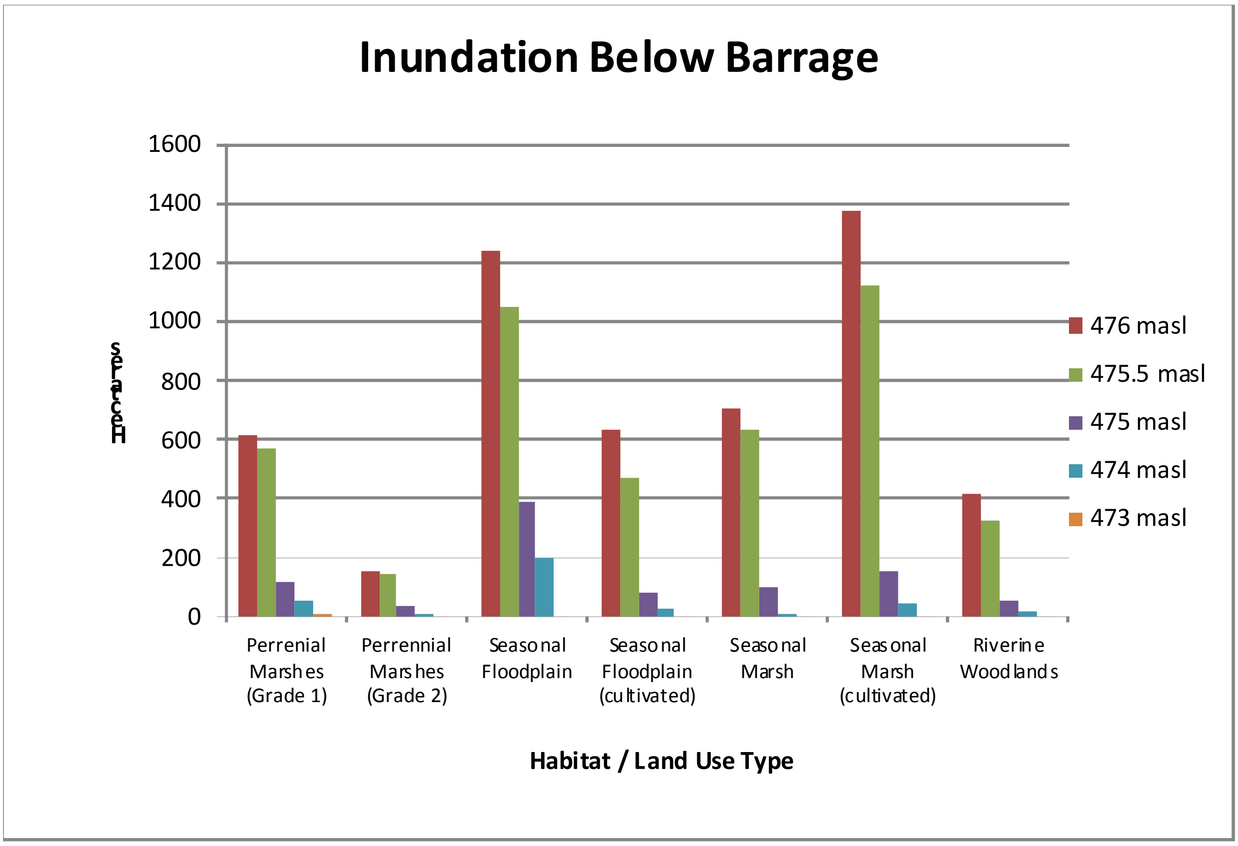


Figure 21. Habitat inundation below Kamuzu Barrage over a range of water levels

3.2 Impacts

3.2.1 Upstream of Kamuzu Barrage

3.2.1.1 Area of Inundation

It can be seen from Figures 10 and 20 that upstream of the Barrage significant inundation of fringing habitats only occurs at water levels of 475 masl and above. As the existing Barrage maintains a mean water level of 475.32 masl only changes to the structure that result in mean water levels above 475.32 masl are relevant in terms of the ecological impacts on fringing habitats.

At water levels of 475.5 masl and above the most highly impacted habitat type is Perennial Marsh, with 3,384.48 ha and 4,278.23 ha of this habitat type being inundated at 475.5 masl and 476 masl respectively. Most of the Perennial Marsh that is susceptible to inundation lies within the boundaries of Liwonde National Park.

Inundation of other habitat types is minimal at 474 masl and moderate at water levels of above 475, with the next highest maximum inundation being that of Seasonal Marsh habitat (i.e. 695 ha at 476 masl).

3.2.1.2 Inundation Period

In addition to the area of habitat inundated any changes in the inundation period must also be considered in an ecological context as this can cause a change in species composition. The data presented in Table 6 shows the predicted increases in the amount of time (expressed in both days per year and proportion of the year) that perennial marsh habitat will be inundated above the existing baseline level with a 20 cm and 40 cm increase in Barrage height.

The predictions in Table 6 indicate that there is no change in the inundation period of perennial marsh habitat for an increase in regulating height of either 20 cm or 40 cm when the level of Lake Malawi is 474 masl. However, small predicted changes in duration do occur at higher Lake levels and when the Barrage's HRWL is increased by either 20 cm or 40 cm. For example, at a Lake Malawi water level of 475 masl there is negligible difference in inundation period between a 20 cm or 40 cm increase in HRWL of the Barrage. The differences are increased slightly at Lake levels of 475.5 masl and 476 masl.

As perennial marshlands are permanent to semi-permanent wet habitats, inundation is likely to be manifested by an increase in water depth rather than an increase in the time that land is covered with water that would otherwise be dry. In addition, as the projected increases in inundation period are small, they probably lie within the natural annual variation of inundation experienced in the system (however data is not available to substantiate this supposition). Consequently the affect of this impact on available habitat quantity and quality above the Barrage is predicted to be low.

3.2.2 Downstream of Kamuzu Barrage

3.2.2.1 Area of Inundation

Downstream of the Barrage the magnitude of habitat inundation is significantly less than above the structure as the Shire River narrows and becomes more incised until it reaches the low wide floodplain of the Elephant Marsh. Water flows are faster in this section and there are less perennial marsh areas which require relatively slow flowing water in which to become established.

In this section significant habitat inundation is only observed at water levels of 475.5 masl and above with seasonal floodplain and seasonal marsh habitats being the most severely impacted (Figures 17 and 21). Perennial marsh habitat is poorly represented in this section of the River and inundation of this habitat type is approximately 1/5 of that above the Barrage at the highest water level of 476 masl.

3.2.2.2 Inundation Period

The data presented in Table 6 shows that seasonal flood plain and seasonal marsh habitats are more significantly impacted by increased inundation period downstream of the Barrage than upstream. This could potentially be an issue for egg laying reptiles, such as crocodiles and turtles that inhabit the Shire River below the Barrage.

Female crocodiles will select a sandbank that is above flood water level, with good drainage and cover nearby to build a nest (Compass, 2000). Such conditions are only found in seasonal flood plain and seasonal marsh habitats in this section of the Shire River. Typically, crocodile eggs can only withstand flooding for a period of up to 12 hours (Mazzotti, 2002). If the water regulation regime at the Barrage leads to nesting sites being inundated for longer than this, decreased rates of egg viability may result.

TABLE 6. INUNDATION PERIOD

Lake Malawi Water Level (masl)	Duration of Inundation			Area of Perrennial Marsh Inundated (ha)			Area of Seasonal Floodplain (uncultivated) Inundated (ha)			Area of Seasonal Marsh (uncultivated) Inundated (ha)		
	Existing Barrage Height (475.32 masl)	20 cm Increase in Barrage Height (475.52 masl)	40 cm Increase in Barrage Height (475.72 masl)	Upstream of Kamuzu Barrage to Mponda	Down-stream of Kamuzu Barrage to Chigaru	Total	Upstream of Kamuzu Barrage to Mponda	Down-stream of Kamuzu Barrage to Chigaru	Total	Upstream of Kamuzu Barrage to Mponda	Down-stream of Kamuzu Barrage to Chigaru	Total
474	68% (248 days)	68% (248 days)	68% (248 days)	18.02	63.19	**81.21**	1.3	197.5	**198.8**	0.8	13.6	**14.4**
475	40% (146 days)	44% (161 days)	45% (164 days)	3,074.95	147.76	**3,222.71**	312.0	388.6	**700.6**	224.7	99.0	**323.7**
475.5	22% (80 days)	26% (95 days)	30% (110 days)	3,384.48	709.16	**4,093.64**	530.8	1,048.5	**1,579.3**	502.0	637.3	**1,139.3**
476	8% (33 days)	12% (40 days)	15% (51 days)	4,308.22	770.7	**5,078.92**	695.0	1,240.3	**1,935.3**	778.2	708.1	**1,486.3**

4 Discussion

At a water level of 475 masl at Lake Malawi (i.e. the no Barrage condition), the existing Barrage height results in an increase of 0.32 masl to a baseline water level of 475.32 masl (i.e. the existing baseline condition). A 20 cm increase in the height of the Barrage will increase the water level to 475.52 masl resulting in the upstream inundation of an additional 309.58 ha (i.e. a 9.15% increase) of perennial marsh habitat above the baseline condition. A 20 cm increase in Barrage height will extend the inundation period of this 309.58 ha by 15 days above the baseline condition; whereas a 40 cm increase will extend the inundation period by 30 days.

At a water level of 476 masl at Lake Malawi a 20 cm increase in the height of the Barrage will result in the upstream inundation of an additional 1,233.27 ha (i.e. a 40.01% increase) of perennial marsh habitat above the baseline condition. A 20 cm increase in Barrage height will extend the inundation period of this 1,233.27 ha by 8 days above the baseline condition; whereas a 40 cm increase will extend the inundation period by 18 days.

The majority of the additional perennial marsh habitat that will be inundated by any increase in the height of the Barrage lies within the boundaries of Liwonde National Park and has significant ecological value to the wildlife inhabiting the Park.

Perennial marshes are essential to the maintenance of the aquatic system in this part of the Shire River as they provide breeding and rearing habitat for economically important species of fish, invertebrates and birds. They also contribute significantly the productivity of the aquatic system in this reach of the river. Perennial marshes and seasonal floodplains are also important foraging areas for elephants and hippopotamus residing within Liwonde National Park (Government of Malawi, 2005).

As described in Section 1, the main vegetative types found in Perrenial Marshes are emergent species (e.g. *Cyperus papyrus*; *Typha capensis*; *Vossia cuspidate*; *Phragmites mauritianus*; *P australis*; and *Thelipterys confluens*), floating aquatics (e.g. *Azolla pinnata*; *Commelina benghalensis*; *Ipomoea aquatica*; *Nymphaea caerula*; *Nymphaea lotus*; *Pycreus mundtii*; and *Salvinia hastate*), and submerged plants (e.g. *Ceratophyllum demersum*; *Ottelia* spp; *Potamogeton pectinatus*; *P. thunbergia*; and *Spirodela polyrhiza*). While floating aquatics and submerged plants can tolerate extended periods of submergence, emergent species are less tolerant. Increasing the height of the Barrage by 20 cm results in minor increases in inundation periods above the existing baseline condition (i.e. 15 days and 8 days for the 475.5 and 476 masl scenarios modelled); this small increase in the period of inundation should be within the tolerance range of emergent aquatic species. However, increasing the Barrage height by 40 cm results in significantly longer inundation periods (i.e. 30 days and 18 days for the 475.5 and 476 masl scenarios modelled), which may be outside the tolerance range of emergent species and result in a shift in species composition.

A 20 cm rise in Barrage height results in minor increases in the area and period of inundation of Perennial Marsh habitat upstream of the Barrage and this is not likely to result in any significant change in species composition or structure of this habitat type. However, a 40 cm rise in height results in the inundation of a much larger area for extended periods of time which is more likely to result in a change in the species composition and structure of this habitat type within Liwonde National Park. Hence, a 40cm rise in the height of the Barrage can only be recommended if accompanied by a monitoring program of the health/extent of Perennial Marshes within Liwonde National Park to track any changes in habitat extent or condition. This should be accompanied by an adaptive management program which regulates the operation of the Barrage in response to the findings of the monitoring program.

Downstream of the Barrage water levels above 475.5 masl primarily result in the inundation of an additional 659.9 ha (i.e. a 270% increase) of seasonal flood plains and 538.3 ha (i.e. a 643% increase) of seasonal marshes above the baseline condition. The primary impact from this will be social, as the majority of these seasonally flooded areas have limited ecological value because they have been modified by the local community to grow crops. Increased periods of inundation will effectively reduce the growing season on the fertile River margins resulting in social and economic impacts for the local community. This issue will be addressed in the Environmental and Social Impact Assessment Report.

Increased inundation periods of seasonal flood plains and seasonal marshes downstream of the Barrage could be an issue for nesting crocodiles and turtles. For example, the dry-season nesting period of the Nile crocodile results in hatching at the start of the wet season, increased periods of inundation at this time resulting from operation of the Barrage may destroy eggs if nests are flooded. In addition, the sandbanks in which they nest are often deposited by wet-season water flows, if Barrage operations result in increased water flows during the early wet-season heavy rains the sandbanks can be severely eroded or washed away, inundating the eggs or washing them out into deep water.

4.1 Environmental Flow Requirements

The primary cause of impact to the fringing terrestrial habitats resulting from implementation of the project will be associated with changes in environmental flows and flooding regimes. These impacts will be most pronounced in the low gradient areas of Southern Lake Malawi, Lake Malombe and the Upper Shire River.

The Middle Shire River is characterised by a steep gradient, well defined incised river channel and riverine woodlands and escarpments. This reach of the river will be relatively immune to variations in volumes or patterns of water release from the Barrage as the channel has capacity to absorb relatively large fluctuations in water level without flooding the surrounding terrestrial habitats. This will hold true provided a minimal baseline environmental flow is maintained in the Middle Shire Reach.

It is important to maintain the seasonal flooding of the marshlands in order to preserve floodplain and seasonal marsh habitat and support the seasonal dambo agriculture that much of the local community relies upon for sustenance during the dry season when seasonal marshes provide temporal fertile land for cropping.

Downstream of the Barrage it is important that operations do not result in artificially prolonged inundation of crocodile and turtle nesting sites located on seasonal flood plain and seasonal marshland during the critical nesting season from October to January.

4.2 Implications for Operation of Kamuzu Barrage

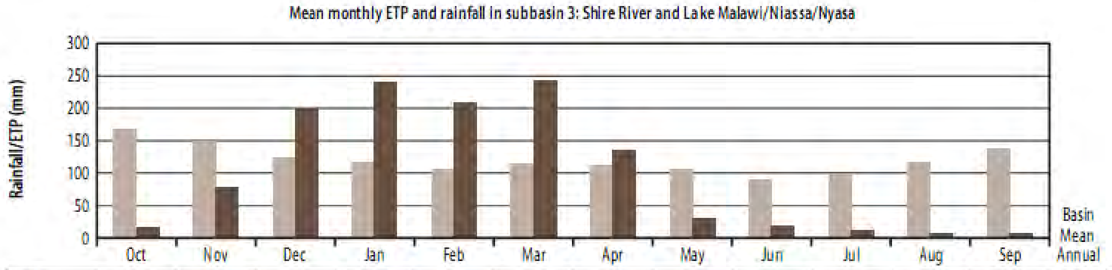
In order to minimise the impacts of the Project to fringing habitats, the Barrage should be operated to mimic the natural seasonal flooding regime of the Shire River, Lake Malombe and the lower part of Lake Malawi, as closely as possible. This is particularly critical when the Barrage is operating at levels resulting in water levels of 475 masl and above at Lake Malawi.

A typical annual hydrograph for the Shire River is shown in Figure 22; peak flows typically occur in February and March while minimum flows are experienced during the dry season in September and October.

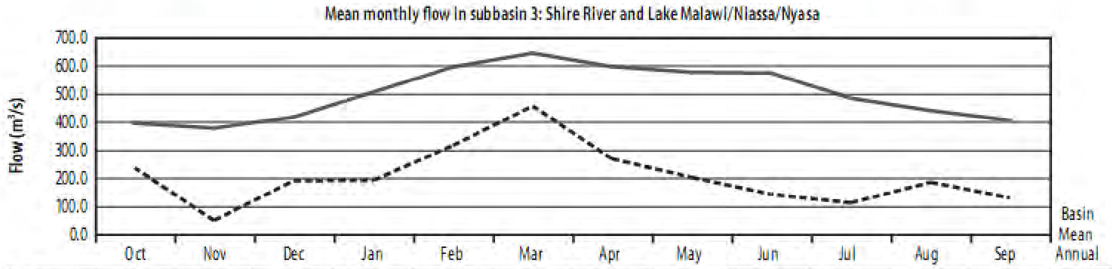
The proposed Project to raise the height of the Barrage will increase the existing HRWL (475.32 masl) in Lake Malawi by 20-40cm i.e. 475.52 – 475.72 masl (which is within the historical range of Lake levels, with a high of 477.25 recorded in 1980). Modelling shows that there will be a minimal change in the area of habitat inundated and the period of inundation associated with a 20 cm increase in Barrage height. However, a potentially significant increase in the area of inundation and the inundation period is possible upstream of the Barrage if the height is raised by 40 cm. This may significantly impact important perennial marsh habitat located along the boundary between the Shire River and Liwonde National Park. It is recommended that if the Barrage is raised by 40 cm, a Perennial Marsh habitat monitoring program is implemented within the boundaries of the Park and an adaptive management program is adopted whereby the operation of the Barrage is regulated in response to the findings of the monitoring program.

It is also recommended that if levels do need to be increased above 474.5 masl then the Barrage should be operated to mimic the seasonal flooding patterns of the system i.e. levels of 475.5 masl permitted during the wet season only (i.e. Dec – April); maintain levels below 475.5 masl during the dry season (May – Oct).

This operational regime will also minimise the incidences of prolonged (i.e. greater than existing levels) inundation of seasonal floodplain and marshland habitats downstream of the Barrage. This habitat type may support crocodile (and turtle) nesting, during the critical incubation period lasting from October to December (Compass, 2000).



	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Basin Mean Annual
ETP	166	150	124	116	106	115	112	105	90	98	116	138	1,436
Rain	16	79	200	240	209	243	136	29	18	11	5	5	1,191



	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Basin Mean Annual
Drought	233.2	48.0	188.8	189.6	313.4	453.7	266.4	200.6	139.5	110.3	182.6	127.1	204.4
Average	392.7	375.3	414.8	503.7	592.7	641.6	593.6	573.7	570.2	481.1	437.2	402.5	498.3

Figure 22. Shire River Hydrograph (World Bank 2010)

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Appendix 1: Description of Biotic Communities at Sampling Sites

SITE NUMBER: 01	DATE: 29/10/2011	TIME: 06:41
COORDINATES: S 16°33'45" / E 035°07'43"	SITE NAME. Elephant Marsh	
BIOME CATEGORY: Seasonal Flood Plain		

DESCRIPTION:

Seasonally wet grassland on an alluvium flood plain. Sparsely covered with grasses and some reeds and papyrus in wet areas and at the margins of the river.

SPECIES LIST:

Species recorded.	Family
Cynodon dactylon (L.) Pers.	Poaceae
Potamogeton	Potamogetonaceae
Parkinsonia aculeata L.	Fabaceae- Mimosoideae
Acacia (invasive one)	Fabaceae- Mimosoideae
Eichhornia crassipes (Mart.) Solms	Pontederiaceae.
Phragmites mauritianus Kunth.	Poaceae
Eichornia crassipes	Pontederiaceae.
Echnochloa colona (L.) Link	Poacaea
Cyperus papyrus L.	Cyperaceae
Panicum	Poaceae
Vernonia cinerea	Asteraceeae

Mimosa pigra L.	Mimosideae
Sphaelanthus randii S.Moore var. Randii	Asteraceeae
Azolla nilotica Mett.	Azollaceae
Helotropium sp.	Boraginaceae
Vossia cuspidata (Roxb.) Griff.	Poaceae
Ludwigia erecta (L.) Hara	Onagraceae
Ipomoea acquatica Forssk.	Convolvulaceae
Gomphocarpus fruticosus (L.) Ait.	Asclepidoideae

SITE NUMBER: 03	**DATE:** 29/10/2011	**TIME:** 08:45
COORDINATES: S 16°32'58" / E 035°08'12"	**SITE NAME.** Elephant Marsh	
BIOME CATEGORY: Perennial Marsh		

DESCRIPTION:

Perennial marsh area in the middle of Elephant Marsh. Comprised largely of emergent or floating macrophytes. This area will remain submerged throughout the year.

SPECIES LIST:

Vossia cuspidata (Roxb.) Griff.	Poaceae
Mimosa pigra L.	Fabaceae- Mimosoideae
Persicaria serrulata (Lag.) Webb & Moq.	Polygonaceae
Ipomoea	Convolvulaceae
Ipomoea aquatica Forssk.	Convolvulaceae
Cissampelos mucronata A. Rich.	Menispermaceae
Ziziphus mucronata Willd.	Rhamnaceae
Ricinus communis L.	Euphorbiaceae
Phragmites mauritianus Kunth.	Poaceae
Vernonia	Asteraceae
Calotropis procera (Aiton) W.T. Aiton	Asclepidoideae
Ficus	Moracea

Tridax procumbens L.	Asteraceae
Lactuca	Asteraceae
Mangifera indica L.	Anacardiaceae
Rynchosia	Papilinoideae
Eichhornia crassipes (Mart.) Solms	Pontederiaceae.
Pistia stratoites L.	Araceae
Zea mays L.	Poaceae
Cyperus cyperoides (L.) Kuntze	Cyperaceae
Schoenoplectus corymbosus (Roem. et Schutt) J.Reyn	Cyperaceae
Echinochloa colona (L.) Link	Poaceae
Nymphea sp.	Nympeaceae
Ottelia ulvifolia (Plunch.) Walp.	Hydrocharitaceae
Cyperus laxus Lam. subsp. buchholzii (Boeck) K. Lye	Cyperaceae
Acacia xanthophloea Benth.	Mimosoideae
Philenoptera violacea (Klotze) Shrire	Papilinoideae
Persicaria limbata (Meisn.)Hara	Polygonaceae

SITE NUMBER: 04	**DATE:** 29/10/2011	**TIME:** 09:32
COORDINATES: S 16°32'55" / E 035°08'02"	**SITE NAME.** Elephant Marsh	
BIOME CATEGORY: Perennial Marsh		

DESCRIPTION:

Perennial marsh area in the middle of Elephant Marsh. Comprised largely of emergent or floating macrophytes. This area will remain submerged throughout the year.

SPECIES LIST:

Vossia cuspidata (Roxb.) Griff.	Poaceae
Mimosa pigra L.	Fabaceae- Mimosoideae
Persicaria serrulata (Lag.) Webb & Moq.	Polygonaceae
Ipomoea	Convolvulaceae
Ipomoea aquatica Forssk.	Convolvulaceae
Cissampelos mucronata A. Rich.	Menispermaceae
Ziziphus mucronata Willd.	Rhamnaceae
Ricinus communis L.	Euphorbiaceae
Phragmites mauritianus Kunth.	Poaceae
Vernonia	Asteraceae
Calotropis procera (Aiton) W.T. Aiton	Asclepidoideae
Ficus	Moracea

Tridax procumbens L.	Asteraceae
Lactuca	Asteraceae
Mangifera indica L.	Anacardiaceae
Rynchosia	Papilinoideae
Eichhornia crassipes (Mart.) Solms	Pontederiaceae.
Pistia stratoites L.	Araceae
Zea mays L.	Poaceae
Cyperus cyperoides (L.) Kuntze	Cyperaceae
Echinochloa colona (L.) Link	Poaceae
Nymphea sp.	Nympeaceae
Ottelia ulvifolia (Plunch.) Walp.	Hydrocharitaceae
Cyperus laxus Lam. subsp. buchholzii (Boeck) K. Lye	Cyperaceae
Acacia xanthophloea Benth.	Mimosoideae
Persicaria limbata (Meisn.)Hara	Polygonaceae

SITE NUMBER: 05	**DATE:** 29/10/2011	**TIME:** 12:40
COORDINATES: S 16°22'24" / E 034°56'16"	**SITE NAME.** Elephant Marsh	
BIOME CATEGORY: Perennial Marsh		

DESCRIPTION:
This site is located within Elephant Marsh; it is a perennial marsh area dominated by *Typher* spp.

SPECIES LIST:

Phragmites mauritiana Kunth.	Poaceae
Vossia cuspidata (Roxb.) Griff.	Poaceae
Eleusine indica (L.) Gaertn.	Poaceae
Sida alba L.	Malvaceae
Mangifera indica L.	Anacardiaceae
Nidorella auricullata DC susbsp. auriculata	Asteraceae
Musa paradisiaca L.	Musaceae
Adansonia digitata L.	Bombacaceae
Pennisetum purpureum Schumach.	Poaceae
Leucena leucocephala (Lam.) De Wit	Mimosoideae
Zea mays L.	Poaceae
Carica papaya L.	Caricaceae
Ziziphus abyssinica Hochst. ex A.Rich.	Rhamnaceae

Cyperus mundtii (Nees) Kunth.	Cyperaceae
Echinochloa colona (L.) Link	Poaceae
Sphaeranthus pedancularis DC subsp. rogesii	Asteraceae
Commelina benghalensis L.	Commelinaceae
Ficus capreifolia Delile	Moraceae
Solanum esculentum L.	Solanaceae
Ocimum gratissimum (L.) subsp. gratissimum	Lamiaceae
Solanum sp.	Solanaceae
Persicaria attenuata (R.Br.) Sojak susbsp. africanum	Polygonaceae
Mimosa pigra L.	Mimosoideae
Abelmoschus esculentus (L.) Moench	Malvaceae
Sesbania macrantha Welw. ex Phill. & Hutch.	Papilionoideae
Prosopis glandulosa Torrey	Mimosoideae

SITE NUMBER: 06	**DATE:** 29/10/2011	**TIME:** 12:52
COORDINATES: S 16°22'28" / E 034°56'12"	**SITE NAME.** Lower Shire River	
BIOME CATEGORY: Seasonal Marshes - Under Cultivation (dambos)		

DESCRIPTION:

This site is a seasonally wet grassland which is under dambo cultivation the principal crop being maize.

SPECIES LIST:

Various crops

SITE NUMBER: 07	**DATE:** 29/10/2011 **TIME:** 14:13
COORDINATES: S 16°04’44” / E 034°49’44”	**SITE NAME.** Kasinthula Growers Pump Station
BIOME CATEGORY: Seasonal Marshes - Under Cultivation (dambos)	

DESCRIPTION:

This is a disturbed seasonally wet grassland area which is under dambo cultivation. Crops include cassava, maize, peas, cassava and tomatoes. Some perennial marsh vegetation exists at the river margin.

A large pumping station is located just upstream of this site which extracts a lot of water from the river for irrigation of sugar cane fields.

SPECIES LIST:

Philenoptera violacea (Klotze) Shrire	Papilinoideae
Trichilia emetica Vahl	Meliaceae
Phragmites mauritiana Kunth.	Poaceae
Senna siamea (L.) Irwin & Bainesby	Caesalpinoideae
Capparis erythrocarpus Isert	Capparaceae
Sterculia africana (Lour.) Fiori	Sterculiacaea
Diospyros senensis Klotz.	Ebenaceae
Lufa cylindrica (L.) M.Roem	Curcubitaceae
Combretum microphyllum (Klotz.) Engl.	Combretaceae
Cryptolepis oblongifolia (Meisn.) Schltr.	Asclepidoideae

Azadirachta indica A.Juss.	Meliaceae
Calotropis procera (Ait.) Ait. f.	Asclepidoideae
Jatropha sp.	Euphorbiaceae
Melanthera scandens (Schum. & Thonn.) Roberty	Asteraceae
Tabernamontana elegans Stapf.	Apocynaceae
Abelmoschus esculentus (L.) Moench	Malvaceae
Musa paradisiaca L.	Musaceae
Maerua angolensis DC	
Vetiveria nigritana (Benth.) Stapf.	Poaceae
Euphorbia hirta L.	Euphorbiaceae
Nidorella auriculata DC	Asteraceae
Cynodon dactylon (L.) Pers	Poaceae
Echinochloa colona (L.) Link	Poaceae
Sorghum bicolor (L.) Moench	Poaceae
Senna alata	Caesalpinoideae
Panicum maximum L.	Poaceae
Phyllanthus reticulata Poir var. reticulata	Euphorbiaceae
Ficus capreifolia Delile	Moraceae
Psidium guajava L.	Myrtaceae
Albizia atunesiana Harv.	
Solanum sp.	Solanaceae
Cissampelos mucronata A.Rich.	Menispermaceae
Ageratum conyzoides L. subsp houstonianum (MMI) Sahn.	Asteraceae
Verbena sp.	Verbenaceae
Lantana camara L.	
Zea mays L.	Poaceae
Vigna unguiculata (L.) Walp.	Papilinoideae
Ipomoea batatas (L.) Lam.	Convovulacaea
Mangifera indica L.	Anacardiaceae
Solanum esculentum L.	Solanaceae
Cajanus cajan (L.) Mill.	Papilinoideae
Amaranthus hybridus	Amaranthaceae

SITE NUMBER:08	**DATE:** 30/10/2011	**TIME:** 07:55
COORDINATES: S 15°54’05” / E 034°44’57”	**SITE NAME.** Majete National Park	
BIOME CATEGORY: Riverine Woodlands (escarpments)		

DESCRIPTION:

This site is located within Majete National Park just downstream of the Kapichira Hydropower Plant. It is open mixed woodland on an escarpment, one of the few escarpment sites sampled due to lack of accessibility.

SPECIES LIST:

Sansevieria burdettii	
Maerua angolensis DC	Capparaceae
Kirkia acuminata Oliv.	Simaroubaceae
Justicia striata (Klotz.) Bullock	Acanthaceae
Asparagus africana	Asparagaceae
Commiphora sp.	
Dalbergia arbutifolia Bak.	
Cissus quadrangularis L.	
Bombax rhodognaphalon K.Schum.	Bombacacae
Pleurostylia africana	
Acacia nilotica (L.) Delile	Mimosoideae
Sterculia appendiculata K.Schum.	Sterculiaceae

Hibscus debeertsii Wild. & Duv.	Malvaceae
Acacia nigrescens Oliv.	Mimosoideae
Combretum microphyllum Klotz.	Combretaceae
Ximenia americanum L. var. microphylla Oliv.	
Urochloa mossambicensis (Hack.) Dandy	Poaceae
Ormocarpum kirkii S.Moore	

SITE NUMBER: 09	**DATE:** 30/10/2011	**TIME:** 08:34
COORDINATES: S 15°52'58" / E 034°44'39"	**SITE NAME.** Majete National Park	
BIOME CATEGORY: Riverine Woodlands		

DESCRIPTION:

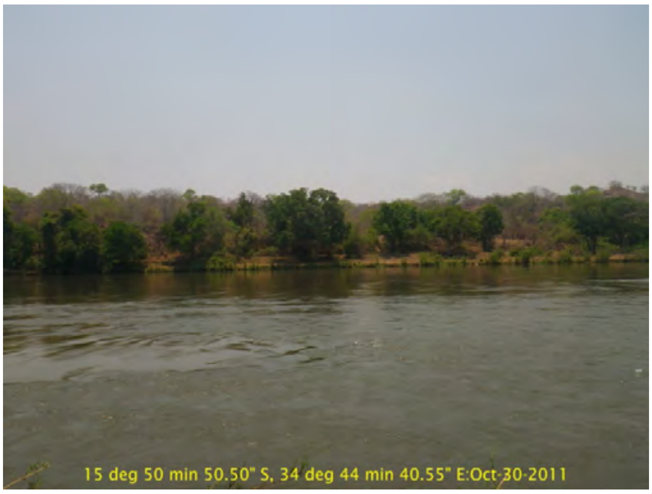
This site is within Majete National Park, located just upstream of a hydropower plant. It is a deciduous riparian woodland. Bank erosion is evident. Wildlife is abundant and Vervet monkeys, baboon, elephants and hippos were observed during the assessment. A number of sandy banks exist in this reach of the Shire which may be crocodile nesting areas (see photo bottom right).

SPECIES LIST:

Cleistochlamys kirkii (Benth.). Oliv.	Annonaceae
Xylopia parviflora (A. Rich) Benth.	Annonaceae
Lantana camara L.	Verbanaceae
Acacia nigrescens Olive	Mimosaceae
Phyllanthus reticulata Poir.	Euphorbiaceae
Jasminum fluminense Vell	Oleaceae
Sterculia appindiculata K. Schum	Sterculiaceae
Jatropha sp.	Euphorbiaceae
Croton macrostachys Hochst. Ex. A. Rich	Euphorbiaceae
Tamarindus indica L.	Caesalpinoideae
Kiggelaria africana L.	Flacourtiaceae

Grewia flavescens Juss.	Tiliaceae
Dovyalis macrocalyx (Oliv.) Warb.	Flacourtiaceae
Zanha golungensis Hiern	Sapindaceae
Cordylia africana Lour.	Caesalpinoideae
Kigelia africana (Lam.) Benth.	Bignoniaceae
Urena lobata L.	Malvaceae
Sida acuta L.	Malvaceae
Ageratum conyzoides L. subsp houstonium (Mill.) Sahu	Asteraceae
Bosia salicifolia Oliv	Capparaceae
Philenoptera bussei (Harm) Sschrire	Papilionoideae
Ormocarpum kirkii S. Moore	Papilionoideae
Holarrhena pubescens (Buch. Ham.) Wall	Apocycenaceae

SITE NUMBER: 10	**DATE:** 30/10/2011	**TIME:** 09:08
COORDINATES: S 15°50’49” / E 034°44’40”	**SITE NAME.** Hamilton Falls	
BIOME CATEGORY: Riverine Woodlands		



DESCRIPTION:

Site is within Majete National Park. It is best described as deciduous open woodland, which grows immediately adjacent to the river bank forming a true riparian woodland gallery. Elephants were spotted not far from the site and the Majete Wildlife Ranger who accompanied the assessment team indicated that crocodiles were very common in the area.

SPECIES LIST:

Tamarindus indica L.	Caesalpinoideae
Kigelia africana	Bignoniaceae
Philenoptera violacea (Klotze) Schrire	Papilionoideae
Maytenus senegalensis (Lam.) Exell.	Celastraceae
Trichilia emetica L.	Meliaceae
Taberamontana elegans	Apocycenaceae
Jasminum fluminense Vell	Oleaceae
Phragmites mauriana Kunth	Poaceae
Azanza garckena (F. Hoffim.) Exell & Hilcoat	Malvaceae
Lantana camara L.	Verbanaceae
Diospyros senensis	Ebenaceae
Schoenoplectus corymbosus (Roem el Schutt) J. Reyn	Cyperaceae

Grewia sp.	Tiliaceae
Urena lobata L.	Malvaceae
Croton macrostachys Hochst. Ex. A. Rich	Euphorbiaceae
Ficus sp.	Moraceae
Cynodon dactylon	Poaceae
Hyphane sp.	Palmae

SITE NUMBER: 11	**DATE:** 30/10/2011	**TIME:** 09:42
COORDINATES: S 15°49'11" / E 034°44'08"	**SITE NAME.** Confluence of Mruloumadzi & Shire Rivers	
BIOME CATEGORY: Riverine Woodlands		

DESCRIPTION:

Site is within Majete National Park. It is best described as deciduous open woodland, which grows immediately adjacent to the river bank forming a true riparian woodland gallery. Elephants were spotted not far from the site and the Majete Wildlife Ranger who accompanied the assessment team indicated that crocodiles were very common in the area.

SPECIES LIST:

Acacia nigrescens Olive	Mimosoidea
Piliostigma thonningii (Schumach.) Milne-Redh.	Caesalpinoideae
Taberamontana elegans	Apocycenaceae
Trichilia emetica L.	Meliaceae
Cleistochlamys kirkii (Benth.). Oliv.	Annonaceae
Tamarindus indica L.	Caesalpinoideae
Philenoptera violacea (Klotze) Schrire	Papilionoideae
Capparis rosea	Capparaceae
Sterculia appendiculata K. Schum.	Sterculiaceae
Breonardia salicifolia	Rubiaceae

Antidesma venosum	Euphorbiaceae
Dalbergia sp.	Papilionoideae
Zanha golungensis Hiern	Sapindaceae
Phragmites mauriana Kunth	Poaceae
Acacia nigrescens Olive	Mimosoidea
Cynodon dactylon (L.) Pers.	Poaceae
Schoenoplectus corymbosus (Roem el Schutt) J. Reyn	Cyperaceae
Maytenus senegalensis (Lam.) Exell.	Celastraceae
Lantana camara L.	Verbanaceae
Phyllanthus reticulata Poir.	Euphorbiaceae
Albizia versicolor	Mimosoidea

SITE NUMBER: 14	**DATE:** 31/10/2011	**TIME:** 10:15
COORDINATES: S 15°10'55" / E 035°10'18"	**SITE NAME.** Sifakado Village	
BIOME CATEGORY: Perennial Marsh		

DESCRIPTION:
Typical Perennial marsh land. Typher spp., Voscia spp. and Phragmites spp. dominate.

SPECIES LIST:

Typha domingensis Pers.	Typhaceae
Phragmites mauritianus Kunth	Poaceae
Vossia cuspidata (Roxb.) Griff.	Poaceae
Faidherbia alba (Del.) A. Chev.	Mimosoidea
Acacia xanthophloea Benth.	Mimosoidea
Cyperus papyrus L.	Cyperaceae
Zea mays L.	Poaceae
Musa paradisica	Musaceae
Aeschynomene elephraxylon (Guill & Perr) Taub.	Papilionoideae
Ipomea aquatica Forssk.	Convolvulaceae
Nidorella auriculata DC	Asteraceae
Argemone mexicana L.	Papaveraceae

SITE NUMBER: 15	DATE: 31/10/2011	TIME: 10:50
COORDINATES: S 15°12'33" / E 035°09'47"	SITE NAME. Citinounugwa Village	
BIOME CATEGORY: Perennial Marsh		

DESCRIPTION:

Perennial marsh, slightly disturbed by grazing and domba agriculture. Typical perennial swampy species represented such as Papyrus spp. Phragmites spp. and Typher.

SPECIES LIST:

Eleusine indica L.	Poaceae
Phragmites mauriana Kunth	Poaceae
Echinochloa pyramidalis (Lam.) Hitchc. & Chase	Poaceae
Sida acuta L.	Malvaceae
Persicaria attenuata (R. Br) Sojak subsp africana	Polygonaceae
Argemona mexicana	Papaveraceae
Cyperus papyrus L.	Cyperaceae
Cajanus cajana (L.) Millsp.	Papilionoideae
Ricimus communus L.	Euphorbiaceae
Typha domingensis Pers.	Typhaceae
Vossia cuspidata (Roxb.) Griff.	Poaceae
Aeschynomene elephraxylon (Guill & Perr) Taub.	Papilionoideae
Launnea cornuta (Hochst. ex Oliv. & Hiern) C. Jeffrey	Asteraceae
Cynodon dactylon (L.) Pers.	Poaceae
Ficus sycamorus L.	Moraceae

SITE NUMBER: 16	**DATE:** 31/10/2011	**TIME:** 11:22
COORDINATES: S 15°15'15" / E 035°07'53"	**SITE NAME.** Nataka Village	
BIOME CATEGORY: Perennial Marsh		

DESCRIPTION:

Perennial marsh land, flanked by some seasonally wet grassland which is being grazed by cattle. The influence of the river is evident some 200+ m from the waters edge as the land is very boggy (photo lower left). Typical perennial marsh species are common including Phragmites spp. and Typher spp.

SPECIES LIST:

Vossia cuspidata (Roxb.) Griff.	Poaceae
Phragmites mauritianus Kunth	Poaceae
Typha domingensis Pers.	Typhaceae
Sesbania sesban L.	Papilionoideae
Cyperus papyrus L.	Cyperaceae
Ludwigia erecta (L.) Hara	Onagraceae
Cyperus alopecuroides Rottb.	Cyperaceae
Azolla nilotica Mett.	Azollaceae
Cyperus sp.	Cyperaceae
Echinochloa pyramidalis (Lam.) Hitchc. & Chase	Poaceae

SITE NUMBER: 17	**DATE:** 31/10/2011	**TIME:** 14:21
COORDINATES: S 15°01’15” / E 035°14’26”	**SITE NAME.** Liwonde National Park (east bank)	
BIOME CATEGORY: Seasonal Floodplain		

DESCRIPTION:

This site is comprised of seasonally wet grasslands on an alluvial flood plain. The flood plain is approximately 150 m wide and will be completely flooded during the wet season (late November – late March). This is an important grazing area for many animal species in Liwonde National Park; water buck and baboons were observed at the site during the assessment.

SPECIES LIST:

Kiggelaria africana (Lam) Benth	Bignoniaceae
Phragmites mauritianus Kunth	Poaceae
Vossia cuspidata (Roxb.) Griff.	Poaceae
Mimosa pigra L.	Mimosoidea
Hyphane sp.	Palmae
Aeschynomene elephraxylon (Guill & Perr) Taub.	Papilionoideae
Eichhornia crassipes (Mart.) Solms - Laub	Pontederiaceae
Persicaria attenuata (R. Br) Sojak subsp africana	Polygonaceae

SITE NUMBER: 18 | **DATE**: 01/11/2011 | **TIME:** 07:00

COORDINATES: S 14°52’25” / E 035°18’15” | **SITE NAME.** Liwonde National Park (east bank)

BIOME CATEGORY: Seasonal Floodplain

DESCRIPTION:

This is a seasonally wet grassland on an extensive flood plain several hundreds of metres wide. Foraging wildlife is abundant on the site with elephant, hippo, warthog, water buck and impala spotted. Termite mounds common.

SPECIES LIST:

Cryptolepis oblongifolia (Meisn) Schltr.	Apocycenaceae
Maerua angolensis	Capparaceae
Echinochloa pyramidalis (Lam.) Hitchc. & Chase	Poaceae
Phragamite mauritianus Kunth	Poaceae
Eichhornia crassipes (Mart.) Solms - Laub	Pontederiaceae
Taberamontana elegans	Apocycenaceae
Philenoptera violacea (Klotze) Schrire	Papilionoideae
Hyphane sp.	Palmae
Acacia xanthophloea Benth.	Mimosoidea
Cissampelose micronata A. Rich	Menispermaceae
Caccia abbreviata Oliv.	Caesalpinoideae

Schoenoplectus corymbosus (Roem el Schutt) J. Reyn	Cyperaceae
Trichlia emetica Vahl.	Meliaceae
Flacourtia indica (Burm.f.) Merr.	Flacourtiaceae
Senna siamea (Lam) Irwin & Bainesby	Caesalpinoideae
Antidesma venosum E. Mey. ex Tul.	Euphorbiaceae
Ziziphus abyssinica Hochst ex A. Rich	Rhamnaceae

SITE NUMBER: 19	**DATE:** 01/11/2011	**TIME:** 08:02
COORDINATES: S 14°50’02” / E 035°17’46”	SITE NAME. Liwonde National Park (east bank)	
BIOME CATEGORY: Seasonal Floodplain		

DESCRIPTION:

This is a seasonal flood plain with mixed Mopanie woodland to the rear; a perennial wetland fringe at the lake margin is absent. Baboons were seen foraging on the grasslands.

SPECIES LIST:

Ocimum gratissimum L. Subsp. Gratissimum var gratissimum	Lamiaceae
Triumfetta pilosa Roth	Tiliaceae
Philenoptera violacea (Klotze) Schrire	Papilionoideae
Echinochloa pyramidalis (Lam.) Hitchc. & Chase	Poaceae
Combretum imberbe Wawra	Combretaceae
Ziziphus abyssinica Hochst ex A. Rich	Rhamnaceae
Pychnostachys urticifolia Hook	Lamiaceae
Cryptolepis oblongifolia (Meisn) Schltr.	Apocycenaceae
Sesbania sesban L.	Papilionoideae
Phragmites mauritianus Kunth	Poaceae
Eichhornia crassipes (Mart.) Solms - Laub	Pontederiaceae
Acacia xanthophloea Benth.	Mimosoidea

SITE NUMBER: 20	**DATE:** 01/11/2011	**TIME:** 08:25
COORDINATES: S 14°48'34" / E 035°17'32"	**SITE NAME.** NA	
BIOME CATEGORY: Riverine Woodlands (fertile Areas)		

DESCRIPTION:

Open Mopane woodland. Tree species grow close to water line, and seasonally wet grassland strip is narrow. This is due to the increased slope[?] in this area and the reduced area of inundation during the wet season (late November – late March). The Perennial marsh at the margins of the lake are absent in this area.

SPECIES LIST:

Euphorbia ingens Boiss.	Euphorbiaceae
Zanha africana (Radlk.) Exell	Sapindaceae
Combretum imberbe Wawra	Combretaceae
Albizia amara (Roxb.) Boivin subsp.	Mimosoidea
Colophospermum mopane (Benth.) J. Leonard	Caesalpinoideae
Maerua angolensis DC.	Capparaceae
Acacia nilotica (L.) Delile	Mimosoidea
Acacia xanthophloea Benth.	Mimosoidea
Echinochloa pyramidalis (Lam.) Hitchc. & Chase	Poaceae

SITE NUMBER: 21	**DATE:** 01/11/2011	**TIME:** 08:54
COORDINATES: S 14°46'29" / E 035°17'18"	**SITE NAME.** Mouth of Lake Malombe	
BIOME CATEGORY: Seasonal Floodplain		

DESCRIPTION:

Mixed woodlands at approximately 50 m from waters edge; there is then a narrow (~50m) seasonally wet grassland on the flood plain merging in to a thin band of perennial marsh land at the lake edge.

SPECIES LIST:

Schoenoplectus corymbosus (Roem el Schutt) J. Reyn	Cyperaceae
Vossia cuspidata (Roxb.) Griff.	Poaceae
Echinocloa pyramidalis(Lam.) Hitchc. & Chase	Poaceae
Acacia xanthophloea Benth.	Mimosoidea
Cordylia africana Lour.	Celastraceae
Faidherbia alba (Del.) A. Chev.	Mimosoidea
Diospyros senensis Klotzch	Ebenaceae
Scrocarya birrea (A. Rich.) Hochst. Subsp. Caffra (Sond.) Kokwaro	Anarcadiaecea
Andropogon gayanus Kunth	Poaceae
Philenoptera violacea (Klotze) Schrire	Papilionoideae
Acacia nilotica (L.) Delile	Mimosoidea
Kiggelaria africana (Lam) Benth	Bignoniaceae

Maerua angolensis DC.	Capparaceae
Euphorbia ingens Boiss.	Euphorbiaceae
Markhamia zanzibarica (DC) K. Schum.	Bignoniaceae
Maytenus senegalensis (Lam.) Exell.	Celastraceae

SITE NUMBER: 22	**DATE:** 01/11/2011	**TIME:** 11:37
COORDINATES: S 14°59'47" / E 035°14'24"	**SITE NAME.** Liwonde National Park (west bank)	
BIOME CATEGORY: Seasonal Floodplain		

DESCRIPTION:

This site is located in the 1 km wide strip of land within Liwonde National Park located on the west bank of the Shire River. This site is comprised of mixed open woodland in the elevated areas, and seasonally wet grasslands in the lower areas that become flooded during the wet season (late November – late March). Perennial marsh land species are found in a narrow band only at the lake margins. The Liwonde National park Ranger who accompanied the assessment team indicated that the few sandy patches at this site were potentially good crocodile nesting sites (see photo lower right).

SPECIES LIST:

Acacia xanthophloea Benth.	Mimosoidea
Adansonia digitata L.	Bombacaceae
Ziziphus abyssinica Hochst ex A. Rich	Rhamnaceae
Phragmites mauritianus Kunth	Poaceae
Maerua angolensis DC.	Capparaceae
Diospyros senensis Klotzch	Ebenaceae
Caccia abbreviata Oliv.	Caesalpinoideae
Rhus natalensis Bernh. ex Krauss.	Anarcadiaecea
Eichhornia crassipes (Mart.) Solms - Laub	Pontederiaceae

Echinochloa pyramidalis (Lam.) Hitchc. & Chase	Poaceae
Cyperus alopecuroides Rottb.	Cyperaceae
Aeschynomene elephraxylon (Guill & Perr) Taub.	Papilionoideae

SITE NUMBER: 23	**DATE:** 01/11/2011	**TIME:** 14:36
COORDINATES: S 14°43'10" / E 035°10'52"	**SITE NAME.** Lake Malombe	
BIOME CATEGORY: Perennial Marsh		

DESCRIPTION:

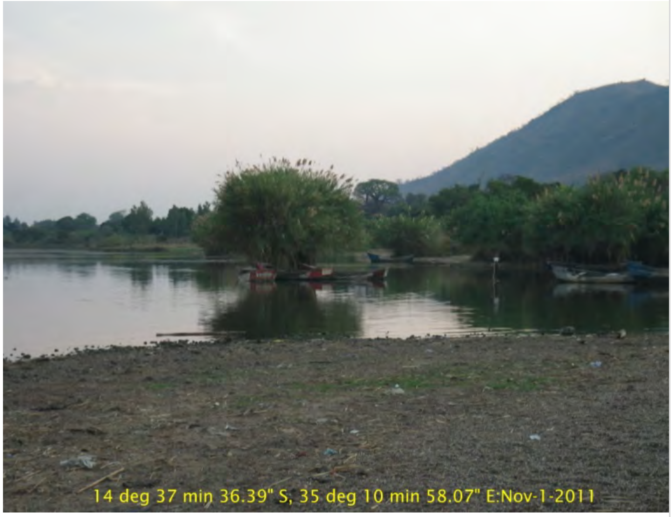
Perennial marshes at lake margins with seasonally wet grasslands behind. Some of the seasonally wet grasslands have been cultivated for dombas. Locals report that lake level is very low at the time of the survey and that during the wet season (late November to late March) the levels will rise 20 m above that at the time of the assessment.

SPECIES LIST:

Phragmites mauritianus Kunth	Poaceae
Cyperas papyrus L.	Cyperaceae
Melanthera scandens (Schumach. & Thonn.) Roberty	Asteraceae
Ipomea rubens Choisy	Convolvulaceae
Aeschynomene elaphraxylon (Guill & Perr) Taub.	Papilionoideae
Musa paradisica L.	Musaceae
Faidherbia alba (Del.) A. Chev.	Mimosoidea
Persicaria attenuata (R. Br) Sojak subsp africana	Polygonaceae
Schoenoplectus corymbosus (Roem el Schutt) J. Reyn	Cyperaceae
Typha domingensis Pers.	Typhaceae
Vossia cuspidata (Roxb.) Griff.	Poaceae

Aleurites moluccana (L.) Willd	Euphorbiaceae
Moringa ovalifolia Dinter & A. Berger	Moringaceae
Carica papaya	Caricaeae

SITE NUMBER: 24	**DATE:** 01/11/2011	**TIME:** 15:17
COORDINATES: S 14°37'35" / E 035°10'58"	**SITE NAME.** NA	
BIOME CATEGORY: Perennial Marsh		



DESCRIPTION:

Lake margins are heavily vegetated with a thin band of perennial marsh species (e.g. Phragmites spp.); this strip is 50 – 100 m wide. The Seasonally wet grasslands behind the perennial marsh have been heavily cultivated and a row of mango trees planted.

SPECIES LIST:

Phragmite mauritianus Kunth	Poaceae
Senna siamea (Lam) Irwin & Bainesby	Caesalpinoideae
Ziziphus abyssinica Hochst ex A. Rich	Rhamnaceae
Ricimus communus L.	Euphorbiaceae
Calotropes procera L.	Apocycenaceae
Mangifera indica L	Anarcadiaecea
Psidium guajava L.	Myrtaceae
Schoenoplectus corymbosus (Roem el Schutt) J. Reyn	Cyperaceae
Faidherbia alba (Del.) A. Chev.	Mimosoidea
Ipomea rubens Choisy	Convolvulaceae
Sesbania sesban L.	Papilionoideae
Senna occidentalis (L.) Link	Caesalpinoideae

SITE NUMBER: 25	**DATE:** 02/11/2011	**TIME:** 07:14
COORDINATES: S 14°37’31” / E 035°20’22”	**SITE NAME.** Kadewere (E. bank of Lake Malombe)	
BIOME CATEGORY: Seasonal Marshes - Under Cultivation (dambos)		

DESCRIPTION:

The vegetation fringing the lake universally consists of a thin band of aquatic vegetation at the waters edge. Behind this is seasonally wet grassland which has been cultivated with numerous ‘dambo’ gardens. Crops observed include: sugar cane; cassava; maize; tomatoes and pumpkin.

Locals report that during the wet season (late November to late March) water levels will rise approximately 50 m from the levels at the time of the assessment.

SPECIES LIST:

Senna occidentalis (L.) Link	Caesalpinoideae
Melanthera scandens (Schumach. & Thonn.) Roberty	Asteraceae
Vossia cuspidata (Roxb.) Griff.	Poaceae
Phragmite mauritianus Kunth	Poaceae
Musa paradisiaca L.	Musaceae
Zea mays L.	Poaceae
Sesbania sesban L.	Papilionoideae
Luffa cylindlica (L.)	Cucurbitaceae
Saccharum officinarum L.	Poaceae

Euphorbia Esculenta	Caesalpinoideae
Senna siamea (Lam) Irwin & Bainesby	Euphorbiaceae
Ricimus communus L.	Euphorbiaceae
Persicaria attenuata (R. Br) Sojak subsp africana	Polygonaceae
Persicaria limbata (Meisn.) Hara	Polygonaceae
Ipomea rubens Choisy	Convolvulaceae
Cyperus hemsphaevicus Boeck	Cyperaceae
Xanthium sp.	Asteraceae
Calotropes procera L.	Apocycenaceae
Solanum panduriforme E. Mey	Solanaceae
Sida acuta L.	Malvaceae
Aeschynomene cristata Vatke	Papilionoideae
Indigofera antunesiana Harms	Papilionoideae

SITE NUMBER: 26	**DATE:** 02/11/2011	**TIME:** 07:50
COORDINATES: S 14°38’58” / E 035°20’10”	**SITE NAME.** Kwisimba (E. bank of Lake Malombe)	
BIOME CATEGORY: Seasonal Marshes - Under Cultivation (dambos)		

DESCRIPTION:

Fishing village on the east bank of Lake Malombe. At the edges of the beach permanent marsh land fringes the lake, behind which seasonally wet grasslands have been developed as dambos. Residents indicate that during the wet season (late November – late March) the water level is 30 – 50 m higher than at the time of the assessment (early November).

SPECIES LIST:

Faidherbia alba (Del.) A. Chev.	Mimosoidea
Rhynchosia sp.	Papilionoideae
Vossia cuspidata (Roxb.) Griff.	Poaceae
Phragmite mauritianus Kunth	Poaceae
Sesbania sesban L.	Papilionoideae
Ipomea rubens Choisy	Convolvulaceae
Nidorella auriculata DC	Asteraceae
Sida acuta L.	Malvaceae
Desmodium tortuosum (SW) DC	Papilionoideae
Euphorbia heterophylla L.	Euphorbiaceae
Saccharum officinarum L.	Poaceae

Ricimus communus L.	Euphorbiaceae
Euphorbia esculenta (Casava)	Euphorbiaceae
Cissampelos micronata A. Rich	Menispermaceae
Boerhaavia erecta L.	Nyctaginaceae

SITE NUMBER: 27	**DATE:** 02/11/2011	**TIME:** 09:23
COORDINATES: S 14°22'46" / E 035°16'41"	**SITE NAME.** Eastern Arm of Lake Malawi	
BIOME CATEGORY: Seasonal Marshes - Under Cultivation (dambos)		

DESCRIPTION:

This is a fishing village. The vegetation consists of Perennial wetlands at the lake margins with Seasonal wetlands and associated dambos behind. Much of the *Typha* areas have been cut and used for grazing or agriculture.

SPECIES LIST:

Phragmites mauritianus Kunth	Poaceae
Ziziphus abyssinica Hochst ex A. Rich	Lamiaceae
Faidherbia alba (Del.) A. Chev.	Mimosoidea
Mangifera indica L	Anarcadiaecea
Sesbania sesban L.	Papilionoideae
Mimosa pigra L.	Mimosoidea
Echinochloa pyramadis (Lam.) Hitchc. & Chase	Poaceae
Aeschynomene elaphraxylon (Guill & Perr) Taub.	Papilionoideae
Euphorbia glaziovil Muell. Arg	Euphorbiaceae
Melia azedarach L.	Meliaceae
Hibiscus diversifolia Jacq.	Malvaceae

Vossia cuspidata (Roxb.) Griff.	Poaceae
Eichhornia crassepes	Pontederiaceae
Senna siamea (Lam) Irwin & Bainesby	Caesalpinoideae
Aleurites moluccana (L.) Willd	Euphorbiaceae
Ipomoea rubens choisy	Convolvulaceae
Crotalaria sp.	Papilionoideae

SITE NUMBER: 28	**DATE:** 03/11/2011	**TIME:** 10:22
COORDINATES: S 14°17'32" / E 035°15'26"	**SITE NAME.** NA	
BIOME CATEGORY: Cleared Woodlands		

DESCRIPTION:

This site is highly modified open woodland, with mature trees growing down to the top of a sandy beach. The area is heavily populated and many of the trees have been felled or coppiced. The slope of the land is relatively steep compared to the flood plain areas, and flooding is minimal, allowing establishment of mature woodland tree species close to the water line.

SPECIES LIST:

Albizia labbeck (L.) Benth	Mimosoidea
Senna siamea (Lam) Irwin & Bainesby	Caesalpinoideae
Adansonia digitata L.	Bombacaceae
Moringa ovalifolia Dinter & A. Berger	Moringaceae
Ziziphus abyssinica Hochst ex A. Rich	Rhamnaceae
Catharanthus roea Don.	Apocycenaceae
Ficus sp.	Moraceae
Delonix regia (Boj. Ex Hook.f.	Caesalpinoideae
Eichhornia crassipes	Pontederiaceae
Typha domingensis Pers.	Typhaceae
Schoenoplectus corymbosus (Roem el Schutt) J. Reyn	Cyperaceae

Aeschynomene elaphraxylon (Guill & Perr) Taub.	Papilionoideae
Sesbania sesban L.	Papilionoideae
Ipomoea rubens choisy	Convolvulaceae
Combretum imberbe Wawra	Combretaceae
Senna cristata Vatke	Caesalpinoideae
Tephrosia sp.	Papilionoideae

SITE NUMBER: 29	**DATE:** 02/11/2011	**TIME:** 11:53
COORDINATES: S 14°25'20" / E 035°13'54"	**SITE NAME.** Lake Malawi Outlet to Shire (west)	
BIOME CATEGORY: Perennial Marsh		

DESCRIPTION:

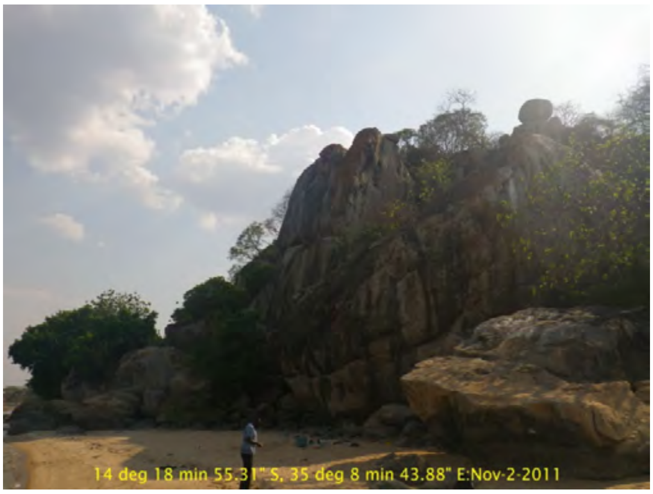
Perennial marsh areas at interface with the lake, with seasonal grassland areas behind and associated dambos. There is a large irrigation pumping station at this site which draws water from the Shire River to irrigate crops several kilometres inland.

SPECIES LIST:

Ziziphus abyssinica Hochst ex A. Rich	Rhamnaceae
Faidherbia alba (Del.) A. Chev.	Mimosoidea
Typha domingensis Pers.	Typhaceae
Sesbania sesban L.	Papilionoideae
Echinochloa pyramadis (Lam.) Hitchc. & Chase	Poaceae
Ipomea rubens Choisy	Convolvulaceae
Vossia cuspidata (Roxb.) Griff.	Poaceae
Tridax procumbens L.	Asteraceae
Wahheria indica L.	Sterculiaceae
Combretum mossambinsis (Klotzch) Engl.	Combretaceae
Cissampelos micronata A. Rich	Menispermaceae

Azadirachta indica A. Juss	Meliaceae
Musa paradisiaca L.	Musaceae
Hyphane sp.	Palmae
Acacia xanthophloea Benth.	Mimosoidea
Aeschynomene cristata Vatke	Papilionoideae
Nidorella auriculata DC	Asteraceae
Persicaria attenuata (R. Br) Sojak subsp africana	Polygonaceae
Commelina benghalensis L.	Commelinaceae
Eichhornia crassipes (Mart.) Solms - Laub	Pontederiaceae
Phragmites mauritianus Kunth	Poaceae
Manhot glaziovii Muell. Arg	Euphorbiaceae
Ocimum gratissimum L. Subsp. gratissimum var gratissimum	Lamiaceae
Crotalaria pallida Aiton	Papilionoideae

SITE NUMBER: 30	**DATE:** 02/11/2011	**TIME:** 12:49
COORDINATES: S 14°18'55" / E 035°08'43"	**SITE NAME.** Sunbird Resort	
BIOME CATEGORY: Dry Bush Savannah		



DESCRIPTION:

Rocky outcrops besides the beach support open canopy woodlands. Behind the beach area is Sunbird Resort with manicured gardens and planted trees.

SPECIES LIST:

Sesbania sesban L. (Merr.)	Poaceae
Trichilia emetica Vahl. subsp. emetica	Meliaceae
Ficus natalensis Hochst.	Moraceae
Ficus sp.	Moraceae
Heliotropium indicum L.	Boraginaceae
Eichhormia crassipes (Mart.) Solms - Laub	Pontederiaceae
Acacia xanthophloea Benth.	Mimosoidea
Hyphane sp.	Palmae
Faidherbia alba (Del.) A. Chev.	Mimosoidea
Boerhaavia erecta L.	Nyctaginaceae

SITE NUMBER: 31	**DATE:** 02/11/2011	**TIME:** 14:33
COORDINATES: S 14°10’05” / E 034°59’09”	**SITE NAME.** Namasso Bay	
BIOME CATEGORY: Dry Bush Savannah (on adjacent rocks)		

DESCRIPTION:

This is Combretum dominated woodland on the rocky outcrops besides the sandy beach. Due to the steep grade of the rocky outcrops the woodland vegetation extends down to the water edge. Behind the beach are manicured gardens of a residential compound.

SPECIES LIST:

Hyphane sp.	Palmae
Ficus bubu	Moraceae
Terminalia catapa	Combretaceae
Sterculia africana (Lour.0 Fiori	Sterculiaceae
Phyllanthus reticulata Poir.	Euphorbiaceae
Cissus cucumerifolia Planch.	Vitaceae
Ziziphus mucronata Willd.	Rhamnaceae
Cordylia africana Lour.	Caesalpinoideae
Dalbergia arbutifolia Baker	Papilionoideae
Cadaba kirkii Oliv.	Capparaceae
Albizia amara (Roxb.) Boivin subsp.	Mimosoidea
Ximenia americana L.	Olaceae

SITE NUMBER: 32	DATE: 03/11/2011	TIME: 10:12
COORDINATES: S 14°15'37" / E 034°48'48"	SITE NAME. Tiainankumba	
BIOME CATEGORY: Seasonal Floodplain		

DESCRIPTION:

Seasonally wet grassland with permanent swamp at the interface with the lake. Currently being used for pasture land for cattle, this area will likely flood during the wet season. Ground is perennially wet at the grassland/swamp interface.

SPECIES LIST:

Hyphane sp.	Palmae
Vossia cuspidata (Roxb.) Griff.	Poaceae
Cyperus alopecuroides Rottb.	Cyperaceae
Schoenoplectus corymbosus (Roem el Schutt) J. Reyn	Cyperaceae
Typha domingenonsis Pers.	Typhaceae
Phragmites mauritianus Kunth	Poaceae
Cyperus papyrus L.	Cyperaceae
Aeschynome cristaty Vitke	Papilionoideae
Faidherbia alba (Del.) A. Chev.	Mimosoidea
Mangifera indica L	Anarcadiaecea
Hibiscus diversifolia Jacq.	Malvaceae

Eichhornia crassipes (Mart.) solms - Laub	Pontederiaceae
Ipomoea rubens choisy	Convolvulaceae
Blepharis acanthodianss Klotzch	Acanthaceae

SITE NUMBER: 33	**DATE:** 03/11/2011	**TIME:** 06:58
COORDINATES: S 14°12’39” / E 034°49’08”	**SITE NAME.** NA	
BIOME CATEGORY: Seasonal Floodplain		

DESCRIPTION:

This site is comprised of a sand berm immediately behind a sandy beach. Behind the berm is a depression which supports seasonally wet grasslands, which is too wet to support the woodland vegetation that proliferates at the margins of the site and on the berm itself. The grasslands were being used for grazing cattle at the time of the assessment but would be flooded during the wet season.

SPECIES LIST:

Acacia xanthophloea Benth.	Mimosoidea
Faidherbia alba (Del.) A. Chev.	Mimosoidea
Phragmites mauritianus Kunth	Poaceae
Senna alata L.	Papilionoideae
Urena lobata L.	Malvaceae
Hyphaena sp.	Palmae
Ziziphus mucronata Willd.	Rhamnaceae
Vossia cuspidata (Roxb.) Griff.	Poaceae
Cyperus alopecuroides Rottb.	Cyperaceae

Government of the Republic of Malawi

Ministry of Water Development and Irrigation
National Water Development Programme

Independent Environmental Impact Assessment for the Upgraded Kamuzu Barrage

Final Environmental and Social Impact Assessment
Volume 2: Water Quality

December 2013

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Abbreviations

BOD	Biochemical Oxygen Demand
°C	Degrees Celsius
C	Carbon
Ca	Calcium
CFU	Coliform Forming Units
Cl	Chlorine
DO	Dissolved Oxygen
EC	Electrical Conductivity
GoM	Government of Malawi
GPS	Global Positioning System
FCB	Faecal Coliform Bacteria
HCl	Hydrochloric Acid
K	Potassium
L	litre
Mg	Magnesium
N	Nitrogen
Na	Sodium
O	Oxygen
nm	nano metres
NO_{3-}	Nitrate
NTU	Nephelometric Turbidity Units
P	Phosphorus
PCA	Principal Component Analysis
pH	Measure of acidity
PO_{4-}	Phosphate
ppm	Parts per Million
S	Sulphur
µS	Micro Siemens
SMEC	Snowy Mountains Engineering Corporation
SRP	Soluble Reactive Phosphate
TDS	Total Dissolved Solids
TN	Total Nitrogen
TP	Total Phosphorous
TSS	Total Suspended Solids
UNECE	United Nations Economic Commission for Europe
WHO	World Health Organization

Glossary

BARRAGE	A Special type of dam which consists of a line of large gates that can be opened or closed to regulate the amount of water flowing downstream. The gates are set between flanking piers which are responsible for supporting the water load. They are often used to control and stabilize water flow for various purposes.
EUTROPHIC	Water with high primary production due to excessive nutrient enrichment, the water is not clear and has a lot of phytoplankton.
FAECAL COLIFORM BACTERIA	A sub-group of total coliform bacteria. They occur in great quantities in the intestines and faeces of people and animals. The presence of faecal coliform bacteria in a drinking water sample often indicates recent faecal contamination, meaning that there is a greater risk that pathogens are present in that water.
MACROPHYTES	Are macroscopic aquatic plant that grows in or near water and is emergent, submerged or floating.
MESOTROPHIC	Water with intermediate level of primary production, greater than oligotrophic but less than eutrophic.
MONITORING	Long-term, standardised measurement and observation of the aquatic environment and water quality in order to define status and trends.
OLIGOTROPHIC	Water with low primary production due to low nutrient content, often more clear with high drinking quality.
pH	The balance of positive hydrogen ions (H+) and negative hydroxide ions (OH-) in water and is a determination of how acidic or basic the water is.
PLANKTON	Are microscopic drifting organisms (animals, plants, archaea, or bacteria) that inhabit the pelagic zone of a water body.
SURFACE RUNOFF	Is the water flow that occurs when the soil is infiltrated to full capacity and excess water from rain, melt water, or other sources flows over the land.
TDS	Is the total amount of dissolved materials/solids (principally calcium, magnesium, potassium, sodium, bicarbonates, chlorides and sulphates) which become salts when evaporation takes place.
TSS	Total Suspended Solids (TSS) includes all particles suspended in water which will not pass through a filter.
TURBIDITY	In simple terms, turbidity is a measure of how clear the water is.
ZOOPLANKTON	Are microscopic invertebrate animals that swim or drift in water. They are at the base of the food chain, feeding on microscopic plants and being fed upon by aquatic insects, fish.
23:21:0:+4S	Inorganic fertiliser recommended for basal dressing, contains 23% Nitrogen, 21% Phosphorous, 0% Potassium and 4% Sulphur.

Acknowledgements

This Report on Consultancy work was prepared by Austin Mtethiwa, Wilson Jere and Elton Nyali. The consultancy team sincerely thank SMEC for instituting and funding this study. The team also sincerely extend its gratitude to Michael Holics and Stayford Phiri of SMEC for their technical guidance. Appreciation is also extended to Bunda College for the equipment and technical expertise provided in the sampling and analysis of water samples. Many thanks to Staff of Liwonde National Park (for provision of boat services, information and space), Fishermen, Community of Businessmen at Liwonde (Kamuzu Barrage) and all those that provided support to this study.

Executive Summary

A water quality study was carried out along the middle Shire River in Malawi in November, 2011 and January, 2012. The study was part of the on-going environmental study by Snowy Mountains Engineering Corporation (SMEC) on the Shire River catchment. The environmental study is aimed at determining the environmental impacts of rehabilitating the Kamuzu Barrage which will raise the maximum regulated water level up to 40 centimetres.

The aim of this water quality study was to collect baseline information on the Shire River water quality within the Kamuzu Barrage catchment as may be affected by the Barrage rehabilitation.

A reconnaissance survey was conducted where five water sampling points were set up followed by actual collection of water samples and onsite water quality measurements. Five sampling points were selected stretching from the outlet of Lake Malombe to an area downstream of the Kamuzu Barrage at Liwonde. The site was selected in consideration that this is the area that will be affected once the work on the Barrage has been accomplished. Temperature, pH, TDS, turbidity and Secchi depth among others, were determined on site. Water samples collected were immediately stored in a cooler box to maintain low temperature and later transferred to Bunda College Laboratory for analysis of various parameters including faecal coliform, BOD, nitrates and phosphorus among others.

Results showed that all five sampling points had faecal pollution (118±3.2 CFU/100 ml, mean) but did not have high phosphorus (20.6±0.18 μg/l, mean) and nitrate levels (0.16±0.04 mg/L, mean). However, the rainy season values were higher than those of the dry season, showing the impact of rain and runoff from the catchment to the river system. Also, those points that were closest to the Kamuzu Barrage and at the outlet of Lake Malombe had high concentrations of coliform counts (124±2.2CFU/100 ml, mean) and those sampling points within the stream catchment area and resorts and lodges gave higher concentrations of phosphorus (24±2.6 μg/l, mean) and nitrates (0.22±0.02 mg/L, mean) than the rest, probably due to the nature of pollution emanating from the lodges and resorts.

Whilst rehabilitation of the Barrage may bring about low TSS, nitrate nitrogen and phosphorus levels may exceed the recommended limits. The impact of these high level concentrations is that they contribute to overgrowth of aquatic plants and algae. These mats of floating plants can impede fishing boats and nets, block out light for other organisms, clog turbines and provide an excellent habitat for disease vectors such as mosquitoes and the snails which host the schistosomiasis parasite.

Furthermore, since the rehabilitation will increase the water level at the Barrage, it is expected that the water levels of Lake Malombe would also increase with time; so too some negligible increase in the level for Lake Malawi. This expectation is made with assumption that the current climatic conditions prevail.

Currently the Shire River water (within the area studied) is within the oligotrophic category although there are signs of changes towards the mesotrophic conditions. Therefore, deliberate monitoring and mitigation measures have to be instituted to ensure detection of any imminent pollution and immediate remedial measures.

1 Background

Snowy Mountains Engineering Corporation (SMEC) International of Australia is carrying out an environmental study for the refurbishing of Kamuzu Barrage at Liwonde in which the regulated water level upstream would be increased by a maximum of 40cm. The Project will be implemented under the National Water Development Project Phase II by the Ministry of Water Development and Irrigation. It is expected that the change in the size of the Barrage may have some effects in several areas including food security, fisheries, water quality, traffic, water users as well as tourism.

Kamuzu Barrage is located on the Shire River in the Southern Region of Malawi in Liwonde, Balaka District (Figure 1). The existing Barrage constructed in 1965 comprises 14 radial gates and shoulders a highway crossing over the bridge. Kamuzu Barrage partly regulates the water levels of Lake Malawi and the Shire River and provides significant benefits to individuals and the Malawian economy as a whole. The regulated Shire River flows benefit the hydropower generation in the Middle Shire. Historically, the water level of Lake Malawi fluctuated over seven metres. Before the Kamuzu Barrage was constructed, water flows in the Shire River varied strongly and in some years even fell almost dry (GoM, 2012).

The Shire River is of great economic importance to Malawi as it generates more than 98% of Malawi's electricity, provides freshwater for irrigation in Malawi's plantations and supports fisheries. It is the only river that flows out from Lake Malawi and joins the Zambezi River before flowing into the Indian Ocean. Wetlands and marshes in the Shire Basin serve as breeding sites for migratory birds, production of crops and are key wildlife conservation areas.

It is with expectation of potential impacts on water quality as a result of Barrage refurbishment that work on water quality was instituted to provide a basis of comparison for the future trends and contribute to the required information needed to properly design the refurbishment of the Barrage.

1.1 Water Quality

Water quality is the physical, chemical and biological characteristics of water that makes it suitable for a specific use. The quality of water can be determined onsite by using probes or chemically in the laboratory and the results are compared to a set of standards as a yardstick for compliance (Graham, 1990).

Water quality affects all water users. Aquatic life, recreational activities such as swimming and boating, agricultural uses such as irrigation are all affected by the physico-chemical, biological and microbiological conditions that exist in water courses. If good water quality is not maintained, it is not just the environment that will suffer; the commercial and recreational value of our water resources will also diminish (Graham, 1990). Many chemical analyses are carried out to ensure that water of appropriate quality is supplied for human consumption.

Although the only natural input to any surface water system is precipitation within its watershed, the total quantity of water in that system at any given time is also dependent on many other factors. These factors include storage capacity in lakes, wetlands and artificial reservoirs, the permeability of the soil beneath these storage bodies, the runoff characteristics of the land in the watershed, the timing of the precipitation and local evaporation rates.

1.2 Literature review

In its outline, the National Water Resources Policy for Malawi indicates the importance of water of acceptable quality for all the needs in Malawi. In achieving sustainable provision of water supply and sanitation services that are equitably accessible and used by individuals and entrepreneurs for socio-economic development at affordable cost. And in promoting efficient and effective utilisation, conservation and protection of water resources for sustainable agriculture and irrigation, fisheries, navigation, eco-tourism, forestry, hydropower and disaster management and environmental protection among others (GoM, 2003). It is therefore necessary that all activities within water bodies and their catchment adhere to this requirement. Among the water bodies that have to meet this requirement is Lake Malawi from which the Shire River emanates.

1.2.1 Lake Malawi Water Quality

Lake Malawi is an oligotrophic lake situated between Malawi, Tanzania and Mozambique in the rift valley of Southeast Africa between 3 and 10°S. With an area of 29,500 km^2, a volume of 8,400 km^3 and a maximum depth of 706m, it is one of the world's largest lakes. Lake Malawi is also the most species rich lake in the world with an estimated more than 1,000 species of cichlids (fish). The Lake is permanently stratified and anoxic below 200 m and has a water cycling time of 750 years due to low outflow volume, with residence time of approximately 114 years. On average, Lake Malawi receives 39 km^3 of precipitation yearly directly on its surface and it has a single rainy season starting in December and ending around May. The climate in Malawi is subtropical and monsoonal. The permanently warm water (23-30°C in surface water, 22.4°C in deep water) makes Lake Malawi different from other lakes. The slow water cycling time of Lake Malawi makes it particularly vulnerable with regards to chemical pollution since dilution will be ineffective in reducing contaminant concentrations. Therefore, it is important to prevent levels of the pollutants from increasing within the Lake Malawi region as well as in other vulnerable ecosystems (Karlsson *et al*., 2000).

Whilst previous research has shown that there is a greater input of nutrients into Lake Malawi by various rivers that empty their water into the Lake from excessive erosion on cultivated lands (Mkanda, 2002), the Shire River outflow only removes nutrients from the surface mixed layer of the Lake. The outflow is minor in comparison to the total inflow of nutrients from other rivers, and is small when compared with other pathways of nutrient removal. For C, N and P, the ratio of particulate to dissolved fractions is greater in inflowing rivers than in the Shire River. Due to its large volume and long hydraulic residence time, Lake Malawi may respond very slowly to increased inputs of certain contaminants.

Nutrient concentrations in Lake Malawi are low, and therefore phytoplankton concentration is also low. The surface water concentrations of dissolved nitrogen and phosphorus are below 0.012 mgL^{-1} and 0.0014 mgL^{-1} respectively, and chlorophyll "a" concentrations (used as an index of phytoplankton abundance) are below 1 $\mu g\ L^{-1}$. The epilithic periphyton of Lake Malawi is dominated by Heterocystous cyanoprokaryotes (blue-green algae/cyanophytes) and diatoms containing endosymbionts capable of nitrogen fixation, though in some locations impacts such as sediment and nutrient loading have shifted the algal community structure towards dominance by diatoms and chlorophytes. In addition to this the Lake is typically slightly alkaline with a pH ranging from 7.7 to 8.6, a carbonate hardness of 107 to 142 mg L^{-1}, and a conductivity of 210 to 285 $\mu S\ cm^{-1}$.

1.2.2 Water Quality Impacts of Barrages

Connell, Bycroft, Millev, and Lather (1981) reported a reduced Dissolved Oxygen (DO) concentrations and elevated Biochemical Oxygen Demand (BOD) and nutrient concentration downstream of barrages. Reduced downstream flushing as a consequence of construction of a barrage has been suggested as a contributing factor to the poor water quality downstream. In support of this, Turnbull (1974) in Connell *et al*. (1981) reported an increase in salinity downstream of barrages, suggesting a reduced rate of flushing. Furthermore, Chaman, Tanveera, and Kumar (2008) showed increase of organic pollution and eutrophication as indicated by a greater concentration of NH_4, NO_2, and Total P, as well as lower dissolved oxygen concentration at a barrage. The enhanced concentrations of BOD were in agreement with decreased DO concentrations. Chaman et al. (2008) further attributed high concentrations of Ca, Mg, Cl and Na ions as a result of sewage and industrial effluents within a barrage catchment and Kirby and Retière (2009) showed that oxygen depletion is induced by entraining suspended fine sediment which accumulate nutrients like phosphorous which can be made available to the surface due to changes in aeration and enhance algal blooms.

The decline in river water quality due to pollution from sewage and industrial effluent may have a direct detrimental impact on the health of water user groups up and downstream. Incidents of diarrhoea, typhoid, jaundice, cholera and skin diseases are of common occurrence among user groups. Polluted river water can also seriously impair the aquatic ecology and biodiversity along the rivers (Hammer & Linke, 2010).

Gray (1992) indicated that the two most significant water quality challenges experienced in a barrage catchment are biological (faecal) and chemical pollution from domestic and industrial effluents which emanate from surrounding residential and industrial sources due to the fact that barrage catchments are often a focus of economic activities. Furthermore, many of the contaminants discharged have an affinity for fine particles and therefore accumulate in the bottom sediments. Episodes of erosion of sediments by storms and changes in oxygen concentration as well as bio-turbation processes may lead to desorption of these contaminants into the water column with potential adverse impacts (Gray, 1992).

Furthermore, changes in water level upstream due to presence of barrages can lead to loss of some macrophytic plants whilst those that are hydrophytic would increase in number and this would affect the biodiversity of macrophytes along the river (Connell et al., 1981; Kirby & Retière, 2009). Water quality monitoring has shown that after heavy rainfall, water quality of barrage reservoirs and other aquatic ecosystems quickly decline. Organic, inorganic and toxic pollutants generated from agricultural and industrial sources are accumulated and get mixed with river water posing a threat to aquatic life and making water unfit for human consumption (Karlsson *et al*., 2000; Mkanda, 2002).

1.3 Objective of the Study

1.3.1 Overall Objectives

The overall objective of this study was to describe the water quality in the Project area and assess impacts of the Kamuzu Barrage in Liwonde as part of the environmental study for the refurbishment of the Barrage.

1.3.2 Specific Objective

The following were the specific objectives of the study:

- To determine the chemical, physical and bacteriological water quality of the Shire River at Kamuzu Barrage.
- To determine the impacts of refurbishment of the Barrage on water quality.
- To develop suitable mitigation measures to minimise impacts on water quality during construction and operation of the Barrage.

2 Materials and Methods

2.1 Study Area

The study was conducted along the Shire River with five sampling point stretching from the outlet of Lake Malombe to a point downstream of the Kamuzu Barrage. The Kamuzu Barrage is constructed on Shire River at Liwonde Road block in Machinga district in the Southern region of Malawi (Figure 1). The study was conducted in November, 2011 and January, 2012.

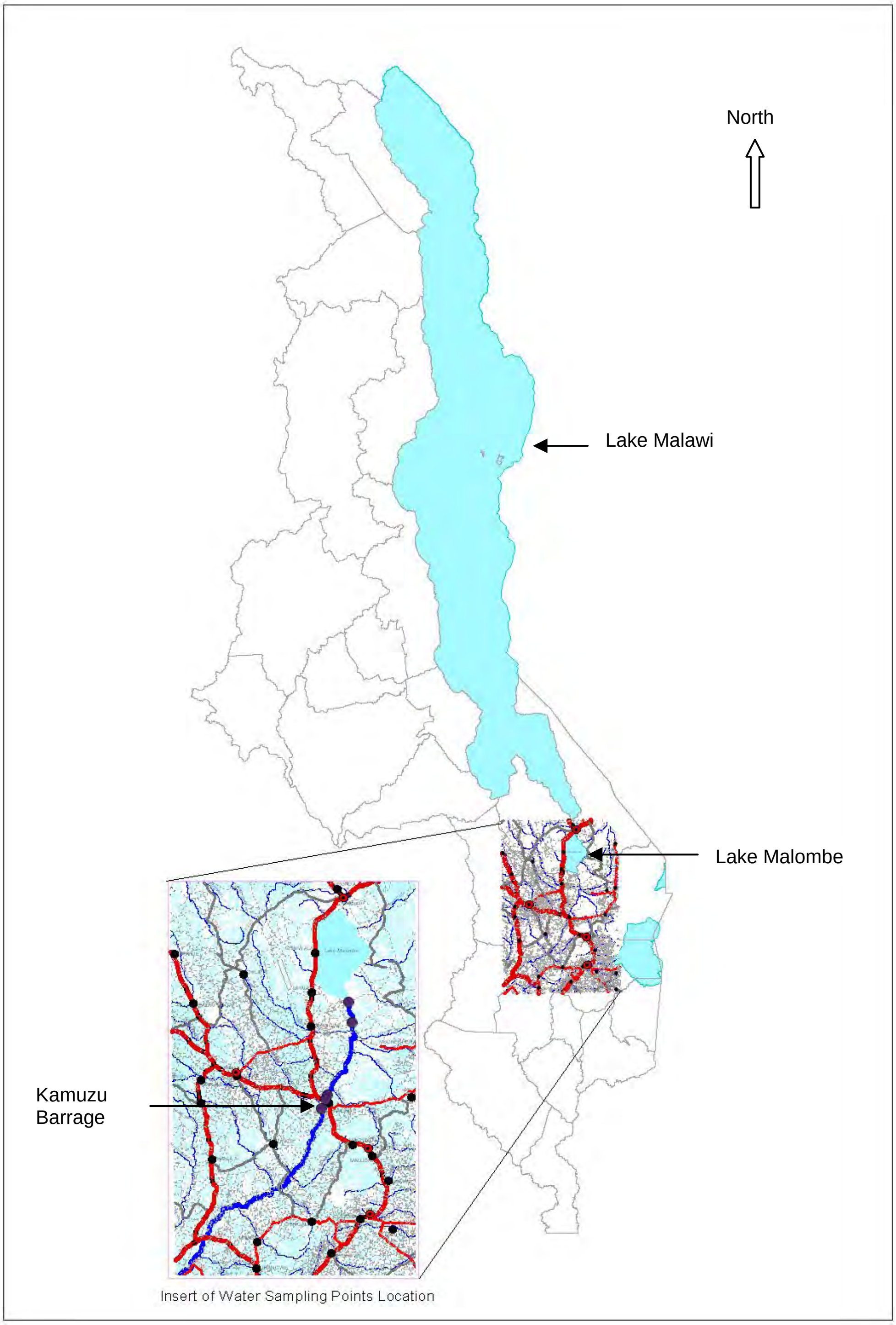


Figure 1. Map of Malawi showing Shire River and the sampling site

(Source: GoM and Mtethiwa, 2012)

2.2 Sampling Points and Design

Five main sampling points were selected, denoted by S1, S2, S3 (S3a, S3b, S3c), S4 (S4a, S4b, S4c) and S5 (S5a, S5b, S5c) in Figure 2.

2.2.1 Sampling Point S1

S1 sampling point was located at the outlet of Lake Malombe. The point was selected with the understanding that Lake Malombe is one of the water bodies whose water quality would be affected by the refurbishment and operation of the Barrage which will affect water levels within the Lake. It was therefore important to determine the current levels of concentration of various water quality parameters to be used as a basis for comparison in future. Three water samples were collected and determined for the various water quality parameters.

2.2.2 Sampling Point S2

S2 sampling point was located adjacent to the Liwonde National Park. This location is one of the busiest areas in terms of wildlife, tourists and boating. The area has a variety of terrestrial as well as aquatic wild animals. Beside this, just above this sampling point, there is a stream that joins the Shire River (Figure 2). As such, it was an important sampling to determine the impact of catchment activities as well as the National Park on water quality.

2.2.3 Sampling Point S3

The S3 sampling point was located after Liwonde National Park and close to Hippo View Lodge. The point was selected with the background to determine the impact of catchment development activities such as lodges and resorts on the water quality to be used as a basis to project the situation after the Barrage has been refurbished. Here three sampling points were used (denoted S3a, S3b, and S3c) and three water samples were collected from each of the sites at each sampling time.

2.2.4 Sampling Point S4

This point was about 15 m upstream from the Barrage and about 50 m from the Hippo View Lodge and the ESCOM Weed Trapper. There were three sampling points denoted S4a, S4b, S4c where three water samples were collected at each sampling time. This point was important to determine the impact of the activities around the Barrage on the water quality as well as the weed boom on water quality. Nevertheless, this was also selected to determine if the water retention period, which is more conspicuous within this area, has any significant effect on the concentration of various water quality parameters.

2.2.5 Sampling Point S5

This point was about 200 m downstream of the Barrage. The point was chosen to determine the water quality after the Barrage, that is, if the Barrage has any impact on the water quality downstream. Just as for Sampling site S4, there were three sampling points here (denoted S5a, S5b, S5c) where three water samples were collected at each sampling time.

2.3 Collection and Handling of Water Samples

A Schindler was used to collect the water which was immediately transferred into 500 ml plastic (polythene) bottles which had been previously rinsed with distilled water. The water samples were kept in a cooler box, immediately after being collected, where they were maintained at very low temperatures by using ice blocks placed in the cooler.

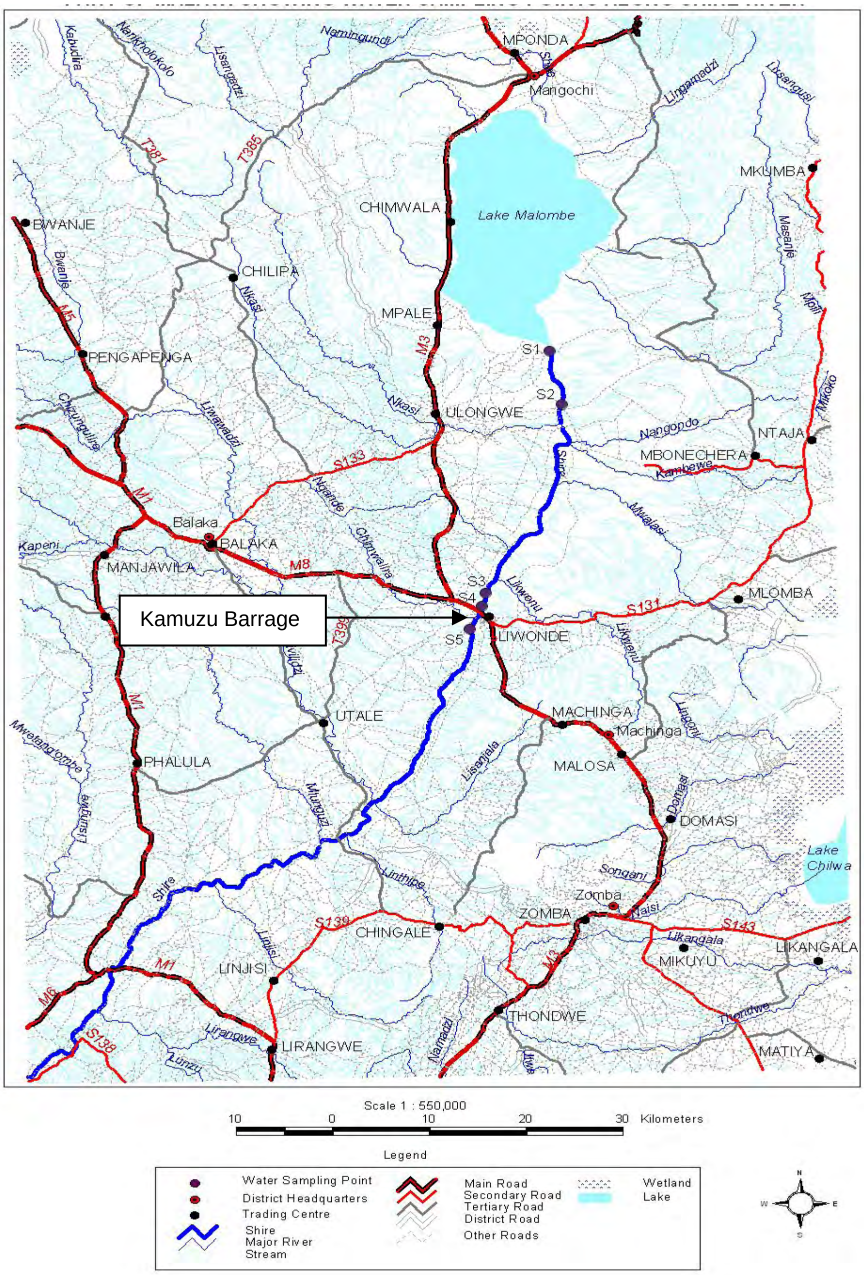
2.4 Important Water Quality Parameters

Water quality parameters are variables (that are part of the water system) that are used to indicate the status of the water (whether the water is of good or bad quality). The following water quality parameters were used in this study:

2.4.1 Dissolved Oxygen (DO)

This is the amount of Oxygen (O_2) dissolved in water. It gets in water either by diffusion (diffusion gradient) from the surrounding air, currents and waves or photosynthesis by aquatic plants and algae. If water is too warm, there may not be enough oxygen in it. When there are too many bacteria, algae or aquatic animal in the area, they may overpopulate hence using DO in great amounts leading to Oxygen deficiency.

Oxygen levels also can be reduced through over-fertilisation of water plants by run-off from farm fields containing phosphates and nitrates (the ingredients in fertilisers). Under these conditions, the numbers and size of water plants increase a great deal. Then, if the weather becomes cloudy for several days, respiring plants will use much of the available DO since they cannot photosynthesise. When these plants die, they become food for bacteria, which in turn multiply and use large amounts of oxygen. The amount of DO an aquatic organism needs depends upon its species, its physical state, water temperature, pollutants present, and more. Fish are cold-blooded animals, so they use more oxygen at higher temperatures when their metabolic rate increases.



(Source: GoM and Mtethiwa, 2012)

Figure 2. Part of map of Malawi showing Lake Malombe and Kamuzu Barrage and water sampling points along the Shire River.

Boyd (1990) and (Chapman, 1996) suggest that 4-5 ppm of DO is the minimum amount that will support a large, diverse fish population. The DO level in good fishing waters generally averages about 9.0 ppm. When DO levels drop below about 3.0 ppm, even the most DO tolerant fish may die.

2.4.2 pH Value

The balance of positive hydrogen ions (H+) and negative hydroxide ions (OH-) in water determines how acidic or basic the water is. The pH scale ranges from 0 (strongly acidic) to 14 (strongly basic). In pure water, the concentration of positive hydrogen ions is in equilibrium with the concentration of negative hydroxide ions, and the pH measures exactly 7 (Quellette & Rawn, 1997). In a lake or pond, the water's pH is affected by its age and the chemicals discharged by communities and industries. Most lakes are basic (alkaline) when they are first formed and become more acidic with time due to the build-up of organic materials. As organic substances decay, carbon dioxide (CO_2) forms and combines with water to produce a weak acid, called carbonic acid. Large amounts of carbonic acid lower water's pH.

Most fish can tolerate pH values of about 5.0 to 9.0. The vast majority of Malawian rivers, lakes and streams fall within this range (Bootsma, 2001)

2.4.3 Phosphorous

The element phosphorus is necessary for plant and animal growth. Nearly all fertilisers contain phosphates (chemical compounds containing the element, phosphorous). When it rains, varying amounts of phosphates wash from farm soils into nearby waterways. Phosphates stimulate the growth of plankton and water plants that provide food for fish. This may increase the fish population and improve the waterway's quality of life. If too much phosphate is present, algae and water weeds such as water hyacinth grow wildly, choke the waterway, and use up large amounts of oxygen. Many fish and aquatic organisms may die.

2.4.4 Turbidity

Is the optical property of a water sample that causes light to be scattered and absorbed rather than transmitted in straight lines through the sample. Simply, turbidity answers the question, "How cloudy is the water?"

Ability of light to pass through water depends on how much suspended material is present. Turbidity may be caused when light is blocked by large amounts of silt, microorganisms, plant fibres, sawdust, wood ashes, chemicals and coal dust. The most frequent causes of turbidity in lakes and rivers are plankton and soil erosion from poor land-use practices in the upper catchment, particularly the clearing of vegetation.

2.4.5 Water Temperature

Is a measure of how hot or cold the water is. The water temperature is results of several factors, among them are: the colour, depth, shoreline vegetation shade, the location (temperate or tropic region), the time of year, the temperature of the water supplying the waterways and the volume of the water.

Fish and most aquatic organisms are cold-blooded. Consequently, their metabolism increases as the water warms and decreases as it cools. Each species of aquatic organism has its own optimum (best) water temperature. If the water temperature shifts too far from the optimum, the organism suffers.

2.4.6 Nitrate (NO_{3-})

Nitrate (NO_{3-}) is a form of the element nitrogen, an essential component of life, is found in the cells of all living things.

Nitrites (NO_{2-}) are relatively short-lived because they are quickly converted to nitrates by bacteria. Nitrites produce a serious illness (brown blood disease) in fish, even though they do not exist for very long in the environment. Nitrates stimulate the growth of plankton and water weeds that provide food for fish. This may increase the fish population. However, if algae grow too abundantly, oxygen levels will be reduced and fish will die.

2.4.7 Biochemical Oxygen Demand

Biochemical oxygen demand or BOD is the amount of dissolved oxygen needed by aerobic biological organisms in a body of water to break down organic material present in a given water sample at certain temperature over a specific time period. The term also refers to a chemical procedure for determining this amount. This is not a precise quantitative test, although it is widely used as an indication of the organic quality of water. The BOD value is most commonly expressed in milligrams of oxygen consumed per litre of sample during 5 days of incubation at 20°C. However, it is often used as a robust surrogate of the degree of organic pollution of water (Chapman, 1996; Chiras, 1998).

2.4.8 Total Dissolved Solids (TDS)

Total dissolved solids (TDS) comprise inorganic salts (principally calcium, magnesium, potassium, sodium, bicarbonates, chlorides and sulphates) and some small amounts of organic matter that are dissolved in a solution (Cech, 2002). TDS is the total amount of dissolved materials/solids which become salts when evaporation takes place and it is an indication of salinity (D. Chapman, 1998). A high TDS load can also increase water hardness – rendering laundry soap ineffective; it can also produce an unpleasant taste to drinking water if exceedingly chlorinated (USEPA, 2010). Many crops are also intolerant to high water salinity.

2.4.9 Electrical Conductivity (EC)

EC measures the flow of electric current in a water sample as various literatures report that dissolved solids (ions) conduct electricity. (Patterson, 1999) indicated that EC provides a good measure of total salinity. (USEPA, 2010) and (Fipps, 2009) reported that there is a linear relationship between TDS and EC i.e. the more the total dissolved salts in a solution, the higher the electric current conducted.

2.4.10 Chlorophyll “a”

D. Chapman (1998) described chlorophyll “a” as the green pigment in photosynthetic plants, indicative of algal biomass. Algae, being primary producers, support secondary producers and other higher organisms (Jeffrey & Humphrey, 1997). The growth of algae requires nutrients (predominantly phosphates and nitrates) in addition to sunlight and temperature. An increase in phosphates and nitrates in a river/lake will cause a rapid multiplication of the algae. Therefore the degree of chlorophyll ‘a’ concentration shows the trophic status of that particular river/lake thus an indicator of water quality.

2.4.11 Sulphate

Ceccotti (1996) stated that sulphur is a “major constituent of amino acids” in all living things and it also enhances the efficient utilisation of N and P. Sulphate occurs in many forms which are highly soluble in water hence if it is mixed with water, acid water may be formed which can damage the environment. Major sources of S include burning fossil fuels as well as decomposition of sulphur-containing organic matter. Bacteria break down the sulphur-containing organic matter into hydrogen sulphide which produces a bad odour. It is indicated that some aquatic organisms which thrive under anaerobic conditions do so by use of sulphate as electron acceptor. Increase in sulphate in drinking water causes gastro-intestinal irritation when magnesium or sodium is present.

2.4.12 Hardness

Hardness in water is defined as concentration of multivalent cations. Multivalent cations are positively charged metal complexes with a charge greater than 1+. They mainly have the charge of 2+. These cations include Ca^{2+} and Mg^{2+}. Hardness can be quantified by instrumental analysis. The total water hardness, including both Ca^{2+} and Mg^{2+} ions, is reported in parts per million or mass /volume (mg/L) of calcium carbonate ($CaCO_3$) in the water. Although water hardness usually measures only the total concentrations of calcium and magnesium (the two most prevalent bivalent metal ions), iron, aluminium, and manganese can also be present at elevated levels in some locations. The presence of iron characteristically confers a brownish (rust-like) colour to the calcification, instead of white (the colour of most of the other compounds). Because it is the precise mixture of minerals dissolved in the water, together with the water’s pH and temperature, that determines the behaviour of the hardness, a single-number scale does not adequately describe hardness. Descriptions of hardness correspond roughly with ranges of mineral concentrations: Soft (0-60ppm), moderate (61-120ppm) and Hard (120-180ppm), and very hard (≥181ppm).

2.4.13 Faecal Coliform Bacteria

The Bacteriological contamination assessment in water is based on measurement of faecal coliform bacteria levels in water. This can be used to determine how much faecal contamination has occurred. Coliform bacteria are a good indicator of the quality of water for drinking or swimming. The higher the coliform count, the more likely the water is to contain some pathogenic agent from faecal contamination. (Chiras, 1998) indicates that rivers in many less developed nations are very heavily polluted with human wastes. Although there will always be coliform bacteria present in natural waters, high levels provide evidence of water pollution from sewage.

2.5 Water Quality Parameters Determined on Site

The following water quality parameters: Electrical Conductivity (EC), Total Dissolved Solids (TDS), Turbidity (Turb), Temperature, Dissolved Oxygen (DO), Salinity and pH were measured on site using a Horiba water checker.

2.6 Water Quality Parameters Determined in the Laboratory

They included the following parameters.

2.6.1 Nitrates

Determination of Nitrate (NO_{3-}) in all water samples was done spectrophotometrically. Absorbance of the solutions was measured on a HACH DR/3000 UV/Visible Spectrophotometer at 410 nm against a blank. The NO_{3-} concentration was calculated from the calibration curve obtained by using standard solutions for NO_{3-} (APHA, 2005).

2.6.2 Soluble Reactive Phosphorous (SRP)

The water samples were filtered immediately through glass fibre filters (Whatman GF/F, 0.6µm pore size. The orthophosphate was then determined colourimetrically using a HACH DR/3000 UV/Visible Spectrophotometer at 880 nm without hydrolysis process. Phosphate concentration was calculated from the calibration curve by using the standard solutions (APHA, 2005), (Wetzel & Likens, 2001).

2.6.3 Sulphate

Determination of Sulphate was done using the gravimetric method after precipitation by barium chloride in hydrochloric acid. Absorbance was measured on a UV/Visible spectrophotometer, Model HACH DR/3000 at 430 nm (APHA, 2005).

2.6.4 Biochemical Oxygen Demand (BOD)

Determination of BOD was done using the Winkler (BOD5) method (APHA, 2005). After incubating the sample at 20°C for five days in the dark, BOD was calculated as follows:

BOD5 (mg/l) = [(Initial DO-Final DO) x Dilution Factor] – Blank

2.6.5 Faecal Coliform Bacteria (FCB)

Membrane filter method was used where 100 ml of sample water was filtered through a cellulose membrane filter. It allows water to pass through it but it retains coliform on its surfaces. The filter was placed in the media (M endo Broth) and incubated for 24 hours at 35 °C. Blue colonies indicated the presence of coliform (APHA, 2005).

2.6.6 Chlorophyll "a"

Determination of chlorophyll "a" was done by using spectrophotometric method as described by (Jeffrey & Humphrey, 1997). The sample was first filtered using a Whatman GF/F glass fibre filter and was then centrifuged. Absorbance of the samples was measured using a U/V spectrophotometer at 750, 664, 647 and 630 nm against a 90% acetone blank. Chlorophyll "a" concentration was calculated using the formula:

Chlorophyll “a” (mg/m^3) = $(11.85*(E_{664}-E_{750}) - 1.54*(E_{647}-E_{750})-0.08(E_{630}-E_{750})*Ve/L*Vf$ (Jeffrey & Humphrey, 1997)

Where: L = Cuvette light-path in centimetres, Ve = Extraction volume in millilitres,

Vf = Filtered volume in litres

2.6.7 Total Suspended Solids (TSS)

A well-mixed volume of the sample was filtered through a weighed standard glass-fibre filter and the residue retained on the filter was dried to a constant weight at 103-105°C. The increase in weight of the filter was taken to represent the Total Suspended Solids in accordance to (APHA, 2005).

2.6.8 Transparency

This was determined by use of a Secchi disc. A Secchi disc is a circular disc painted black and white with a diameter of about 15 cm. It has a calibrated rope/string tied to it. Transparency was determined by lowering a Secchi disc into the water at a perpendicular position and a reading on the calibrated rope was recorded at a point where it just disappeared and then it was further lowered into the water until it completely disappeared. A second reading of the Secchi disk was obtained at a point where the disc reappeared when it was being lifted from the water. An average of the two readings gave a Secchi depth which determines water transparency.

2.7 Laboratory Facilities

Bunda College laboratory and equipment was used to analyse the samples.

3 Results and Discussion

Results in Tables 1 and 2 show that of the three selected graphed parameters, turbidity and phosphorus concentrations were higher during the rainy season than the dry season. The same tendency is also portrayed by BOD, TSS and Secchi depth as indicated in Tables 1 and 2 below. Variation in readings of these parameters is based on the seasonality and locality and therefore is largely a sign of effects of catchment activities.

3.1 Selected Water Quality Parameters

3.1.1 Turbidity

During rainy season, surface runoff carries with it silt and other substances. Once these enter the aquatic ecosystem, they mix with the clear water reducing its transparency and increasing its turbidity (Table 1). The amount of silt in the runoff is exacerbated by poor agronomic practices. This is the scenario around the catchment of Shire River especially the upper area. The GoM (2003) reported that there is widespread dimba (dry season) farming in the Mangochi area (an average of about 13% of farming being dimba farming). However, from observation, the dimba farming in the project area is much higher than the reported 13%. The dimba farming in the area occurs along the Shire River and Lake Malombe and is associated with poor agronomic practices and application of fertilisers which is responsible for release of silts and nutrients into the water that increases turbidity of the water and macrophyte production (GoM, 2003).

Also, it was observed that there are a number of buildings along the Shire River especially at the Kamuzu Barrage. These are mostly resorts and lodges. Construction processes often leads to clearing of the land giving rise to bare and loosened soil. Once rains come, soil particles are dislodged and carried away by runoff into the aquatic ecosystem.

Turbidity in excess of 50 NTU is disadvantageous to fish because turbid water clogs the gills bringing discomfort and sickness. Besides this, high turbid water reduces visibility in fish. As a result, two disadvantages arise, firstly: the fish will mostly starve because they cannot find food affecting their productivity; and, secondly fish cannot see their predators. As a result most of them are easily caught. The more the fish are caught the lower the recruitment success hence affecting the population and catch in subsequent years. Very high turbid water reduces hatching of eggs since the eggs are covered by sediments (Boyd, 1990).

High turbid water also creates ideal conditions for the growth of pathogenic bacteria that affect water users. If turbidity is high, effectiveness of chemicals, such as chlorine, that are used to kill the pathogens in water abstracted for other domestic uses, is poor.

TABLE 1. MEAN READINGS OF SELECTED WATER QUALITY PARAMETERS FOR THE DRY SEASON

Location	Chlorophyll "*a*" (mg/l)	Hardness (mg/l)	Phosphorus (µg/l)	Secchi depth (cm)	Turbidity (NTU)
Upstream of the weed trapper (S3)	24.301 ± 0.010^a	10.00 ± 0.029^a	23.550 ± 0.104^a	68.42 ± 8.53^a	42.67 ± 0.94^a
Upstream of Barrage (S4)	18.463 ± 0.088^b	8.4433 ± 0.088^b	17.329 ± 0.310^b	41.00 ± 2.50^b	41.73 ± 0.35^b
Downstream of Barrage (S5)	15.962 ± 0.035^c	7.725 ± 0.098^c	15.491 ± 0.066^c	54.67 ± 3.54^c	59.52 ± 3.44^c

^{X} Means having the same letter in any given column are not significantly different from each other at 0.05% level of significance.

Furthermore, high turbid water reduces the amount of sunlight entering the water. This then means that primary production in terms of phytoplankton, which is food for fish, would be heavily reduced. Reduction of the the available food for fish affects fish productivity.

With the fore going levels of turbidity and activities around the catchment, it is predicted that unless other catchment protection measures are taken, there is an impending danger of increased turbidity in the Shire River after the Barrage has been rehabilitated and raised. This is because upstream water levels will increase making the water more readily available for catchment farming.

Turbidity levels of above 150 NTU are not recommended for flowing water as they are a source of the above problems and turbidity of more than 5 NTU is not recommended for drinking water.

3.1.2 Chlorophyll "a"

The findings of this study show that the wet season chlorophyll "a" concentrations (Table 2) are lower than the dry season values (Table 1). This is attributed to the dilution effects of the rains. This dilution is both directly on the phytoplankton concentration that translates to low chlorophyll "a" concentration and to the nutrient (nitrogen) that is responsible for proliferation of phytoplankton responsible for this chlorophyll "a". Evidence is shown by the NO_{3-} concentration determined above, there is a decline in the concentration of the nutrient and hence subsequent reduction in chlorophyll "a" (Tables 1 and 2).

The green pigment (chlorophyll) which is present in most photosynthetic organisms provides an indirect measure of algal biomass and an indication of trophic status of a water body. The growth of algae in water is directly related to the concentration of nutrients (principally nitrogen and phosphorous), temperature and light. Water bodies with low levels of nutrients (oligotrophic) have chlorophyll a of less than 2.5 µg/L whereas water with high levels of nutrients (eutrophic) have high chlorophyll a (concentrations of more than 45 µg/L) Excessive concentration of P and N leads to overgrowth of phytoplankton a condition called algal bloom. This is not good for aquatic organisms as it would lead to reduced oxygen concentration and increased carbon dioxide concentration at night. The increase in carbon dioxide leads to formation of weak carbonic acid which may increase the acidity of the water to levels not conducive to aquatic organisms, including fish. The reduced oxygen level at night will lead to a situation where aquatic organisms are stressed and offer reduced productivity. On the other hand, algal blooms will reduce light depth as most of the radiation will be blocked by floating algae.

Despite all this, the levels of chlorophyll "a" concentrations both in the diluted (rainy) and undiluted (dry) state is below the water eutrophication state. This then means that Shire River water, in terms of nutrient enrichment, has not yet reached an alarming state, (Tables 2 and 3 and Appendix 1).

It was expected that the increased concentration of phosphorous in the rainy season would trigger an increase in phytoplankton hence chlorophyll "a" as the two are directly linked. However, the reduced chlorophyll "a" in the presence of increased phosphorus concentration may signify that at this time dilution had more influence on the chlorophyll a concentration than the nutrients.

TABLE 2. MEAN READINGS OF SELECTED WATER QUALITY PARAMETERS FOR THE WET SEASON

Site	Chlorophyll "a" (mg/l)	Hardness (mg/l)	Phosphorous (µg/l)	Secchi depth Transparency (cm)	Turbidity (NTU)	Coliform (CFU/100ml)
Shire outlet at Lake Malombe S1)	22.55 ± 0.02^{c}	128.61 ± 1.10^{b}	18.36 ± 0.06^{c}	66.25 ± 1.38^{a}	75.00 ± 1.53^{b}	95.83 ± 1.92^{c}
Liwonde National Park (S2)	21.99 ± 0.11^{b}	132.28 ± 1.13^{a}	19.73 ± 0.04^{b}	69.67 ± 0.88^{a}	120.0 ± 1.1	103.17 ± 1.83^{c}
Upstream of weed trapper (S3)	21.89 ± 0.19^{b}	125.32 ± 1.18^{c}	22.42 ± 0.21^{b}	53.33 ± 4.41^{b}	48.26 ± 0.09^{e}	119.75 ± 5.14^{b}
Upstream of Barrage (S4)	18.03 ± 0.54^{a}	130.11 ± 0.75^{ab}	22.48 ± 0.26^{a}	50.58 ± 0.58^{bc}	44.00 ± 0.00^{d}	124.08 ± 0.55^{b}
Downstream of Barrage (S5)	17.36 ± 0.22^{c}	103.60 ± 0.73^{d}	20.25 ± 0.04^{b}	45.58 ± 1.12^{c}	62.89 ± 0.01^{c}	148.50 ± 2.25^{a}

^{x} Means having the same letter in any given column are not significantly different from each other at 0.05% level of significance.

3.1.3 Phosphorus

Intense ecological interest in phosphorus stems from its major role in metabolism in the biosphere (Chapman, 1996). In comparison to relative supply of other major nutritional and other structural components of the biota (C, N, O, S), phosphorus is the least abundant and commonly limits biological productivity in aquatic ecosystem (Wetzel & Likens, 2001) Phosphorus will come from the biota as well as the sediments and other colloidal matter. These are either lost by sedimentation or hydrolysed to orthophosphate which is rapidly assimilated by biota leading to low concentrations of phosphorus in the upper layer (trophogenic zone) of the water body, where enough light is present to permit photosynthesis.

Because of the role of phosphorus in primary production, an excess amount of it induces phytoplankton and macrophytes production in water bodies. It is therefore imperative to ensure a substantive amount of phosphorus is reduced to ensure oligotrophic conditions (Chapman, 1996).

In this study, P concentrations were higher during the rainy season than during the dry season (Tables 1 and 2; Figures 3 and 4). These results support the facts that runoff from rains bring additional input of P into the aquatic ecosystem. As indicated above, the surrounding catchment of the Shire River is heavily cultivated for dimba and field crops and phosphorus fertiliser such 21:23:0:+4S is mostly used. This implies that during the rainy season, a substantial amount of phosphorus is carried into the aquatic ecosystems through runoff. Apart from agricultural areas, runoff also comes from lodges, resorts and other residential areas along the River. These areas can be another source of phosphorus where a lot of detergents are used. There is not much variation in different sites, although higher concentrations were recorded at the Barrage than Lake Malombe (mouth of Shire River). Probably this portrays how the catchment development activities and water residence time contributes to phosphorus input and accumulation into the aquatic system respectively (Mumba and Kaunda, 1999).

TABLE 3. MEAN CONCENTRATION OF SELECTED WATER QUALITY PARAMETERS FOR THE SHIRE RIVER (1993-1997)

PARAMETER	YEAR				
	1993	1994	1995	1996	1997
Conductivity (µS/cm)	382	475	320	297	321
TDS (mg/L)	151	300	155	158	170
Nitrate (mg/L)	<0.1	4.1	<0.1	<0.1	<0.1
Sulphate (mg/L)	<0.1	14.4	4.6	5.2	4.4
Hardness (mg/L)	80	82	92	84	94
Turbidity (NTU)	7	84	10	10	25
TSS (mg/L)	11	36	12	12	28

Source: GoM, 2003

3.1.4 Faecal Coliform Bacteria

Faecal Coliform Count in the form of Coliform Forming Units (CFU) is high (Table 2) showing that the water is contaminated with faecal matter. This may indicate that bacteria have been brought into the river system by rain water which washed away faecal matter from the catchment. In terms of numbers, there is a low count at the mouth of Shire River at Lake Malombe and increased CFU at the Barrage. Since faecal coliform is of animal origin, going by these results means that there is more faecal pollution at Liwonde than at the mouth of Shire River (Table 2). For untreated, chlorinated supplies, such as surface water or shallow or deep well waters, the detection of faecal coliform alone can generally serve as an adequate guide for the presence of pathogenic organisms of faecal origin (WHO, 1996). The faecal matter may have also contributed to the increase in phosphorus concentration during the wet season as shown in Table 2.

The source of these could be the fishermen who may defecate into the water whilst fishing, the community which roams around the river bank for plant biomass hunting, livestock grazing along the catchment and effluent discharges from the resorts and lodges within the river catchment.

If measures are not taken to ensure sanitary measures are followed, it is expected that when water levels increase, the number of activities along the river would also increase leading to increased faecal pollution.

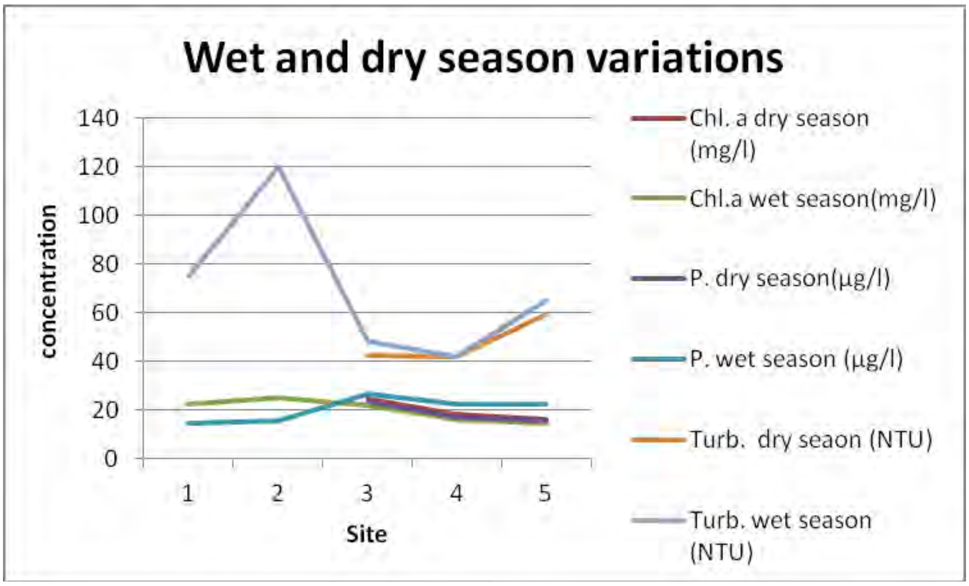


Figure 3. *Trends of selected parameters in dry and wet seasons at different sampling points*

3.2 Phosphorous, Nitrogen and Aquatic Weeds

A combination of phosphorus and nitrogen is very crucial in relation to aquatic primary production. Excessive concentrations of the two nutrients will lead to a eutrophic state of the water which may be manifested by macrophyte growth (aquatic weeds) rather than in the growth of phytoplankton. The effect of eutrophication can be highly detrimental to water quality and severely limit the uses for which the water is meant. In relation to concentration of the phosphorous and nitrogen, the water of the Shire River is basically within the oligotrophic category.

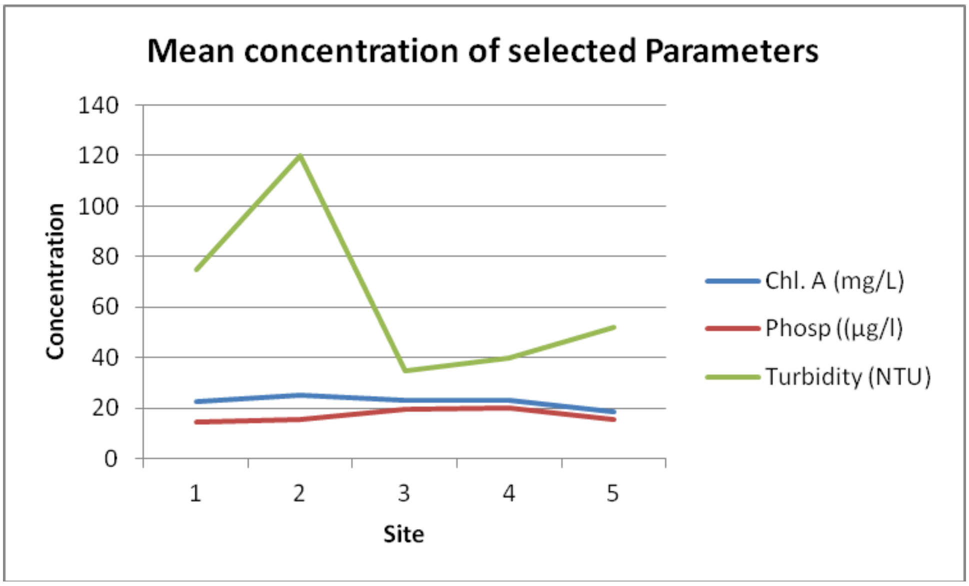


Figure 4. *Mean concentrations of selected parameters at various sampling points*

4 Comparison of the Results with Previous Studies

Previous studies conducted between 1994-1997 (GoM, 2003, Table 3) on selected water quality parameters show higher readings of Total Dissolved Solids (TDS) and Electrical Conductivity (EC) and lower Turbidity (among other parameters) in comparison to the current findings. Increase in turbidity by close to three fold indicates the increase in pollution over the years. However, although there are these differences, the water quality was still in the oligotrophic category in both situations.

TDS is a result of inorganic and organic substances with Ca, PO_4^{-3}, NO_{3-}, Na, K and Cl being the common chemical constituents whilst EC is a result of ion concentration, mobility, oxidation state as well as temperature of the water. TDS is directly related to EC such that TDS=0.5 times conductivity. Also, the environmentally acceptable conductivity of rivers is between 50-500µS/cm while less than 200mg/L TDS has no effect on aquatic organisms including fish spawning. Values outside these ranges would negatively affect productivity of the aquatic ecosystem. Therefore using this guideline, the water quality situation is within the oligotrophic category since research has shown that concentrations of less than 200mg/L TDS have no effect on aquatic organisms including fish spawning (Chapman, 1996).

5 Possible Water Quality Impacts due to Heightened Barrage

5.1 Impacts during Construction Phase

5.1.1 Increased Siltation and Turbidity of Water Downstream

It is anticipated that activities during construction of the Barrage will lead to temporary increased production of silt leading to more turbid water downstream. Apart from this, since water will be impounded, there will be reduced flow of water affecting the nutrient retention of the river and therefore concentration leading to isolated algal blooms and proliferation of other parasitic water borne diseases.

5.1.2 Increased Levels of Water Upstream

It is anticipated that once the water has been impounded due to the increased height of the Barrage gates, the level of the water upstream would increase. Also, nutrients from upstream that have not been assimilated by the aquatic biota will accumulate within the impoundment. An increase in nutrients especially phosphorus and nitrogen may lead to algal blooms as well as growth of aquatic weeds upstream.

5.2 Impacts during the Operation Phase

Barrages are likened to damming in rivers and/or weirs in most studies. This is because of the changed flow regime downstream, increased water levels and increased retention time of water in the reservoir upstream. Due to the foregoing outlined factors associated with barrages, there are likely changes in water quality as described below.

5.2.1 Nutrient Enrichment due to Increased Water Retention

There is likely to be sedimentation of nutrients due to reduced flushing of the water within an impoundment. Furthermore, because the depth of the Barrage reservoir is relatively shallow, wind driven events can lead to a substantial turbation (turnover), allowing periodic pulses of nutrients into the surface layer of the water. These nutrient pulses then stimulate algal growth making the water nutrient-enriched (Baldwin *et al*., 2007).

In general, longer water retention times will result in greater settlement of sediments and nutrients within the water storage resulting in lower turbidity. However, during prevailing winds, the bed sediments would be disturbed causing re-suspension of the settled sediments and nutrients and leading to highly enriched water. Therefore whilst TDS is expected to be low, total nitrogen and phosphorus levels may exceed the guidelines. This may cause increased growth of aquatic plants and algae. Nutrient-enriched tropical reservoirs are particularly prone to colonisation by aquatic plants. Mats of floating plants can impede fishing boats and nets, block out light for other organisms, clog turbines and provide an excellent habitat for disease vectors such as mosquitoes and the snails which host the schistosomiasis parasite.

5.2.2 Potential Contamination by Wastewater from Resorts, Lodges, Markets and Fishing Activities around the Barrage

Currently there are a number of resorts and lodges around the Barrage area. Partly it is because the presence of larger volumes of water and its locality. The probability is high that, with time, there would be an increased number of such structures which will have an impact on water quality if proper measures are not adhered to regarding the discharge of both solid and liquid wastes which they will generate. The household wastes are sources for nutrient and pathogen production. Since there is potential increase in primary production, it follows that fish recruitment would increase leading to increased fishing activities around the Barrage. The fishing activities have the potential to reduce water quality in the Barrage reservoir through human waste and food remains entering the water.

Under conditions of high river discharge there may be little variation in water quality since nutrients would be flushed out, but under low discharge conditions substantial reductions in dissolved oxygen concentration and increases in nutrient and chlorophyll “a” concentrations would be noted in the zone immediately upstream and downstream of the Barrage (as noted by Connell *et al*. 1981).

6 Proposed Mitigation Measures

In order to prevent the anticipated impacts of this Barrage and ensure clean water, the following are proposed mitigation measures.

6.1 Mitigation Measures during Construction Phase

6.1.1 Water Pollution Monitoring

During construction, it is suggested that pH, nutrient load, chlorophyll “a”, BOD and turbidity be measured every fortnight to ensure any upsurge is detected for prompt correction measures.

6.2 Mitigation Measures during Operation Phase

6.2.1 Catchment Management

The river catchment is one of the expected sources of nutrients that may pollute water resources. It is therefore necessary to devise ways to manage the catchment to mitigate the pollution. These may include;

- Implementation of land conservation practices (catchment management measures) such as agroforestry and recommended land use practices to impede run-off.
- Protecting the river buffer zone from encroachment by agriculture and settlements through enforcement of existing laws, and imposing heavy fines on offenders.
- Encouraging the formation of local authorities (committees) in the management of catchment areas.

6.2.2 Proper Waste Water Management Practices

Since waste is one of the expected sources of water pollution in the area the following is proposed:

- Implementation of proper waste management and treatment procedures;
- Complying with international standards for solid waste and liquid waste disposal.

6.2.3 Public Awareness / Stakeholder Involvement

Public awareness campaigns should be encouraged on the need to protect water resources from pollution and the dangers of polluted waters. People are encouraged and mobilised to fully participate in any activity if they feel the sense of involvement and belonging.

6.2.4 Sanitary Measures

There is a need to institute proper sanitary measures at the Kamuzu Barrage in Liwonde and in the river catchment to reduce the risk of eutrophication which is a seed for phytoplankton and macrophyte proliferation in aquatic ecosystems.

6.2.5 Water Monitoring System

There is a need to set up at least five monitoring points both upstream and downstream of the Barrage. At these points, pH, N, P, turbidity, BOD chlorophyll “a”, and faecal coliform bacteria should be measured every three months. This will assist detection of any adverse changes in the water quality and allow corrective measures to be implemented promptly.

7 Conclusion

The water quality of the Shire River is within the oligotrophic category although the concentrations of various parameters pose an impending threat of shifting to mesotrophic conditions with time especially due to anthropogenic activities as well as input from runoff from the surrounding communities. The consequences of such activities are already conspicuous on turbidity, faecal coliform bacteria, hardness and nutrients which are increasing.

Also it has been shown that catchment development activities significantly contribute to increased pollution of the water. This means that measures have to be taken to ensure that catchment development activities (such as farming and resort developments) do not enrich the Shire River with nutrients and pathogenic bacteria.

Furthermore, it has been shown that reduced flow of water also contributes to increased pollution of the river. For example, at the Barrage where water flow is regulated, concentrations of various parameters have been shown to increase in the sediments upstream due to accumulation and downstream due to reduced flushes.

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Appendix 1: Standard Guidelines for Flowing Water

Class I; Oligotrophic, Class II; ά- mesotrophic, Class III; ß-mesotrophic,

Class IV; ά-Eutrophic

TABLE 4. STANDARD GUIDELINES FOR WATER QUALITY FROM UNECE

Variable	Class I	Class II	Class III	Class IV	Class V
DO (mg/L)	> 7	7- 6	6-4		<3
BOD (mg/L)	< 5	5-10	10-20	21-30	>50
Phosphorus (µg/L)	<15	15-40	40-75	75-190	>195
Total Nitrogen (µg/L)	<300	300-750	750-1500	1500-2500	>2500
Chlorophyll "a" (µg/L)	<4.00	4-15	15-45	45-165	>165
Hardness (mg/L)	<20	-	-	-	>80
Turbidity (NTU)	<5	-	-	-	>20

Source: (UNECE, 2003)

Appendix 2: Raw Data for the Dry Season

TABLE 5. RAW DATA FOR THE DRY SEASON

Sampling Point	Temp °C	pH	DO (mg/L)	Cond (µS/cm)	Turb (NTU)	TDS (mg/L)	Sal (g/L)	Depth (cm)	Sech (cm)	Chl "a" (mg/L)	BOD (mg/L)	P (µg/L)	Hard (mg/L)	Sulph (mg/L)	TSS (mg/L)	N (mg/L)
S3	24.513	7.993	5.525	0.239	42.075	0.155	0.100	2.050	38.500	18.377	3.433	17.277	94.467	14.667	1.767	0.160
S3	24.500	8.110	5.575	0.238	41.025	0.155	0.100	1.663	46.000	18.373	3.433	16.803	94.267	15.310	1.700	0.140
S3	24.538	7.950	5.400	0.239	42.100	0.155	0.100	2.200	38.500	18.640	3.500	17.907	94.567	14.587	1.767	0.147
S4	24.500	8.063	6.020	0.239	63.425	0.155	0.100	3.120	52.500	15.987	3.000	15.420	87.233	13.067	1.433	0.137
S4	24.475	8.010	6.070	0.239	62.475	0.155	0.100	3.250	58.750	15.893	3.000	15.503	87.567	13.100	1.233	0.117
S4	24.475	8.100	5.820	0.239	52.650	0.155	0.100	2.500	52.750	16.007	3.000	15.550	87.467	13.197	1.267	0.120
S5	24.615	8.010	6.698	0.238	43.700	0.155	0.100	2.538	64.000	24.287	4.100	23.350	99.500	16.103	1.767	0.197
S5	24.628	8.200	6.920	0.238	40.800	0.155	0.100	2.500	78.250	24.320	4.200	23.697	99.467	15.907	1.867	0.190
S5	24.620	8.093	5.623	0.238	43.500	0.155	0.100	1.833	63.000	24.297	4.200	23.603	99.400	15.927	1.800	0.197
S3=upstream of Barrage; S4=downstream of Barrage; S5=upstream of ESCOM weed trapper																

NB: Depth denotes the depth at which water samples were taken.

Appendix 3: Raw Data for the Wet Season

TABLE 6. RAW DATA FOR THE WET SEASON

Sampling Point	Temp °C	pH	DO (mg/L)	Cond (µS/cm)	Turb (NTU)	TDS (mg/L)	Sal (g/L)	Depth (cm)	Sechi (cm)	Chl a (mg/L)	BOD (mg/L)	P (µg/L)	Hard (mg/L)	Sulph (mg/L)	TSS (mg/Ll)	N (mg/L)	Coliform (CFU/100ml)
S1	28.64	7.34	8.50	0.23	66.00	0.15	0.10	2.15	60.00	21.52	4.80	15.84	122.96	14.79	2.88	0.17	130.00
S1	28.42	7.50	8.83	0.23	64.30	0.15	0.10	1.75	45.00	22.03	4.60	15.23	126.60	14.61	2.70	0.15	114.00
S1	28.59	7.51	8.47	0.23	58.40	0.15	0.10	1.80	55.00	22.13	4.80	15.19	126.39	14.82	2.80	0.16	115.25
S2	30.67	7.68	8.86	0.18	46.70	0.19	0.10	1.65	51.75	28.57	5.20	22.99	128.64	16.17	2.45	0.22	124.50
S2	30.65	7.67	8.86	0.18	51.90	0.19	0.10	1.70	50.00	26.94	5.20	22.28	131.06	16.37	2.43	0.22	123.00
S2	30.68	7.69	8.84	0.18	46.70	0.19	0.10	1.60	50.00	28.56	5.28	22.16	130.65	16.46	2.53	0.21	124.75
S3	29.28	7.45	7.56	0.23	44.90	0.13	0.10	1.45	44.00	20.94	4.50	15.19	102.27	14.75	1.93	0.14	144.00
S3	29.26	7.47	7.58	0.23	44.88	0.13	0.10	1.60	47.75	21.69	4.40	15.33	104.76	14.28	2.10	0.12	151.00
S3	29.27	7.49	7.55	0.23	44.90	0.13	0.10	1.50	45.00	21.44	4.40	15.22	103.78	14.92	2.13	0.13	150.50
S4	26.23	5.61	8.05	0.20	122.00	0.13	0.10	1.90	71.00	24.78	4.80	15.75	131.27	15.31	2.48	0.14	105.00
S4	26.30	5.60	8.06	0.20	118.00	0.13	0.10	1.70	68.00	25.11	4.95	15.79	134.53	15.33	2.55	0.13	99.50
S4	26.23	5.62	8.04	0.20	120.00	0.13	0.10	1.70	70.00	25.09	4.80	15.66	131.04	15.39	2.50	0.14	105.00
S5	27.44	6.21	8.12	0.19	72.00	0.12	0.10	1.90	64.75	22.58	4.15	14.36	128.51	14.86	1.80	0.10	99.50
S5	28.24	6.23	8.10	0.19	76.00	0.12	0.10	1.70	69.00	22.52	4.10	14.47	128.82	14.87	1.73	0.11	93.00
S5	28.31	6.25	8.13	0.19	77.00	0.12	0.10	1.70	65.00	95.00	4.6	0.04	128.52	14.26	22.55	0.10	14.91

NB: Depth denotes the depth at which the water was sampled

Appendix 4: Pictures of the Shire River Catchment

Figure 5. *Shire River catchment area at the Kamuzu Barrage, used as a dumping site.*

Figure 6. *A researcher getting set for sampling.*

Figure 7. Water sampling and on-site measurements at Sampling Point 4 at the Kamuzu Barrage.

Figure 8. The Shire River as a water source for domestic purposes.

Figure 9. Fishing along the Shire River - another source of water pollution.

Appendix 5: Persons and Organisations Consulted

1. Dr. Daniel Sikawa, Bunda College
2. Mrs F. Moyo, Ministry of Agriculture, Irrigation Department
3. Mrs J. Kamwamba, Natural Resources College
4. Mr. N. Nyalugwe, Ministry of Agriculture, Lilongwe ADD
5. Mr. M. Mbwandira, ESCOM
6. Mr G. Phiri, Natural Resources College
7. Mr. F. Chidzalo, Liwonde road block
8. Mr. D. Pataliya, Liwonde road block
9. Mr. J Matanda, Fisherman, Liwonde road block
10. Mrs K. Pindani, Liwonde road block
11. Mr. Gambatula, Liwonde National Park
12. Mr. V. Malinki, Fisherman, Lake Malombe
13. Mr. F. Mpita, Fisherman, Lake Malombe
14. Mrs. F. Kapalamula, Fishmonger, Liwonde road block