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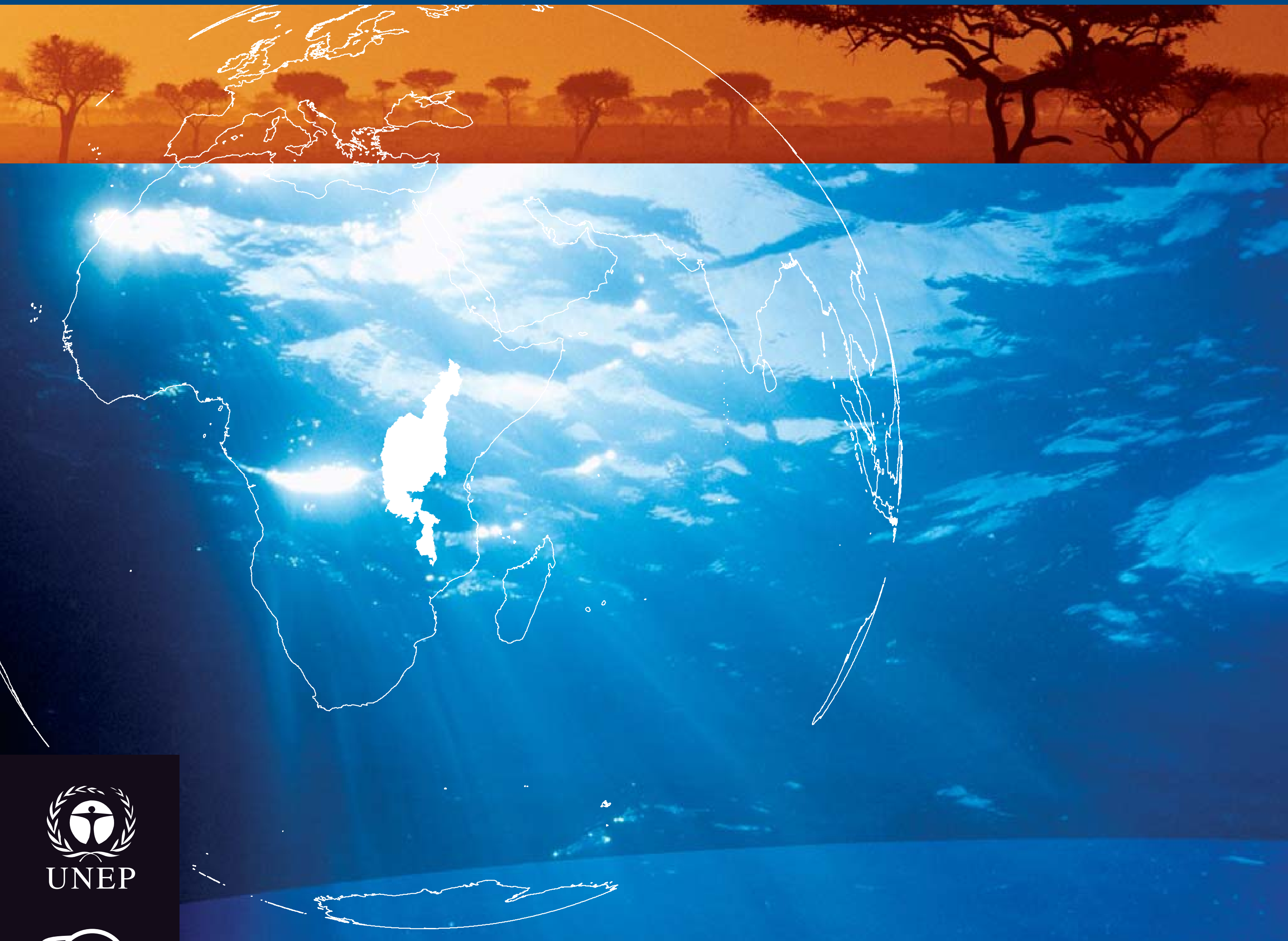

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East African Rift Valley Lakes

GIWA Regional assessment 47

Odada, E.O., Olago, D., Kulindwa, K.A.A., Bugenyi, F., West, K., Ntiba, M., Wandiga, S. and J. Karimumuryango

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Regional assessment 47
East African Rift Valley Lakes

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Executive summary

The East African Rift Valley Lakes (EARVL), GIWA region 47, runs from the northern end of Lake Turkana Basin to the southern tip of the Lake Malawi/Nyasa Basin and includes all the natural habitat and associated human communities found within the Rift Valley and on the adjacent escarpments (Figure 1). It encompasses parts of the following countries; Ethiopia, Kenya, Sudan, Uganda, Tanzania, Rwanda, Burundi, Democratic Republic of Congo (DR Congo), Zambia, Malawi and Mozambique. The main lakes include Victoria, Tanganyika, Malawi, Turkana, Albert, Edward, George and Kivu. All are tropical and together comprise the African Great Lakes ecoregion. However, each lake lies within its own separate drainage basin, with its own assemblage of endemic organisms, most notably the cichlid fish species-flocks. Each lake differs substantially with respect to limnology, catchment dynamics and human impacts (Hamilton 1982).

For the purpose of GIWA assessment, the following lakes that are characteristic of most of the transboundary water bodies in the region were selected for the exercise: Lake Turkana, Lake Victoria, Lake Tanganyika and Lake Malawi. These are the largest of the East African Rift Valley lakes and are among the oldest lakes in the world. All these lakes are extremely sensitive to climate change.

Lake Turkana, the largest closed-basin lake is up to 115 m deep, moderately saline and alkaline, and lies in a topographically closed basin located in the arid northwestern part of Kenya, though the delta of the Omo River, the principal affluent, lies within southwestern Ethiopia. Lake Victoria is, by area, the second largest lake in the world and the largest in Africa, though relatively shallow, with a maximum depth of 80-90 m. More than 80% of its water input is derived directly from rainfall on the lake surface, and about 7% flows from the western side of the basin through the Kagera River. It is drained by the Nile River from Owen Falls on its northern rim. Lake Tanganyika is the longest lake in the world (673 km) though only 12–90 km wide. Its average depth is 570 m, with a maximum depth of 1 470 m, making it the world's second deepest lake. The lake drains westwards through the Lukuga River into the basin of the Congo River. Lake Malawi is long and narrow, the fourth deepest inland water body in the world (700 m) and the world's fourth largest body of freshwater. It drains southwards via the Shire River to the Zambezi Basin.

Lakes Victoria, Tanganyika and Malawi are famous for their endemic species flocks of cichlid fishes. Lake Tanganykia hosts a large flock, estimated to include more than 700 cichlid fish species (Snoeks 2000). Lake Malawi's total fish fauna comprises some 800 species, more than any other lake in the world, and nearly all of its cichlids are endemic (Ribbink 2001). Lake Victoria's formerly rich cichlid fauna has become drastically reduced in recent decades.

The EARVL region is home to some of the poorest communities in the world. Most of the Lake Turkana Basin is populated with pastoralists, mostly nomadic, but a few are fishermen. The lower Omo Valley supports subsistence agriculturalists in the north and agro-pastoralists in the south extending to the Kenya border. In the catchment area as a whole, the population is estimated at 15.2 million out of which 12.3 million live in the Ethiopian part of the catchment. The Basin is the poorest and has the lowest population density and economic activity of all the other large lake basins of the region. The Lake Victoria Basin is the most heavily populated basin, and supports one of the densest rural populations in the world. An estimated population of roughly 30 million people whose incomes are estimated to lie within the ranges of 90-270 USD per capita per year live in the Basin. The catchment is mainly agricultural, though most of the population living along the lakeshore relies directly or indirectly on the fishing trade. An estimated 10 million people reside in the Lake Tanganyika catchment (UNDP 2000); outside urban centres, subsistence and small-scale commercial fishing and farming dominate people's livelihoods (Quan 1996, Meadows & Zwick 2000). In the Lake

Malawi Basin, Malawi's land area is densely populated at 116 persons per km^2 (UNEP-IETC 2003) representing 80% of the total lakeshore population (World Bank 2003).

It is only during the past 10 years or so that the East African countries have instituted, at government level, policies on the environment that adopt an integrated and sustainable approach to environmental management. New national environmental policies/acts have been enacted in both Ethiopia (1997) and Kenya (1999), and environmental authorities have been set up to implement the policies which seek to promote sustainable environmental management and development. The new Kenya Water Act (2002) provides for the establishment of Water Resources Management Authorities that will have wide-ranging powers to manage and protect water resources at river or lake basin scales. International conventions and agreements that Kenya, Uganda and Tanzania are signatories to, or subscribe to, include: Technical Cooperation for the Promotion of the Development and Environmental Protection of the Nile Basin (Tecconile), Initiative for Nile Basin Management, the Convention for the Establishment of the Lake Victoria Fisheries Organisation (LVFO), the Agreement on the Preparation of a Tripartite Management Program for Lake Victoria, and the Treaty establishing the EAC. The international conventions and agreements include: the Convention on Wetlands of International Importance (Ramsar), the Convention for International Trade in Endangered Species of Wild Fauna and Flora (CITES), the Convention on Conservation of Biological Diversity, and the Code of Conduct for Responsible Fisheries (CCRF).

The assessment identified the priority GIWA concerns for Lake Turkana as Habitat and community modification and freshwater shortage; for Lake Victoria the priorities were Pollution and Unsustainable exploitation of fish and other living resources; and for the lakes Tanganykia and Malawi the priority concerns were identified as Unsustainable exploitation of fish and other living resources and Habitat and community modification.

The Lake Victoria Basin was chosen for Causal chain and Policy options analyses on account of the diverse, linked issues and complexities that have contributed to its environmental degradation, as well as the interventions that have been initiated in order to address and mitigate the environmental degradation. Because of the similarity of environmental problems affecting the East African Great Lakes, as well as similarities in the socio-political, economic and health status of the various riparian countries, the Lake Victoria Causal chain and Policy options analyses presented in this report are considered to be applicable to the other basins of the region. For Lake Victoria, under the concern Unsustainable exploitation of fisheries and other living resources, overexploitation and destructive fishing practices were identified as key issues; under the concern Pollution, the important issues identified were microbiological, eutrophication, chemical and suspended solids. It was, however, noted that the issue "suspended solids" had several components that were interrelated with the microbiological, eutrophication and chemical issues, having both synergistic and cumulative effects in their association. The suspended solids issue was, therefore, nested in the microbiological, eutrophication and chemical issues.

In the Causal chain analysis for Lake Victoria, the root cause of Unsustainable exploitation of fish resources was identified as the existence of a market for fish, both domestic and, more importantly, export. Other root causes are inadequate regulation, poverty, poor institutional and legal arrangements, low civic education and awareness, low management capacity by communities, availability of market for undersized fish, and corruption. Whereas these root causes lead to unsustainable exploitation practices for subsistence fishing, in most cases profit is the main factor driving the process. The environmental degradation of the Lake Victoria Basin over the last three decades (due to high population, massive algal blooms, water-borne diseases, water hyacinth infestation, oxygen depletion, introduction of alien fish species etc.) has been determined as placing a present value of 270–520 million USD at risk to the lake communities, if the large export fishery for Nile perch was lost (World Bank 1996). The collapse of the Nile perch fishery may become a reality sooner rather than later in the event that things are left in a "business as usual" scenario.

The principal causes of Pollution in Lake Victoria lie in its catchment areas in both urban and rural settings. The role of the Kagera River as a main contributor of suspended solids, nutrients and water hyacinth is an extremely important consideration when evaluating policy options for sustainable management of the Lake. Untreated industrial and municipal effluent together with agricultural run-off are the main contributors of microbiological and chemical pollution and are a source of nutrients contributing to eutrophication, while suspended solids are derived from erosion of degraded catchments, riverbanks and lake-edge environments due to poor agricultural practices and high grazing intensities. All these contaminants make the Lake water unfit for recreation, consumption and other uses, unless a huge processing cost is incurred. Pollution destroys habitats for freshwater life forms while at the same time making them unavailable for nutritional purposes. For the majority of people living by the lake shore and subsisting by fishing, this implies that malnutrition and health problems will entrench themselves and exacerbate the deepening poverty among their ranks.

The feasibility of policy options in the Lake Victoria is looked upon in conjunction with the establishment of the regional integration of the East African Community (EAC 2000). The East African Community offers a good prospect for the success of the proposed policies, in that it provides a conducive environment for Kenya, Uganda and Tanzania to work together towards common goals. Some means are required in order to incorporate both Burundi and Rwanda in the management structure of the Lake since, even though they do not share the lake shore, they form a significant part of the Lake's catchment area and are a principal polluter, being the source of the highest sediment load and the original entry point for water hyacinth.

Policy options that address overexploitation of fish are:

- Quota for fishing
- Quota for processing
- Review of the rules and regulations and existing policies
- Civic education and awareness

Policy options that address destructive fishing practices are:

- Strengthening monitoring and enforcement of restrictions; enforcing the rule of law;
- Provision of civic education and awareness; empowering and involving more communities in management;
- Imposing size restrictions on fish processing factories;
- Provision of credit to artisanal fishers.

Policy options that address the issues of pollution are:

- Accreditation of analytical laboratories for standards enforcement;
- Liberalisation of waste disposal activities to involve the private sector and communities;
- Revision of regulations in urban planning that have not taken into account environmental issues, and improvement of monitoring and enforcement;
- Improvement of natural resource management and farming practices through training, governance and agricultural technology;
- Stronger vetting of technology promoted by national and international agencies;
- Strengthening enforcement of regulations for mandatory effluent treatment in municipalities and industries;
- Incorporating all stakeholders in the drafting of regulations and in monitoring and enforcing agreed regulations;
- Integration of institutional framework, regulations and laws at two levels: national and regional;
- Creation of a public complaints institution with powers to investigate and recommend prosecution;
- Enforcing compliance with international conventions e.g. Ramsar, CITES, and the Biological Diversity Convention of Agenda 21;
- Strengthening the capacity of National Environmental Protection Authorities to enable a more effective enactment of legislation by providing trained manpower and sufficient funding.

The successful implementation of these policy options will never be achieved without involving, in a participatory manner, the communities living on the lake shores who depend on fishing as a source of subsistence livelihood and income generation. Capacity building in terms of civic education and leadership and management skills will enhance this empowerment.

Abbreviations and acronyms

BMU	Beach Management Unit
BOD	Biological Oxygen Demand
CCRF	Code of Conduct for Responsible Fisheries
CITES	Convention on International Trade in Endangered Species
CPUE	Catch per Unit Effort
DRC	Democratic Republic of Congo
EAC	East African Community
EARVL	East African Rift Valley Lakes
EIA	Environmental Impact Assessment
ENSO	El-Niño-Southern Oscillation
EU	European Union
GEF	Global Environment Facility
GDP	Gross Domestic Product
GNP	Gross National Product
HACCP	Hazard Analysis Critical Control Point
HDI	Human Development Index
ITCZ	Inter-Tropical Convergence Zone
IUCN	International Union for Conservation of Nature
LMEMP	Lake Malawi Ecosystem Management Project
LVB	Lake Victoria Basin
LVDP	Lake Victoria Development Programme
LVEMP	Lake Victoria Environmental Management Project
LVFO	Lake Victoria Fisheries Organisation
LVFRP	Lake Victoria Fisheries Research Project
LVRLAC	Lake Victoria Regional Local Authorities Cooperation
MCS	Monitoring Control and Surveillance
MSY	Maximum Sustainable Yield
NEMC	National Environmental Management Council
NTU	Nephelometric Turbidity Unit
PA	Protected Area
PPP	Purchasing Power Parity
QC	Quality Control
RRA	Rapid Rural Appraisal
SADC	Southern Africa Development Community
SAP	Strategic Action Programme
SSOP	Sanitation Standard Operating Procedures
SST	Sea-Surface Temperature
Tecconile	Technical Cooperation for the Promotion of the Development and Environmental Protection of the Nile Basin
UNECIA	Universities of Northern England Consortium for International Activities
WHO	World Health Organization

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Regional definition

This section describes the boundaries and the main physical and socio-economic characteristics of the region in order to define the area considered in the regional GIWA assessment and to provide sufficient background information to establish the context within which the assessment was conducted.

The Regional definition of Lake Tanganyika is excerpted with permission from the document "Results and Experiences of the UNDP/GEF Conservation Initiative (RAF/92/G32)" compiled by Kelly West in 2001 (West 2001). The GIWA assessment of Lake Tanganyika was based largely on experience gained from this 5-year UN-sponsored project to study the biodiversity of Lake Tanganyika and the threats to the Lake, and to devise a management plan.

Boundaries of the East African Rift Valley Lakes region

The East African Rift Valley Lakes (EARVL), GIWA region 47, runs from the northern end of Lake Turkana Basin to the southern tip of Lake Malawi/Nyasa Basin and includes all the natural habitat and associated human communities found within the Rift Valley and on the adjacent escarpments (Figure 1). It encompasses parts of the following countries; Ethiopia, Kenya, Sudan, Uganda, Tanzania, Rwanda, Burundi, Democratic Republic of Congo (DR Congo), Zambia, Malawi and Mozambique. The main lakes in the region include Victoria, Tanganyika, Malawi, Turkana, Albert, Edward, George and Kivu. All are tropical and together comprise the African Great Lakes ecoregion. However, each lake lies within its own separate drainage basin, with its own assemblage of endemic organisms, most notably the cichlid fish species-flocks. Each lake differs substantially with respect to limnology, catchment dynamics and human impacts (Hamilton 1982).

Figure 1 Boundaries of the East African Rift Valley Lakes region.

Physical characteristics

The Task team decided that the lakes be tackled separately within the context of their respective drainage basins. For the purpose of GIWA assessment, the following lakes that are characteristic of most of the transboundary water bodies in the region were selected for the exercise: Lake Victoria, Lake Tanganyika, Lake Malawi and Lake Turkana. These four are the largest of the East African Rift Valley lakes and are among the oldest lakes in the world – they are all classed as Ancient Lakes (Brooks 1950). All these lakes are extremely sensitive to climate change. Lake Turkana, for example, is a topographically closed basin (i.e. no outlet) and its level has varied by 20 m within the past century alone (Owen et al. 1982). Over 75% of the water lost from Lake Malawi is by evaporation. If annual rainfall over this lake were to decrease by 30%, the lake level would drop 100 m within 150 years (Owen et al. 1990). There is abundant geophysical and sedimentological evidence for its level having been 100-200 m lower than present several times in the past few thousand years (Scholz & Rosendahl 1988). All the four rift lakes are sensitive in this way as well as in their chemical and biological responses to variation in the hydrological budget.

Lake Turkana

Lake Turkana is located in the Great Rift Valley in the arid northwestern part of Kenya at about 3° N and 36° E (Figure 2). Most of the Lake lies in Kenya, but part of the Omo River (which supplies about 90% of water to the Lake) delta lies in southwestern Ethiopia. Lake Turkana is the largest closed-basin lake in the East African Rift, and loses water mainly by evaporation. It can be considered as the ″arid region end-member“ of the large rift valley lakes and a modern analogue for ancient rift environments in Africa and elsewhere (Halfman et al. 1989). The Lake's catchment area is about 130 860 km^2 while the Lake is 250 km long, has a mean width of 30 km and a surface area of about 6 750 km^2. The average depth is 35 m while the maximum depth is 115 m. The reason for Turkana's world-wide fame as the purported "Cradle of Mankind", are the findings of early hominids, including remains of various *Australopithecus species*, *Homo habilis*, *Homo erectus* and *Homo sapiens* (Finke 2001).

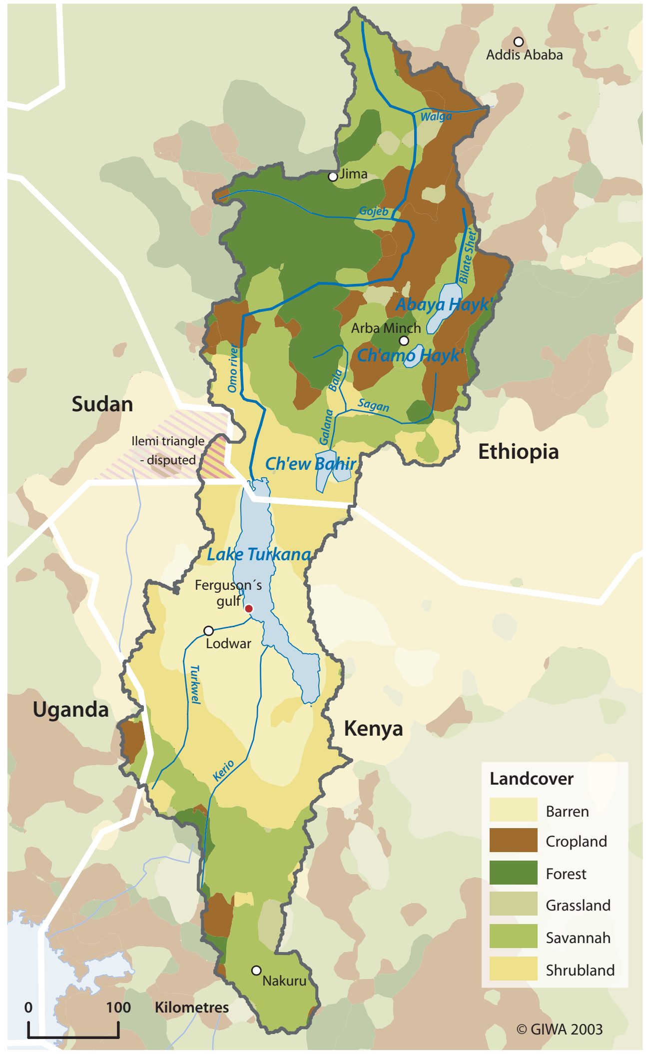

Figure 2 Lake Turkana Basin.
(Source: data from Loveland et al. 2000)

Geology and geomorphology

Lake Turkana lies within a broad depression known as the Turkana depression, between the Kenya and Ethiopia domes in that part of the East African Rift Valley System known as the Gregory Rift. The Gregory Rift, which is topographically well-defined throughout most of Kenya, splays out into a broader, less distinct zone of rifting within the vicinity of the Lake. The Turkana Depression has generally been regarded as a diffuse zone of faulting, linking the rift segments to the north and to the south (Dunkelman et al. 1988). Tertiary volcanic rocks are found in the south and along most of the western side of the Lake, while Quaternary sediments dominate the western and northern side of the Lake. Three volcanic islands are found in the Lake; the North, Central and South islands.

The only perennial river entering the Lake is Omo River, flowing southwards from Ethiopia into a delta at the northern end of the Lake. All the other rivers of the west area with the exception of the Turkwel River are dry for most of the year, flowing for only a few days or even hours after rain (Walsh & Dodson 1969). The Omo River provides about 90% of the water flowing into the Basin (Cerling 1986), draining southward from the Ethiopian plateau where mid-year monsoonal rainfall exceeds 1 500 mm (Halfman & Johnson 1988). The River contributes about 19 billion m^3 of water each year (Beadle 1981).

The western coastal plain extends up to 25 km inland from the lake shore to the Labur-Lothidok ranges, rising gently westwards to over 100 m above the lake level (Walsh & Dodson 1969). The drainage pattern of the western area centres around two major basins: Lake Turkana and Lotagipi swamp. The Turkwel River carries water into the Lake via an extensive delta for several months in a normal year. The River is approximately 300 km long, rising on the slopes of Mount Elgon, where it is known as the Suam (Dodson 1971). The Turkwel River is now being dammed for hydroelectric power generation at Turkwel Gorge, about 150 km west of the Lake.

Most of the lake's southern shoreline is rocky, consisting of layers of lava boulders or minor cliff faces where recent lava flows have extended to the water line. In the southwest corner of the Lake, however, the shoreline opens out to form a gently curving arc with sandy and shingle beaches. The eastern area is generally fairly flat-lying, with ephemeral streams draining into the Lake, but their contribution to the total water and sediment flux input is very small.

The age of Lake Turkana is given a conservative estimate of 4.3 million years (by K-Ar and $^{40}Ar/^{39}Ar$ methods), which is recorded from the lowermost tuff bed within the Koobi Fora Basin (McDougall 1985). Seismic reflection profiles of Lake Turkana, penetrating about 60 m below the lake floor, show that the predominant pattern of sedimentation is one of simple and rapid basin infilling; the profile suggests an abundance of gas (probably methane) in the Holocene sediments, particularly near the major rivers and in the deepest basins where sedimentation rates are fairly high (Johnson et al. 1987).

Climate and vegetation

The mean annual temperature is 30°C, mean annual rainfall is below 255 mm/year (Survey of Kenya 1977), and the evaporation rate is 2 335 mm/year (±0.347 mm) (Ferguson & Harbott 1982). The annual mean maximum temperature range is 30 to 34°C, while the annual mean minimum temperature is 23.7°C (Survey of Kenya 1977). The region is semi-arid. The majority of the yearly rainfall occurs in two seasons, from March to June, with a peak in April, and from October to December, with a lesser peak in November or December. The occurrence of rainfall is, however, erratic and unpredictable.

Grassy plains with yellow spear grass (*Austrostipa flavescens*) and *Commuphera* and *Acacia* sp. characterise the vegetation of the region. Acacia thorn scrub, with larger acacia trees along the river courses, grow around the Lake. The fairly high alkali content of the Lake's waters greatly limits the range of species of vegetation. Galleries of forest occur along the affluent watercourses, being characterised by River acacia (*Acacia elatior*), Soapberry tree (*Balanites aegyptiaca*) and Doum palm (*Hyphaene coriacea*) (Hughes & Hughes 1992). Saltbush (*Salvadora persica*) forms a bushland on Central and South islands (Hughes & Hughes 1992).

Physical and chemical limnology

Lake Turkana receives run-off and sediment from a wide geographical area. The Omo River provides about 90% of the water that flows into the Lake (Cerling 1986). The seasonal Turkwel and Kerio rivers contribute most of the remaining fluvial input. Other streams, direct rainfall and subterranean flow are considered insignificant in the water budget (Yuretich & Cerling 1983). All water input is approximately balanced by evaporation, the surface level lying at approximately 372 m above sea level.

The Lake is moderately saline (2.5‰), alkaline (pH = 9.2), and is well mixed by strong diurnal winds (Yuretich & Cerling 1983). The principal ions are Na^+ (sodium), HCO_3^- (bicarbonate), and Cl^- (chloride), with relatively low concentrations of Ca^{2+} (calcium), Mg^{2+} (magnesium), and $(SO_4)^{2-}$ (sulphate) (Halfman et al. 1989). In the north, salinity is seasonally reduced through mixing with dilute Omo River floodwaters. The evaporation rate has been estimated at 2 335 mm/year. The Lake undergoes far greater changes in salinity than in temperature (Johnson et al. 1990). Its high alkalinity promotes rapid equilibration of CO_2 with the atmosphere (Peng & Broecker 1980). The water has a residence time of about 12.5 years (World Lakes Database 2002). The euphotic zone is about 6 m, and the Lake is always turbid (Kallqvist et al. 1988). Yuretich (1979) observed that sediment plumes up to 100 km long extend southward from the Omo River delta during flood seasons.

The water level of this closed basin lake is determined by the balance between the influx from rivers and groundwater and the evaporation from the lake surface, and has an annual water level fluctuation of about 1.25 m. The lake level is therefore sensitive to climatic variations, and is subject to marked seasonal fluctuations as well as to long-term periodical changes.

The growth of deltas in Lake Turkana is controlled by the erratic supply of sediment, and the short- and long-term fluctuations in lake level are brought about by climatic change and tectonic activity (Frostick & Reid 1986). Although fluvial activity is generally infrequent (only the Omo River is perennial), the sediment load is high, in common with other arid environments (up to 1 600 tonnes/km^2/year), and delta construction is rapid (Frostick & Reid 1986). Shoreline features of the Lake include major spits of the western lake shore; the shores around Longech, Lolibekai and Menar are associated with high energy (Ferguson & Harbott 1982).

Primary spits of the eastern shore such as Mvite and Koobi Fora are subject to relatively little wave action but are maintained by currents running along both the river and lake margins, creating extensive submerged and often steep-sided sand bars (Ferguson & Harbott 1982).

The modern sediments of Lake Turkana are primarily detrital silicates and are dominantly fine grained (Yuretich 1979, Olago & Odada 2000). Carbonate is the next most abundant component to the detrital silicate fraction and has two main components; ostracod carapaces, and micron-sized crystals of carbonate (Yuretich 1979, Halfman 1987). The average sedimentation rate, based on radiocarbon dating by Halfman and Johnson (1988), has been estimated at 2.7 mm/year and constitutes the most reliable rate for Lake Turkana.

Biological limnology

Lake Turkana is famous for its colour. It is sometimes referred to as the Jade Sea, which is largely due to the presence of blue-green algae in the phytoplankton community. Today, however the lake colour, especially in the north, is brown because of sediment (Haack & Messina 2001). The Lake has a little-modified fauna and a low level of endemicity with few cichlid fish (Lowe-McConnell 1995). The principal emergent macrophytes are the grasses *Paspalidium germinatum* and *Sporobolus spicatus* which cover the seasonally exposed shallows and provide important nurseries for fish (Hughes & Hughes 1992). There are extensive *Potamogeton* (pondweed) beds in the shallow bays (Hughes & Hughes 1992).

The dominant phytoplankton are the blue-green algae *Microcystis ceruginosa* and the green algae *Botryococcus braunii*, while in Ferguson's Gulf the blue-green algae *Anabaenopsis arnoldii* is dominant (Kallqvist et al. 1988). The development of phytoplankton is limited by the availability of nitrate and light (Hopson 1982). Light limitation is caused by turbid water and vertical mixing. The zooplankton are dominated by protozoans in terms of numbers, but by crustaceans in terms of biomass (Hughes & Hughes 1992). The zooplankton community consists mainly of Copepods (World Lakes Database 2002). There are five gastropod molluscs and two species of shrimp (Hughes & Hughes 1992).

Lake Turkana, although no longer in contact with the Nile, evidently was so in the recent past and it has a very similar fish fauna to that of Lake Albert (Uganda) (Lowe-McConnell 1995). Of the 48 species of fish that have been identified in the Lake (36 species) and inflowing Omo River (12 species) (Lowe-McConnell 1995), 30 are widespread Sudanian types, 8 have restricted distributions and 10 are endemic (Hughes & Hughes 1992). The 10 endemic species all live in the pelagic zone or deep water (Lowe-McConnell 1995). Common species include: *Alestes baremose*, African tetras (*A. dentex*); Nile perch (*Lates niloticus*); Snooks, endemic (*L. longispinis*); Bagrid catfishes (*Bagrus bayad*); Squeakers or upside-down catfishes (*Synodontis schall*); and Cichlids, such as *Oreochromis niloticus*, *O. galilaeus*; and *Tilapia zillii* (Hughes & Hughes 1992). A few endemic species among the non-cichlids reflect Lake Turkana's geographical isolation for a relatively short time (Table 1) (Lowe-McConnell 1995).

Table 1 Endangered, endemic and rare fish species of Lake Turkana.

Endangered	Endemic	Rare
Bagrus bayad Forsskål (Catfish)	*Lates rudolfianus* Worth. (Nile perch)	*Hydrocynus forskalii* Curier
Alestes baremose Linn. (Tigerfish)	*Haplochromis rudolfianus* Trevaras (Tilapia)	
Alestes dextrex Linn. (Tigerfish)	*Labeo horie* Heckel (Barbels)	
Alestes imberi Linn. (Tigerfish)	*Polypterus bichir* Günther (Bichirs)	
Alestes minutus (Tigerfish)	*P. senegalus* (Bichirs)	
Alestes nurse Rüppel(Tigerfish)		
Citharinus intermedius Warth. (Ray-finned fish)		
Distochordus niloticus Linn.		
Barbus bynni rudolfianus Worthington (Minnows and carps)		
Barbus hindii Günther (Minnows and carps)		
Labeo horie Heckel (Minnows and carps)		

(Source: National Biodiversity Unit 1992)

Wildlife

On the eastern side of the Lake is Sibiloi National Park (a Natural World Heritage Site). Mammals include Burchell's and Grevy's zebras (*Equus burchelli*) and (*E. grevyi*), Grants gazelle (*Gazella granti*), Beisa oryx (Oryx *gazella beisa*), Hartebeest (*Alcelaphus buselaphus*), Topi (*Damaliscus lunatus*), Lesser kudu (*Tragelaphus imberbis*), Lion (*Panthera leo*), and Cheetah (*Acinonyx jubatus*). There are many crocodiles along the lake shore and on Central Island; *Crocodylus niloticus* and *Varanus niloticus* (Hughes & Hughes 1992).

Lake Turkana is an important flyway for north-bound migrants. Over 350 species of aquatic and terrestrial birds have been recorded in the Lake (Hughes & Hughes 1992). Common resident birds in Lake Turkana include pelicans, flamingos and herons (Gichuki & Gichuki 1992). Turkana is an important resting site for large numbers of visiting water-edge birds such as Kentish plover (*Charadrius alexandrinus*), Broad-billed sandpiper (*Limicola falcinellus*), Long-tailed skua (*Stercorarius longicaudus*) and Pomerine skua (*S. pomarinus*) (Gichuki & Gichuki 1992). Central Island has a breeding population of African skimmer (*Rhyncops flavirostris*) which nests in banks. It is also an important staging post for migrating birds including warblers, wagtails and little stints (Cunningham Van-Someren 1981).

Figure 3 Protected areas in the Lake Turkana Basin.

Lake Victoria

Lake Victoria (1° S and 32° E) is, by area, the second largest lake in the world and the largest in Africa, being almost twice the size of Lake Tanganyika (32 900 km^2) and Lake Malawi (28 760 km^2) (Figure 4). It is perched high (1 134 m above sea level) on the African craton between the western and eastern rift valleys (Johnson et al. 2000). This equatorial lake has a surface area of 68 800 km^2 and an adjoining catchment area of 184 000 km^2. Lake Victoria is, however, a relatively shallow lake, with a maximum depth of 80-90 m compared to Tanganyika and Malawi whose maximum depths are 1 470 m (Capart 1949, Tiercelin & Mondeguer 1991) and 700 m (Johnson & Ng'ang'a 1990), respectively. Kenya, Uganda and Tanzania border the Lake and share 6%, 43% and 51%, respectively, of the lake surface.

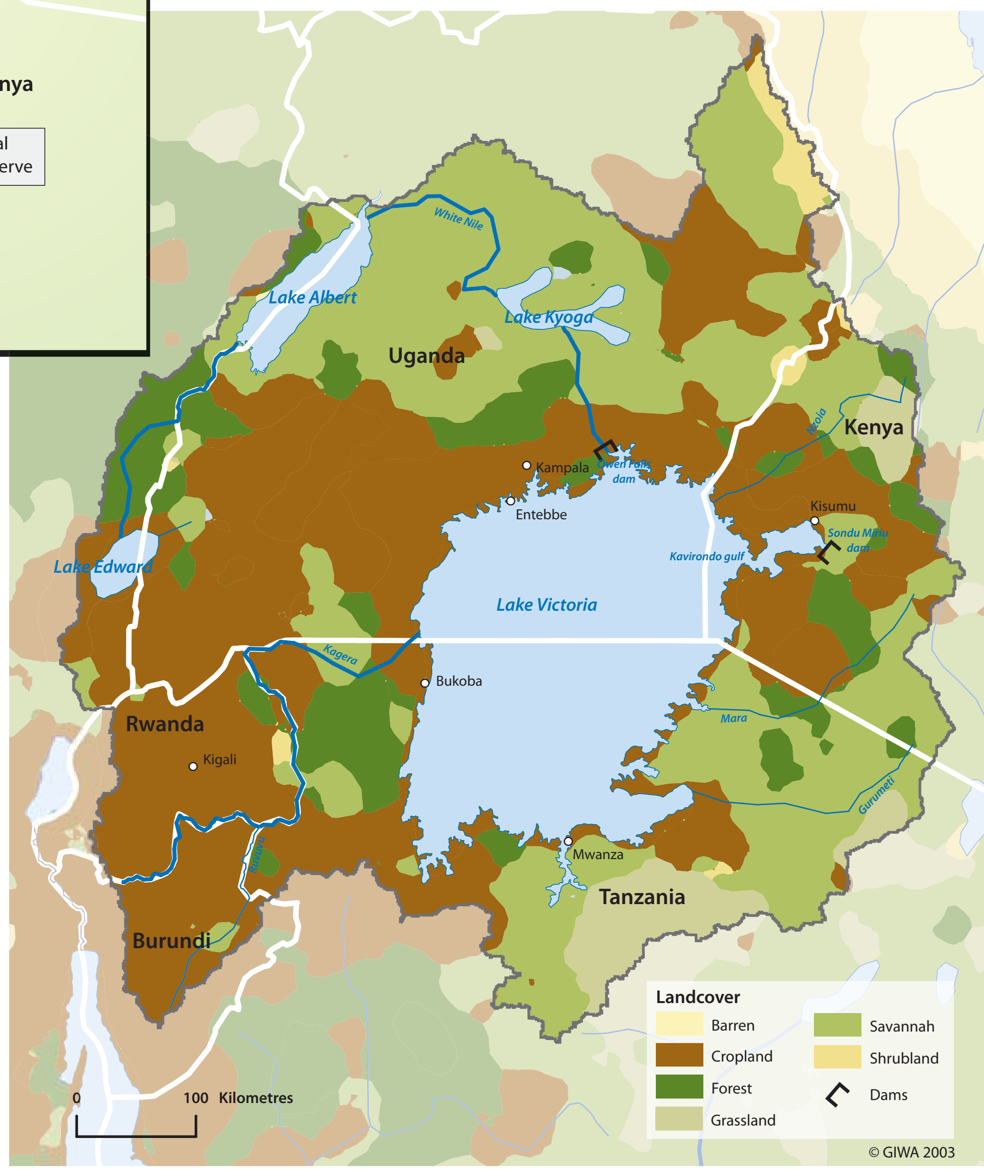

Figure 4 Lake Victoria Basin.
(Source: data from Loveland 2000)

Protected areas and cultural heritage sites

Omo National Park in southwest Ethiopia is a protected area (Figure 3). Koobi Fora, to the north of Alia Bay on the eastern shore of the Lake, is an important archaeological site where extensive palaeontological finds have been made. Human fossils include the remains of *Australopithecus rodustus*, *Homo habilis*, *Homo erectus* and *Homo sapiens*. Central Island is a part of the protected Sibiloi National Park on the eastern shore of the Lake. The southeastern section of the Lake is also protected in the Mount Kulal Biosphere Reserve, approved in 1978, and includes the South Island National Park of 3 880 ha. (Hughes & Hughes 1992). Part of the gorge section of the Turkwel River is protected in the Nasolot National Reserve, and a 25 km section of the left bank of the Kerio River is situated in the South Turkana National Reserve, 100 km north of Kitale township (Hughes & Hughes 1992).

Climate

The interannual variability of rainfall is remarkably coherent throughout most of eastern Africa despite quite diverse climatic mean conditions. The largest portion of this variability is accounted for by the "short rains" season of October–December. Rainfall variability in the region shows strong teleconnections to the rest of Africa and to the global tropics. Rainfall in eastern Africa is strongly quasi-periodic, with a dominant time-scale of variability of 5 to 6 years (Nicholson 1996). This is also a dominant time-scale for the El Niño-Southern Oscillation (ENSO) phenomenon and for Sea Surface Temperatures (SSTs) fluctuations in the Equatorial Indian and Atlantic oceans. Rainfall variability is closely linked to both ENSO and SSTs in the Indian and Atlantic Oceans, and it tends to be enhanced in East Africa during ENSO years (Ropelewski & Halpert 1987, Ogallo 1989).

The water balance is dominated by rainfall on the Lake, evaporation, and the Nile River outflow, with river inflow making minor contributions (Spigel & Coulter 1996). More than 80% of the water is derived directly from rain onto the lake surface, while evaporation from the Lake accounts for a significant amount of its annual water loss (Johnson et al. 2000). The Kagera River contributes about 7% of the total inflow.

Physical limnology

Hydrological and hydrodynamic data for Lake Victoria (and other East African Lakes) are scarce, fragmentary and often not easily accessible. A resurgence of work is now underway over a wide range of disciplines since the Lake has been under severe ecological pressure for the last four decades. The Lake has an intricate and highly indented shoreline of more than 3 500 km. It has numerous islands, shallow bays and connecting channels, and extensive areas of wetland. These morphological features are significant for exchange of water between the littoral and pelagic regions of the Lake (Spigel & Coulter 1996). Lake Victoria has a flushing time of 140 years and a residence time of 23 years (Bootsma & Hecky 1993).

Surface water temperature is between 24 and 28°C (Ochumba 1996), and evaporative cooling during the dry season is important in the heat balance and mixing regime (Talling 1966). Temperature profiles measured in Lake Victoria show a lack of well-defined mixed layers and seasonal thermoclines; the temperature gradients tend to be more diffuse, and horizontal variability greater, than in Lake Tanganyika and Lake Malawi (Spigel & Coulter 1996). Measurements carried out in the Kenya sector of the Lake show that anoxic water occurs below a depth of 35 m, with the oxycline at 10 to 50 m (20 to 30 m for most of the year) (Ochumba 1996). Sporadic upsurges of the oxycline to depths as shallow as 10 m in the open lake have been associated with fish kills (Ochumba 1996).

Biological limnology

Much of the lake margin is swampy; islands of *Cyperus papyrus*, with its typical associates, detach from the fringing swamps (Hughes & Hughes 1992). The current phytoplankton community is dominated by the cyanobacteria *Cylindrospermopsis* and *Planktolyngbya*, and the diatom *Nitzchia* (Komarek & Kling 1991, Hecky 1993). Zooplankton consist of abundant copepods and cladocerans (Branstrator et al. 1996). As recently as the 1960s, Lake Victoria supported an endemic cichlid fish species flock of more than 500 species (Seehausen 1996), but these have progressively disappeared from the catches to become poorly represented today.

Lake Tanganyika

At 673 km along its major axis, Lake Tanganyika is the longest lake in the world and ranges from 12 to 90 km in width with a shoreline perimeter of 1 838 km (Figure 5, Table 2, Hanek et al. 1993). The countries of Burundi, Democratic Republic of Congo, Tanzania and Zambia share Lake Tanganyika. Of the Lake's shoreline perimeter, 9% is in Burundi, 43% is in DR Congo, 36% is in Tanzania, and 12% is in Zambia (Hanek et al. 1993).

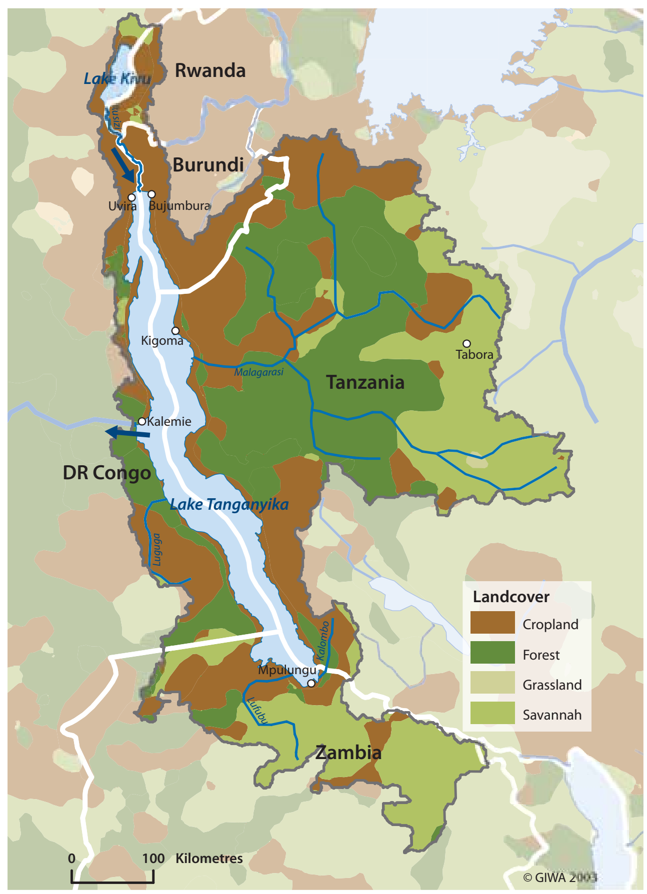

Figure 5 Lake Tanganyika Basin.
(Source: data from Loveland 2000)

Table 2 Physiographic statistics for Lake Tanganyika.

Latitude	03°20' - 08°48' S
Longitude	29°03' - 31°12' E
Age (years)	about 12 million
Altitude (m)	773 above sea level
Length (km)	673
Width (km)	12-90, average about 50
Surface area (km^2)	32 600
Volume (km^3)	18 880
Shoreline perimeter (km)	1 838
Maximum depth (m)	1 320 (northern basin), 1 470 (southern basin)
Mean depth (m)	570
Catchment (km^2)	220 000
Stratification	permanent, meromictic
Oxygenated zone (m)	70 (north), 200 (south)
Temperature (°C)	23-27
pH	8.6-9.2
Salinity (‰)	~0.46

(Source: modified from Coulter 1994)

A catchment area of 220 000 km^2 feeds Lake Tanganyika (Table 2). The Lake's average depth is 570 m, with a maximum depth of 1 320 m in the northern basin and 1 470 m in the southern basin, making it the world's second deepest lake, after Lake Baikal. Lake Tanganyika is fed by numerous small rivers and two major afffluent rivers; the Rusizi River draining Lake Kivu to the north, and the Malagarasi River draining western Tanzania south of the Lake Victoria Basin. A single outlet, the Lukuga River, drains Lake Tanganyika, though the flow of this river has changed direction in historical times (Beadle 1981). This river is a tributary of the Congo River, which belongs to GIWA region 42, Guinea Current.

Geology and geomorphology

Based on sediment accumulation rates in the Basin, geologists have estimated that Lake Tanganyika has existed for approximately 12 million years (Scholz & Rosendahl 1988, Cohen et al. 1993a). More recent studies indicate that between 4.9 million years and 3.6 million years ago, the proto-Lake Tanganyika corresponded to an approximately 400 km long lake resembling the present-day lake between the latitudes 3° and 7° S (Tiercelin & Lezzar 2002). At about 2 million years ago, a major episode of rifting associated with intense volcanism in the Kivu Province resulted in the final development of the Kivu and North Tanganyika lake basins (Ebinger et al. 1989, Lezzar et al. 1996) while the southward rift propagation along the Lake Tanganyika Rift resulted in the final morphology of the Mpulungu sub-basins at the southern end of Lake Tanganyika from about 2 million years ago up to the present-day (Tiercelin & Lezzar 2002). Lake Tanganyika is the oldest of the African Lakes, and after Lake Baikal in Russia, it is the second oldest lake in the world. Modern annual lake level variation is about 1 m (Edmond et al. 1993). Geologic processes have largely determined the shoreline substrates around the Lake. Of the 1 838 km shoreline perimeter, 43% is rocky substrate, 21% is mixed rock and sand substrate, 31% is sand substrate and 10% is marshy substrate (Coenen et al. 1993).

Climate

Lake Tanganyika has two wet seasons in a year, March/April and December, with mean annual rainfall ranging from 1 200 mm in the northern part to 1 600 mm in the southern part (Nicholson 1996). The interannual variability of rainfall is remarkably coherent throughout most of eastern Africa and is similar to that described for Lake Victoria (see above).

Physical limnology

Most of Lake Tanganyika's water loss is through evaporation. Calculations from Lake Tanganyika's water budget suggest a water residence time of 440 years and a flushing time of 7 000 years (Coulter 1991). Lake Tanganyika, with an approximate surface area of 32 600 km^2 and volume of 18 880 km^3, contains 17% of the Earth's free freshwater (statistics from Hutchinson 1975, Edmond et al. 1993, Coulter 1994).

Lake Tanganyika can be generally characterised by the limnological parameters in Table 3 (Bailey-Watts 2000, Bailey-Watts et al. 2000). Although permanently oligotrophic in appearance (Wetzel 1983), periodic phytoplankton blooms occur (Dubois 1958, Hecky & Kling 1981, Coulter 1991, Salonen et al. 1999). It is stratified into an oxygenated upper layer, penetrating to about 70 m depth at the north end and 200 m at the south, and an anoxic lower layer, which constitutes most of the Lake's water volume (Beauchamp 1939, Hutchinson 1975, Spigel & Coulter, 1996). The oxygenated and anoxic layers generally do not mix, though wind-induced upwelling results in some mixing at the Lake's southern end (Spigel & Coulter, 1996). The temperature and pH of surface waters vary between 23-28°C and 8.6-9.2, respectively (Coulter 1994).

Table 3 Basic limnological parameters for Lake Tanganyika.

Parameter	Lakewide	Burundi	Tanzania	Zambia
Transparency (m)	7-16	ND	ND	ND
Conductivity (µS/cm)	700	ND	ND	ND
Chlorophyll a concentration (µg/l)	ND	ND	1.5-6	4-14
Ammonium-nitrogen (mg/l)	ND	0.5-1.0	ND	ND
Nitrate-nitrogen (µg/l)	ND	500-1 000	< 100	75-130
Phosphate-phosphorous (µg/l)	ND	500	7-8	12
Total phosphorous (µg/l)	ND	ND	30	12
Sulfate (mg/l)	ND	3-4	ND	ND

Note: ND = No Data. (Source: data from Bailey-Watts 2000)

Biological limnology

The Lake's morphology, a steeply sided rift cradling a deep anoxic mass capped by a thin oxygenated layer, has profound implications for the distribution of organisms. Most of Lake Tanganyika's water mass is uninhabited. Organisms are limited to the Lake's upper oxygenated zone. Because of the steeply sloping sides of the Lake's basin, benthic organisms (which rely on the substrate for at least some aspect of their life cycle) are limited to a thin habitable ring fringing the Lake's perimeter which extends sometimes only tens of metres offshore.

Like lakes Victoria and Malawi, Lake Tanganyika is famous for its endemic species flocks of cichlid fishes (Figure 6). It hosts a large flock, estimated to include more than 700 cichlid fish species (Snoeks 2000). More than 250 cichlid species are parsed between several sub-flocks (Snoeks et al. 1994). However, unlike the other African Great Lakes, Lake Tanganyika also hosts species flocks of non-cichlid fish and invertebrate organisms, including gastropods, bivalves, ostracods, decapods, copepods, leeches and sponges. Table 4 (modified from Coulter 1994) lists the numbers of species in Lake Tanganyika by taxonomic grouping. The invertebrate species numbers are probably significantly underestimated, as these groups in general have received relatively little attention from taxonomists and in addition, much of Lake Tanganyika's coast has not been adequately explored. Nonetheless, it is clear that this level of invertebrate diversity exceptional. Lake Tanganyika, with more than 2 000 species of plants and animals, is among the richest freshwater ecosystems in the world.

More than 600 of these species are endemic to the Tanganyika Basin, i.e. they are not found anywhere else. This includes a remarkable 98% of the cichlid fish species, 59% of the non-cichlid fish species, 75% of the gastropod species, 60% of the bivalve species, 71% of the ostracod species, 93% of the decapod species, 48% of the copepod species, 60% of the leech species, 78% of the sponge species, and others, more than 600 species in all, are unique to the Tanganyika Basin (Coulter 1994). It

Figure 6 Cichlids.
(Photo: Corbis)

Table 4 Inventory of species in Lake Tanganyika.

Taxon	Species	Endemic (%)
Algae	759	ND
Aquatic plants	81	ND
Protozoans	71	ND
Cnidarians	2	ND
Sponges	9	78
Bryozoans	6	33
Flatworms	11	64
Roundworms	20	35
Segmented worms	28	61
Horsehair worms	9	ND
Spiny head worms	1	ND
Pentastomids (small group of parasites)	1	ND
Rotifers	70	7
Snails	91	75
Clams	15	60
Arachnids (spiders, scorpions, mites, ticks)	46	37
Crustaceans	219	58
Insects	155	12
Fish (family Cichlidae)	250	98
Fish (non-cichlids)	75	59
Amphibians	34	ND
Reptiles	29	7
Birds	171	ND
Mammals	3	ND
Total	2 156	

Note: ND = No Data. (Source: modified from Coulter 1994)

is thought that the proto Lake Tanganyika was colonised by organisms from the ancient Congo River system (which pre-dates the Lake), and these pioneer species evolved and radiated within the Lake Basin, creating the great diversity (Coulter 1994). In many cases these taxa also represent endemic genera and sometimes endemic families. With its great number of species, including endemic species, genera and families, it is clear that Lake Tanganyika makes an important contribution to global biodiversity. Lake Tanganyika is an extraordinary biological system and it provides a natural laboratory for investigating a myriad of evolutionary and ecological questions (e.g. Michel et al. 1992).

Lake Malawi

Lake Malawi is known by a different name in each of its three riparian countries. In Malawi, it is called Lake Malawi, in Mozambique, it is called Lake Niassa, and in Tanzania, Lake Nyasa. Lake Malawi is long and narrow and the southernmost of the Western Rift Valley Lakes (Figure 7). The Lake merits the adjective "great" by almost any measure, e.g. area, depth, age, diversity, but most assuredly it is a great resource for its riparian peoples. Lake Malawi is the fourth deepest inland water body in the world, with its greatest depths (700 m) extending below sea level. With a surface area of 28 800 km^2, it is the ninth largest by area and the fourth largest body of freshwater on the globe. The Lake is the third largest in Africa with respect to surface area after Lake Victoria and Lake

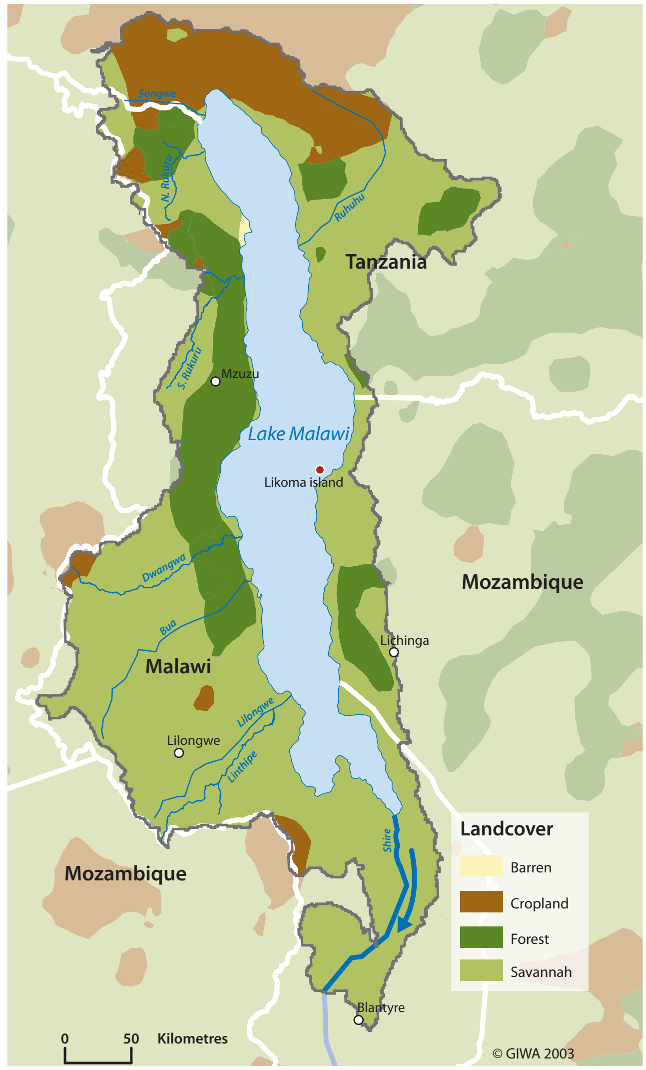

Figure 7 Lake Malawi Basin.
(Source: data from Loveland 2000)

Tanganyika, and the second most voluminous after Lake Tanganyika. The total catchment area is small for a lake of this magnitude: 126 500 km^2 of which 97 750 km^2 is land catchment (Drayton 1984).

A narrow strip along the eastern shore, comprising 7% of the total land catchment, is shared between Mozambique and Tanzania (Eccles 1984). A further 19% consisting of the Ruhuhu Basin (11%), the northern lakeshore and highlands (6%) and part of Songwe Basin (2%) lie in Tanzania. The main part of the catchment, 51%, lies entirely within Malawi (Eccles 1984). Most of the catchment lies in areas where the natural vegetation are *Brachystegia-Julbernardia* woodland, although considerable areas of the drier southern lakeshore littoral were covered by forest and dominated by Acacia species, dependent on groundwater from the Lake or from the escarpments (Eccles 1984).

Geology and geomorphology

The Lake Basin is situated at the southern end of the western arm of the East African Great Rift Valley. The geology of the catchment is relatively simple, with most of the Basin consisting of ancient metamorphic rocks and granites of the basement complex with scattered coverings of Cretaceous sediments in the south, more recent Cenozoic lake sediments along parts of the western and southern lakeshores and, in the north, volcanics of the Rungwe volcanic field in Tanzania. The process of rifting was accompanied by regional uplift which reinforces the dramatic topography created by graben formation. The age of the Lake has been estimated to be about 2 million years (e.g. Fryer & Iles 1972, Crossley 1979, Owen et al. 1990) This is, however, an estimate of the time when the Lake assumed roughly its present form and in which water was continuously present (Patterson & Kachinjika 1995). More recent studies indicate that at about 8.6 million years ago, faulting associated with initial volcanic activity in the proto-Rungwe volcanic province resulted in a broad asymmetric lake basin prefiguring the northern part of Lake Malawi (Ebinger et al. 1989). A major expansion of lacustrine conditions in the Lake Malawi basin about 3.6 million years ago is recorded from the fossiliferous Chiwondo Beds as a consequence of a wetter climate (Bromage 1995) in Central and Eastern Africa. Basin subsidence and rift tectonics continued up to 450 000 years ago (Tiercelin & Lezzar 2002) (see Figure 8). The present day lake is flanked by mountain ranges which rise over 2000 m above the Lake's surface and in many places, especially in its northern half, fall as precipitous escarpments to the shore and continue underwater with undiminished gradient to great depths (Beadle 1981). This morphological feature has developed from the pattern of rift faulting, where the lake depression consists of series of grabens and half grabens (Johnson & Ng'ang'a 1990).

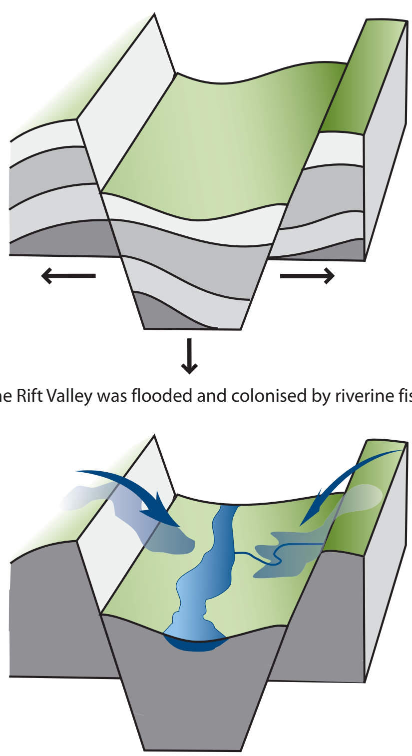

Figure 8 Formation of the African Rift Valley Lakes.
(Source: redrawn from Ribbink 2001)

Ribbink et al. (1983) note that relative to the sculptured coastline of Lake Victoria, Lake Malawi has a smooth coast with few major indentations or notable bays. About 70% of the coastline consists of gently sloping sandy beaches, vegetated areas and swamps. Steep rocky shores

Table 5 The islands and reefs of Lake Malawi.

Island	Comment
Bandakusha	Off Bandwe Point. Also called Mphandikusha.
Boadzulu	
Chemwezi	
Chinduga Rocks	Between the Maleri Islands and Chipoka harbour
Chinyamkwazi	
Chinyamwezi	
Chirwa	South of Chilumba
Chisumulu	
Machili	
Membe	
Chitande	Off Chilumba
Crocodile Rocks	
Domwe	
Eccles Reef	
Harbour	Southern entrance of Monkey Bay
Kanchedza	South of Monkey Bay
Kande	
Katale	Near Chilumba
Likoma	
Maingano	
Masimbwe	
Mbamba	
Mbuzi	
Lundo	Northeast of Mbamba Bay
Maleri	
Nakantenga	
Nankoma	
Mara Rocks	Off Usisya
Mara/Mala Rocks	Off Mara Point 4 nautical miles south of Cobue
Mbamba	Off Mbamba Bay Tanzania
Mbenji	
Fuawe	
Mbowa	Off Usisya
Mehlsaeka Rocks	Between Mbamba Bay and Liuli
Mpandi	Southern eastern Arm
Mphandi	South of Usisya
Mumbo	
Namalenji	
Ngkuyo	Southeast of Mbamba Bay
Ngkuyo Reef	Southeast of Mbamba Bay
Otter	Off otter point, Lake Malawi National Park
Papia	Luili
Tchulutche Reef	Off Metangula
Thumbi East	
Thumbi West	
West Reef	
Zimbabwe	

(Source: GIWA Task team)

compose the remaining 30%. The topography of the lake bottom is poorly known. However, trawling records and data from bottom profiles collected by research vessels indicate that, in the oxygenated regions at least, most of the bottom is sandy or of mud, sometimes being more of an organic ooze in nature (Ribbink et al. 1983). There are numerous islands, islets and rocky reefs/outcrops in the Lake. Table 5 present 47 of the major islands and reefs. A feature of all islands is that the dominant habitat is rocky, with many of the smaller islands and reefs being exclusively of rock (Ribbink et al. 1983, Konings 1995). The exceptions are the larger islands, Likoma and Chizumulu, which do support beaches. The largest island is Likoma, which has several beautiful beaches in addition to its rocky shores.

Climate

The Lake Basin has a tropical continental climate with maritime influences from the Mozambique Channel to the east. Regional climate ranges from tropical, warm and semi-arid to sub-tropical and humid and is strongly influenced by altitude and the large surface area and volume of water of the Lake. Although the Lake has a tropical setting it is sufficiently far south to experience marked seasonal variations (Eccles 1974, 1984). The Basin experiences three seasons. A "cool" dry period from May to August when air temperature at the lakeshore may drop to 15°C, though the daily average is 20–22°C. This period is characterised by strong southeasterly winds that are locally referred to as the Mwera. From September to November it is very hot and dry with a daily average air temperature around 28°C, but exceeding 40°C from time to time. From late November to April is the rainy season, which is usually of shorter duration in the southern than in northern part of the Lake Basin. The annual amounts of rainfall average less than 800 mm in the Rift Valley area, 800-1 000 mm in the Medium-Altitude Plateaux, and from 1 000-1 500 mm in the High-Altitude Plateaux. The prevailing winds during the wet season are northerly and average daily air temperatures are 25°C. The lake level rises during the wet season, from rain that falls both on the Lake and in the catchment, giving annual fluctuations of level between 0.4 m and 1.8 m. Most of the region receives adequate rainfall for rain-fed agriculture, although there is evidence that droughts have become more common in the recent years (e.g. Clay et al. 2003). In the high altitudes of the mountains that surround the Lake, air temperatures are considerably lower, and approach zero at night in some particularly high elevations of the Nyika Plateau and Livingstone Mountains.

Physical limnology

The principal characteristics of the contemporary Lake are summarised in Table 6. By virtue of its tropical setting, the Lake is permanently stratified thermally (Eccles 1974), though water temperatures and lake stratification follow seasonal patterns. Surface water temperatures of the open lake range from 23°C in the cool windy season to 28°C in the warm season (Eccles 1974). In more sheltered areas the lake surface temperature can be close to 30°C. Below 250 m the temperature is constantly between 22.5°C and 22.75°C (Gonfiantini et al. 1979), but above that depth there is a seasonal cycle of stratification (Figure 9a). From September to December there is a warming of the surface waters and stratification strengthens. By May the upper 60-90m is homothermal at about 27°C (Eccles 1974) (Figure 9a). The beginning of the cool, windy season heralds a weakening of the thermocline,

Table 6 Physical and physico-chemical characteristics of Lake Malawi.

Physical & physico-chemical characteristics	
Area (km^2)	28 800
Max. depth (m)	706
Mean depth (m)	290-426
Depth of oxygenated water (m)	170-210
Altitude (m)	471
Proportion below sea level (m)	230
Shoreline length (km)	1 500
Max lake length (km)	569
Max lake width (km)	87
Mean width (km)	50-60
Secci disc transparency (m)	12-20
pH surface	7.9-9.1
pH 300 m	7.8
Conductivity surface (µS/cm)	215-225
Conductivity 300m (µS/cm)	200-230
Primary productivity (g/m/year)	252
Total catchment (km$^{2)}$	126 500
Land catchment (km^2)	97 750
Hypolimnion (m)	Below 230
Metalimnion (m)	125-230
Epilimnion (m)	0-125
Volume of hypolimnion (km^3)	Ca 2 800
Volume of metalimnion (km^3)	Ca 2 600
Volume of epilimnion (km^3)	Ca 3 000
Volume (km^3)	Ca 18 400
Major inflowing rivers	9
Outflowing rivers	1
Inflow (km^3/year)	29
Precipitation over lake (km^3/year)	41
Inflow: Malawi (%)	43
Inflow: Mozambique (%)	4
Inflow: Tanzania (%)	53
Outflow (km^3/year)	12 ca (20%)
Evaporation (km^3/year)	54 ca (80%)
Annual fluctuation in level (m)	0.4-1.8
Proportion of world's total available surface freshwater (%)	7
Flushing time (year)	750
Residence time (year)	140
Age (year)	Ca 2 million
Number of lake basins	1
Wet season: southern part	November to March
Wet season: northern part	December to May
South easterly winds (Mwera)	May to September
Northerly winds (Mpoto)	November to March
Fish landings (tonnes/year)	60 000
Temperature hypolimnion (°C)	22.1-22.75
Temperature metalimnion (°C)	22.5-23.5
Temperature epilimnion (°C)	23.0-29.5

Note: More than one figure indicates either the extremes of natural range, as in temperature, or extremes in estimates by different sources of information.

(Source: Beadle 1981, Gonfiantini et al. 1979, Drayton 1984, Eccles 1984, Johnson & Ng'ang'a 1990, Crul 1997, Craig 1992, Patterson & Kachinjika 1995, Government of Malawi 1998).

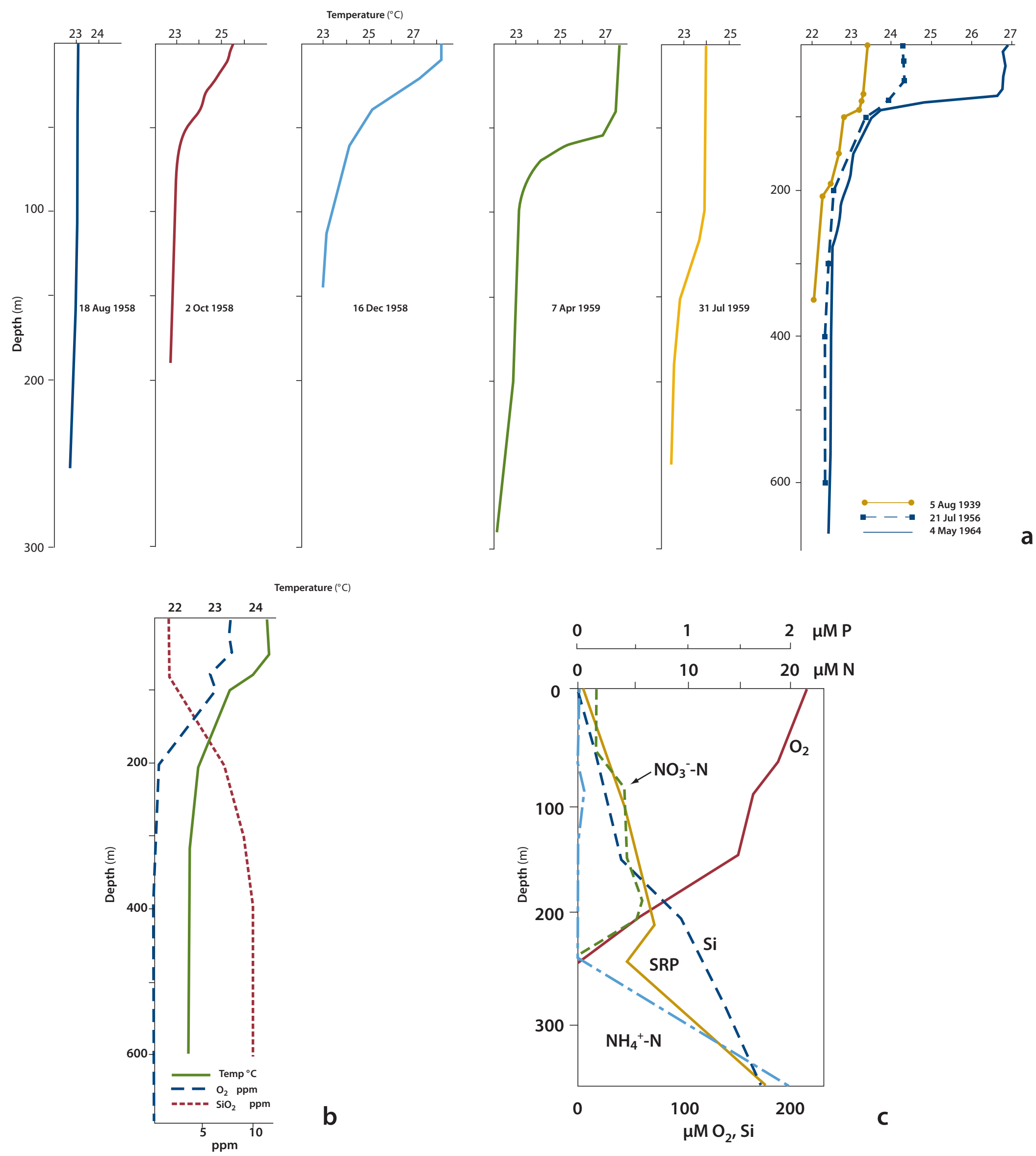

Figure 9 Temperature, oxygen and dissolved nutrient concentrations in Lake Malawi.

(a) Temperature and depth profiles showing seasonal development of stratification at a standard station off Nkhata Bay. The profile for 18 August 1958 shows the closest recorded approach to a homothermal condition (from Eccles 1974 after Iles 1960). The illustration on the extreme right shows the temperature depth profile at the deepest point in the Lake. It also indicates a slight warming of the hypolimnion between 1939 and 1964 (from Eccles 1974 after Beauchamp 1953).

(b) Profiles of temperature, oxygen and silica at the deepest point of the Lake showing complete deoxygenation at approximately 230 m (from Eccles 1974 after Jackson et al. 1963).

(c) Nutrient and oxygen profiles of the Lake showing deoxygenation with increasing depth and an accumulation of nutrients in deep water (After Bootsma & Hecky 1993).

(Source: redrawn from Ribbink 2001)

so that by July it is poorly defined and there is a gradual temperature gradient of 23°C at the surface to 22.5°C at 250 m. In addition to the primary thermocline there are shallow diurnal thermoclines that form on warm calm days. Furthermore, internal waves exist, which may have an amplitude of 50 m and a periodicity of 16 to 30 days (Jackson et al. 1963, Eccles 1974). There is some evidence of warming of the Lake over time (Figure 9a, extreme right).

Because of the Lake's great depth, wind energy applied to its surface is unable to mix the water column beyond 200 m at any time during the annual meteorological cycle; full atmospheric exchange is restricted to the surface mixed layer which can be as little as 40 m. The surface waters, therefore, are well oxygenated, but the oxygen content decreases with depth until the waters become anoxic between 170 and 210 m depth (Figures 9b-c). All waters deeper than this are devoid of aerobic life. Thus, in addition to being thermally stratified, the Lake also shows marked oxygen and nutrient gradients (Figures 9b-c). The deep-water anoxia is created by the decomposition of the rain of organic sediments produced by algal photosynthesis in the well-illuminated, euphotic zone of the surface mixed layer. This constant rain of organic matter produced in the Lake, in addition to the mineral and terrestrial material brought in from the atmosphere and via rivers, transports nutrients into the deep water. Because of the lack of annual turnover of the Lake's volume, as occurs in temperate great lakes, nutrients accumulate to high concentrations in the deep water (Figures 9b-c). The upper limits on the deep-water nutrient concentrations are determined by the rate of downward transport by sedimentation, regeneration of dissolved nutrients from the sedimentary material and the slow return of nutrients through vertical exchange of the deep water with the upper 200 m. This vertical exchange of water is slow, with the present-day deep water having formed more than 50 years ago on average. The physical mechanisms that control this deep-water exchange are still poorly understood but because of the huge mass of nutrient rich water at depth, any acceleration or slowing of this exchange will have significant effects on the Lake's biological productivity.

Currents are common in the Lake and can affect nutrient cycling, plume dispersal, fish feeding (Fryer & Iles 1972), fishing, boat activity and swimmers. However, most reports regarding surface currents are anecdotal with little indication of the existence, force, direction, timing, generation, speed and volume of water involved in currents. Eccles (1974) reports currents of 0.5 km/hour, and Hamblin et al. (1999) have recorded surface currents of a little over 0.83 km/hour but there are suspicions that currents of considerably greater magnitude occur from time to time. Currents of considerable velocity are recorded on the navigational charts for the Lake, particularly between Likoma and Chisumulu (2 to 3 knots, i.e. nearly 6 km/hour). Indications from the movement of plumes and orientation of sand spits on the shoreline suggest that there is a clockwise circular surface current within the Lake. An appreciation of the currents of the Lake may be fundamental to an improved understanding of some of the major processes.

The available evidence suggests that natural water circulation of the Lake is controlled by winds and radiant energy exchange as well as inputs to the Lake from rivers. The lengthwise orientation of the Lake coincides with the southeast winds (Mwera), which dominate the atmospheric flows of southern Africa. The long, narrow structure constrains horizontal circulation. The channelling of the southeasterly winds, especially in July through August, creates a persistent upwelling system: the winds push surface waters north, to be replaced with deeper, cooler waters in the south; nutrients can be cycled from the nutrient sink in the deep anoxic water by these upwellings (Figure 10), and perhaps by the internal waves (Eccles 1974). Return currents from the north occur primarily at depth and cause disturbance and further mixing across the interface of warm surface waters with deeper, cooler, nutrient rich water (Figure 10). Although this upwelling system is unable to overcome the Lake's meromixis (permanent stratification) it does ensure a steady renewal of nutrients to the upper mixed layer with maximum nutrient loading in June through August. This upwelling system is the basis of the productive fisheries in the southern arms of the Lake.

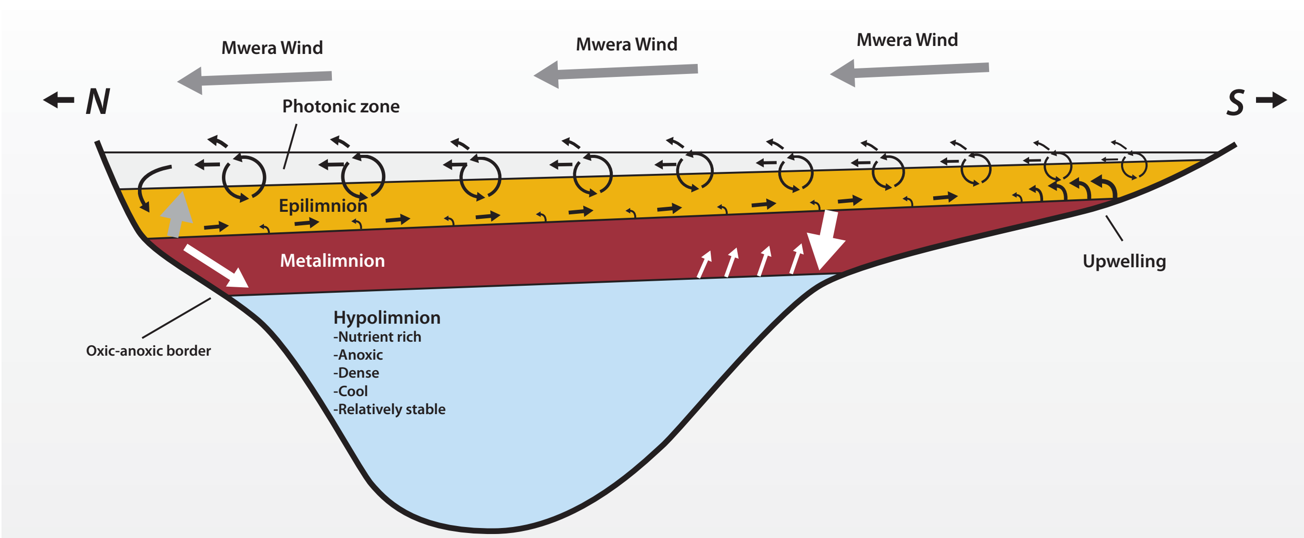

Figure 10 Surface winds, water movement and upwelling in Lake Malawi.

The southeasterly wind (Mwera) blows up the length of the Lake causing mixing, especially in the photic layer. It pushes the warmer waters northwards, tilting the stratification in the southerly portion and upwelling occurs, carrying nutrient rich waters to the fishing grounds. When the wind stops blowing, as it does periodically through the Mwera season, then the Lake tends to bounce back causing seiches and internal waves. These in turn facilitate some mixing of deeper waters and a retrieval of a small part of the nutrient rich deep water and internal waves. These in turn facilitate some mixing of deeper waters and a retrieval of a small part of the nutrient rich deep water.

(Source: redrawn from Ribbink 2001)

The river inflows to the Lake are mostly rather short from the escarpments and nearby mountains, and their volume depends directly on the rainfall in the catchment of each stream or river. The hydrology is delicately balanced. The level of the Lake and the volume of the outflow react rapidly to changes in local rainfall between wet and dry seasons as well as to longer term fluctuations (Spigel & Coulter 1996). These changes may transform certain inshore habitats. Except where the escarpments drop directly into the Lake, there are coastal plains of varying width, which are alternately flooded or exposed. The water level changes can have marked impacts on fish catches because the floodplains act as very productive nursery areas. The outlet via the Shire River to the Zambezi is intermittent, with seasonally dependent flow rates. The rise and fall of the Lake is seasonal but also exhibits longer-term trends (Eccles 1974, Beadle 1981, Bootsma & Hecky 1999). For example, from 1896 there was a progressive fall to a minimum in 1915, at which time the outflow ceased. From then on the level rose steadily to a maximum in 1935 when, in the wet season, it was about 6 m above the maximum of 1915. At this point the outflow was resumed once the sand bar that had been built up during the low period was breached. More recently, in 1997, the level dropped so low that the hydroelectric plant on the Shire River was threatened by the possibility of not having sufficient water to drive it. As Malawi is heavily dependent on this electricity source, great concern was engendered.

Hydrology and biology

Lake Malawi has more species of fish than any other lake in the world. The Lake contains a large fish fauna comprising some 800 species from 14 families; 99.9% of the cichlids are endemic (Ribbink 2001). The cichlid fish communities of the inshore regions are the richest, most diverse, most stenotopic, and hence the most vulnerable to fishing pressure (Ribbink 2001). Many of these fishes are colourful and highly sought after by the aquarium trade. The inshore distribution of these fishes and their inquisitive behaviour make them attractive to view and adds immeasurably to the tourism potential of the Lake. The existence of this biodiversity has attracted international interest and together with other resource use of this international lake has led to the implementation of the SADC/GEF Lake Malawi Biodiversity Conservation Project.

More than 260 rivers flowing into the Lake are depicted by the National Atlas of Malawi (Government of Malawi 1985). This is probably an underestimate, as the Mozambique and Tanzanian coasts, although included in the atlas, were not given as much detailed attention as the Malawi coast. The vast majority of these rivers are short, being less than 10 km in length, and flow in the wet season only. Many of the smaller rivers are in the steeply shelving parts of the shoreline, cutting their way down the mountainsides from their small, but steeply sloping catchments. The only outflowing river, the Shire, exits to link Lake Malawi to Lake Malombe (Figure 7). Jackson et al. (1963) subdivided river habitats into upper, middle and lower reaches as well as estuaries. According to Jackson et al. (1963), the upper reaches are fast flowing, "cold" and highly oxygenated. In the middle and lower reaches the water slows and becomes warmer; macrophytes (reeds in particular) are common.

The broad physical aquatic habitats represent ecological zones within the Basin, each supporting unique communities of organisms, and each playing a role in the ecological and evolutionary processes that sustain the biodiversity of the Lake (Ricardo-Bertram et al. 1942, Jackson et al. 1963, Beadle 1981, Ribbink et al. 1983, Konings 1995). Each of these broad habitats can be subdivided into finer resolution and, partly due to the third dimension of aquatic habitats, each of these subdivisions (sometimes called micro-habitats e.g. Fryer 1959, Jackson et al. 1963, Fryer & Iles 1972, Ribbink et al. 1983, Ribbink 1991) also support identifiable communities of organisms. These subdivisions are related to substratum type as well as factors such as depth, exposure to wave-action and water flow. Associated with depth are changes in light penetration, affecting photosynthesis and visibility, and in oxygen availability; all of these factors have individual and cumulative effects on the distribution of organisms within the Lake. Limnological factors, such as nutrient cycling, currents and upwelling (both currents and upwelling can be wind generated) have impacts on those processes that maintain productivity and that regulate the distribution of organisms.

Socio-economic characteristics

Lake Turkana

Population and infrastructure

The area is populated with Turkana pastoralists to the west (Turkana District, Kenya) and Gava pastoralists to the east (Marsabit District, Kenya) of the Lake respectively. The Karo, Hammer and Geleb pastoralists occupy the lower Omo Valley in Ethiopia. Those living to the west and east of Lake Turkana are mostly nomadic, but a few are fishermen. Those in the lower Omo Valley are subsistence agriculturalists in the north and agro-pastoralists in the south extending to the Kenya border. They obtain their water from Lake Turkana and the surrounding seasonal rivers. In the catchment area as a whole, the population is estimated at 15.2 million out of which 12.3 million live in the Ethiopian part of the catchment (GIS analysis based on ONRL 2003). There is a good tarmacked access road from the major towns in the south to Lodwar, the district headquarters of the region in Kenya. The Turkana area itself has very scarce and poor roads and telecommunication facilities. Both Lodwar and Kalokol towns have well maintained airstrips, and there is a fairly regular flight schedule between Kalokol and Nairobi, Kenya's capital city.

Socio-economic activities

The Turkana-Marsabit region bordering Lake Turkana to the west and east, respectively, is classified as one of the poorest regions in Kenya. Calorie intake is well below the UNICEF minimum of 2 000 per day. Investment levels are extremely low and consequently the employment levels. The mainstay of the economy is fishing and subsistence farming, mainly sorghum, maize and millet. Fishing is largely done for subsistence. There has been an attempt to introduce commercial fish farming but this effort has not been successful because of the high investment in trawling and shipping. The rest of the economy in this area comprises livestock rearing, especially goats and zebu cattle, The vegetation and/or land use within the catchment area is as shown in Table 7 (World Lakes Database 2002).

Table 7 Land use in the Lake Turkana catchment.

Land use		Area (km^2)	Area (%)	Note
Natural landscape	Woody vegetation (semi desert scrub, mainly acacias)	6 543	5	
	Herbaceous vegetation (semi-desert grassland with annual and perennial scrub)	58 887	45	
Agricultural Land	Crop field	3 272	2.5	No fertiliser applied
	Pasture	62 159	47.5	Occasionally millet fields
Total		130 860	100	

(Source: World Lakes Database 2002)

Table 8 Quantity of fish (tonnes) landed in Kenya, 1965-1968.

Source	1965	1970	1975	1980	1985	1990	1995	1998
Lake Victoria	13 000	16 988	16 581	26 914	88 589	185 101	181 888	158 876
Lake Turkana	1 095	4 854	4 236	12 384	7 460	3 180	2 232	4 268
Others*	3 050	4 003	1 993	2 988	2 630	2 552	2 591	3 709
Fish farming	130	ND	ND	596	1 085	975	1 083	217
Total freshwater catch	17 275	25 845	22 810	42 882	99 764	191 808	187 794	167 070
Marine catch	5 725	7 910	4 531	5 336	6 209	9 972	5 995	5 522
Total fish catch	23 000	33 755	27 341	48 218	105 973	201 780	193 789	172 592
Lake Victoria, share of Kenyan fish catch (%)	56.5	50.3	60.7	55.8	83.6	91.7	93.9	92.1
Lake Turkana, share of Kenyan fish catch (%)	4.8	14.4	15.5	25.7	7.0	1.6	1.2	2.5

Notes: Others include other freshwater sources of fish such as lakes, rivers and dams.*
ND= No Data.

(Source: Ikiara 1999, updated from Republic of Kenya Economic Survey 1999)

Fishing takes place both in the unprotected Omo River delta (Hughes & Hughes 1992) and in the Lake. Based on measured primary phytoplankton productivity, an empirical model predicted a total fish yield of 22 000 tonnes per year for Lake Turkana, and the sustainable yield of traditionally exploited fish from the offshore areas of the Lake is estimated at 15 000 to 30 000 tonnes per year (Kallqvist et al. 1988). The development of commercial fisheries began about 1961 at Ferguson's Gulf (Hopson 1982). The number of people estimated to be involved in commercial fisheries in Turkana District in 1982 was 30 000 to 40 000 (Kallqvist et al. 1988). Reduced fish landings and marketing problems subsequently led to fisheries being much less profitable: the main reason for the decline in fish landings was the collapse of the tilapia fisheries in the Ferguson's Gulf area (Kallqvist et al. 1988). The quantity of fish landed has thus drastically reduced due to under-exploitation, and today Lake Turkana has less than 3% of total fish catches in Kenya (Table 8). The number of fishermen along the west shore of the Lake has, however, increased to 58 263 (Republic of Kenya 2002b). This suggests that the fishing activities are mainly for subsistence. The fisheries industry of Lake Turkana is currently operating way below its sustainable yield limit.

Health

Vector-borne diseases include many tropical ailments, such as malaria, onchocerciasis, and leishmaniasis (CIHI 1996). Diarrhoeal diseases, which typically result from contaminated drinking water or food, afflict a significant proportion of children and adults throughout Kenya (CIHI 1995). Other common diseases related to quality of water and sanitation include intestinal worms, schistosomiasis, common eye infections such as trachoma, and skin diseases (CIHI 1995 and 1996). Guinea worm is endemic in the Lake Turkana Basin (CIHI 1995 and 1996). Malaria is becoming an increasingly significant public health problem in Ethiopia with perennial transmission taking place near bodies of water, swamps and irrigation projects (CIHI 1996). In the low-lying, dryland areas around Lake Turkana, there is little information on malaria incidence. However, in this area, malaria is probably unstable and epidemics may occur only in years with substantial rainfall (cf. Warsame 1991). Malaria incidence and mortality in Ethiopia are thought to be rising due to drug shortages, insufficient health care services, increasing drug resistance, and the diverse distribution of mosquito vectors (CIHI 1996).

Legal and institutional framework

Drought-related poor food security, insecurity because of wars in bordering countries, cattle rustling, ethnic conflicts over grazing grounds, chronic water scarcity, lack of adequate health facilities and health care, poverty, and deforestation are the major political and management concerns in the Basin.

New national environmental policies/acts have been enacted in both Ethiopia (1997) and Kenya (1999), and environmental authorities have been set up to implement the policies which seek to promote sustainable environmental management and development. There are no specific laws relating to the use of the Lake Turkana or its affluent river waters, though each country has a water act that covers the use of waters in all water bodies within the respective countries. The new Kenya Water Act (2002) provides for the establishment of Water Resources Management Authorities that will have wide-ranging powers to manage and protect water resources at river or lake basin scales. One of the important new regulations in this Act is the recognition of, and provision for, the public and communities to participate in managing the water resources within each catchment area. The District Development Plans (2002–2008) for Turkana District (west of Lake Turkana) and Marsabit District (east of Lake Turkana) in Kenya have the following priority issues in relation to water resources: improvement of fish production; environmental conservation, improvement of rural water supply and sanitation; disaster management (e.g. droughts, degradation of natural resources); and improving the tourism potential of the lake districts (Republic of Kenya 2002a and b).

Both countries subscribe to the Desertification Convention. Kenya is now a signatory to the Ramsar Convention. One of the proposed national actions is to collaborate with Ethiopia to accede to the Ramsar Convention and to undertake joint transboundary wetland conservation programmes for the Lake Turkana/Omo River transboundary wetlands.

Lake Victoria

Population and settlements

The Lake Victoria Basin supports one of the densest and poorest rural populations in the world, with human population density being well over 100 persons per km^2 (Cohen et al. 1996) and up to 1 200 persons per km^2 (Hoekstra & Corbett 1995). It is thus the most heavily populated basin within the East African Rift Valley Lakes region. It is multi-ethnic in composition, comprising various communities from Kenya, Uganda, Tanzania, Burundi and Rwanda. The population of the region is expected to double within the next two decades (World Bank 1999). The annual population growth is 2–4% in most parts of the Lake Basin but urban population growth is over 5–10% per year in most of the larger towns (Scheren et al. 2000).

Socio-economic activities

The Lake catchment is mainly (80%) an agricultural catchment (Majaliwa et al. 2000). Subsistence agriculture, pastoralism and agro-pastoralism currently support about 21 million people in the Basin, with average incomes in the range of 90–270 USD per year (World Bank 1996). The Lake Basin as a whole (lake and catchment) provides for the livelihood of about one third of the combined population of the three East Africa Community Partner States (Kenya, Tanzania and Uganda), and about the same proportion of the combined gross domestic product. Most of the population living along the lakeshore relies directly or indirectly on the fishing trade, thus loss of fisheries has serious socio-economic implications. While aspects of the future of the Lake such as its peoples and their activities, environment, climate, agriculture, tourism, industry, commerce, history and geography are of immense interest to researchers, economic managers and policy planners, the Lake's fishery tends to receive the greatest attention.

Major economic sectors

The gross economic product in the Lake Basin lies between 3 and 4 billion USD annually (World Bank 1996), and an estimated population of roughly 30 million people whose incomes are estimated to lie within the range of 90-270 USD per capita per year. The major economic sectors in the Lake Victoria Basin, in terms of their contributions to total GDP and employment creation for the countries, are fisheries, agriculture and manufacturing. In Tanzania the agriculture sector contributes about 45% of total GDP, while manufacturing contributes 7.4% of the total GDP. The fisheries sector contributes about 3% to the GDP of Tanzania and Uganda and 0.5% to the GDP of the Kenyan economy (Bwathondi et al. 2001, URT/JICA 2002).

Fish has traditionally been the most affordable source of animal protein with an average regional per capita consumption of about 12 kg (Bwathondi et al. 2001). Tilapia is preferred by about 70% of the consumers on average (SEDAWOG 1999, URT/JICA 2002) around the Lake with consumers from the Tanzania side of the Lake preferring Tilapia by more than 75% (URT/JICA 2002). The fishing industry provides employment for between 0.5 and 1 million Ugandans, more than 0.8 million Tanzanians and 0.8-1.5 million Kenyans, and most of the fish landed in these countries come from Lake Victoria (Bwathondi et al. 2001). Lake Victoria contributed 48.3% of the fish landed in Uganda in 1994, 90% of the fish landed in Kenya in 1998, and 60% of the fish landed in Tanzania in 1998 and 2001 (Bwathondi et al. 2001).

It is estimated that the present value of annual export earnings from the fishery is about 600 million USD, which represents revenue to the lake community of 240-480 million USD per year (Duda 2002). The main/target species in the fisheries sector is the Nile perch. The Nile perch fisheries produces about 300 000 tonnes of fish per year in Lake Victoria (FAO 1998), a market that technically did not exist prior to the introduction of that species in the late 1950s. However, there are concerns that this income generation is not benefiting the local peoples; they lost their favourite species and the perch is harvested for foreign markets. The latter is one reason why fish consumption has declined and there is concern about malnutrition in Lake Victoria region (Kaufman 1992, Jansen 1997). The fishery that was multi-species before 1980 is now a three species fishery dominated by the Nile perch (*Lates niloticus*), Nile tilapia (*Oreochromis niloticus*) and the native sardine-like cyprinid locally known as Omena/Dagaa/Mukene (*Rastrineobola argentea*). There are currently 31 licensed fish processing factories in the Lake Victoria region (Ntiba et al. 2003).

Within the Lake Victoria Basin, there are large-scale farms of coffee, tea, cotton, rice, maize, sugar and tobacco (Ntiba et al. 2001). On a more local scale, the extensive papyrus that fringes the Lake is harvested for thatching houses and making carpets/mats. Agricultural production has increased with the increase in population, for example, between 1958 and 1988, the population increased by 30% and the agricultural production increased by 50% (FAO 1991). In 1995, it was estimated that 32% of the catchment land area was under cultivation (Scheren et al. 2000). For the past two to three decades, subsistence farming without proper agronomic practices was the main type of activity being carried out in the lake catchment, and which has led to land degradation by enhancing soil erosion (Meertens et al. 1995).

In the manufacturing sector, there are e.g. breweries, sugar refineries, soft drink and food processing factories, oil and soap mills, leather tanning factories, mining companies and textiles (Ntiba et al. 2001).

Areas where water-related engineering activities/structures are located are Yala swamp (Kenya), Sondu-Miriu Dam (Sondu-Miriu River, Kenya) and Owen Falls Dam (Nile River outlet, Uganda). The Lake Victoria water is mainly used for human consumption by the riparian communities, and its water level is protected by the Nile Basin Treaty. Therefore, no withdrawals or diversions of the feeder rivers have taken place.

Health

Lake Victoria is a source of affordable protein in the form of fish, and a source of water for the communities that live around it. Surprisingly, the health status of populations living around the Lake is far below what it should be, with the most common health issues related to food and nutrition, and to diseases associated with lack of safe sources of water (Karanja 2002). Some of these health problems arise out of the fact that the Lake is also a repository for human, agricultural, mining and industrial waste. The water for domestic consumption for these communities is mainly taken without treatment (Bwathondi et al. 2001).

Legal and institutional framework

It is only recently, during the past 10 years or so, that the East African countries have instituted, at government level, policies on the environment that adopt an integrated and sustainable approach to environmental management. It is, therefore, refreshing that institutions that consider conservation and sustainability as priority issues in the conservation of environmental resources are now beginning to get a foothold in the management of the Lake Victoria Basin. Overwhelmingly, the politics of management and ownership of Lake Victoria fall into the larger context of the establishment and development of the East African Community (EAC) (EAC 2001). Within the Community, two institutions on Lake Victoria have been established. These are Lake Victoria Fisheries Organisation (LVFO), which is specific for fisheries, and the Lake Victoria Development Programme (LVDP) covering general development matters of the Basin. During the 1990s, two other projects were established, namely, the Lake Victoria Fisheries Research Project (LVFRP), financed by the European Union, and the Lake Victoria Environmental Management Project (LVEMP), financed by the World Bank and the Global Environmental Facility (GEF) (Bwathondi et al. 2001). The LVFRP Phase II, implemented by the research institutes of the riparian countries of Kenya, Uganda and Tanzania, started in June 1997. Its main objectives were to encourage sustainable development of the Lake Victoria Basin by assisting the LVFO in the creation and implementation of a viable regional management of the lake fisheries (Bwathondi et al. 2001). The Lake Victoria Regional Local Authorities Cooperation (LVRLAC) was set up in 1997 to begin to collaborate in addressing the region's socio-economic concerns in relation to the deteriorating conditions of Lake Victoria and its surroundings (Kiyaga-Nsubuga 2002).

The EAC Partner States recognise three important and convergent issues relating to Management of Shared Waters. These are firstly, that they share an interest in the well-being of the Lake and its living resources and in the rational management and sustainability of these resources. Secondly, the Lake Victoria region needs to develop as an economic growth zone. Thirdly, that management decisions relating to any portion of the Lake, within the territorial limits of any one of the Partner States will affect the others, and hence the concomitant necessity that management decisions take such issues into account.

Prior to the 1960s, most agreements (except the 1929 Nile Waters Agreement) dealing with development and uses of the Nile waters have been on bilateral basis (UNECA 2000). In 1967, the United Nations Development Programme (UNDP) and the World Meteorological Organisation (WMO) initiated the Hydromet Project for the hydrometeorological survey of the equatorial lakes basin. This project was initially endorsed by Egypt, Sudan, Kenya, Uganda and Tanzania, and later on included Rwanda, Burundi and DR Congo, with Ethiopia as an observer (UNECA 2000). The Kagera River Basin Agreement was signed by Burundi, Rwanda and Tanzania, with establishment of the Kagera Basin Organisation (KBO) in 1977.

Other international conventions and agreements that Kenya, Uganda and Tanzania are signatories to or subscribe to are summarised in Bwathondi et al. (2001). The relevant regional agreements include: Technical Cooperation for the Promotion of the Development and Environmental Protection of the Nile Basin (Tecconile), Initiative for Nile Basin Management, the Convention for the Establishment of the Lake Victoria Fisheries Organisation (LVFO), the Agreement on the Preparation of a Tripartite Management Program for Lake Victoria, and the Treaty establishing the EAC. The international conventions and agreements include: the Convention on Wetlands of International Importance (Ramsar), the Convention for International Trade in Endangered Species of Wild Fauna and Flora (CITES), the Convention on Conservation of Biological Diversity, and the Code of Conduct for Responsible Fisheries (CCRF).

The Nile Basin Initiative was formally launched in 1999 by the Council of Ministers of Water Affairs of the Nile Basin States, and it includes all Nile countries and provides an agreed basin-wide framework to fight poverty and promote socio-economic development in the region. Its vision is "to achieve sustainable socio-economic development through the equitable utilisation of, and benefit from, the common Nile Basin water resources". Core support for the Initiative is provided by the Nile countries. The early partners supporting this Initiative included UNDP, the Canadian International Development Agency (CIDA) and the World Bank, but the number of donors is still growing.

Lake Tanganyika

Population and settlements

The four riparian countries that share Lake Tanganyika (Tanzania, Burundi, DR Congo and Zambia) are among the poorest in the world. The Human Development Index (HDI) is an indexed measure of standard of living (per capita GDP), longevity (life expectancy at birth), and education (combination of adult literacy rates with primary, secondary, and tertiary school enrolment ratios). In comparison with 174 states, DR Congo was ranked 152nd, Zambia 153rd, Tanzania 156th and Burundi 170th (UNDP 2000). See Table 9 (extracted from World Bank 1999 and UNDP 2000) for relevant indicator statistics for these countries. Life expectancy in Lake Tanganyika's riparian nations averages 42-51 years. Literacy rates range from 45-76%. Per capita income ranges from 110-320 USD per year with significant proportions of the populations living below the national poverty lines and on less than 1 USD per day. While

Table 9 Socio-economic statistics for Tanganyika's riparian nations.

	Burundi	DR Congo	Tanzania	Zambia
Population in the country (in millions)	6.7	49.8	32.9	9.9
Population in the Basin (in millions)	2.5	2.6	3.5	0.5
Population growth rate (%)	2.0	3.2	2.4	2.2
Population per km^2	249.9	20.6	35.4	12.7
Life expectancy at birth (years)	42	51	47	43
Adult literacy (% > age 14)	45.8	58.9	73.6	76.3
School enrolment (% of school age population)	51	78	67	89
Per capita GNP (USD)	120	110	240	320
Population < National poverty line (%)	36.2	ND	51.1	86
Population living on < 1 USD/day (%)	ND	ND	19.9	72.6
Population without access to:				
Safe water (%)	48	32	34	62
Health service (%)	20	ND	7	25
Sanitation (%)	49	ND	14	29
Share of income or consumption (%):				
poorest 20%	7.9	ND	6.8	4.2
richest 20%	41.6	ND	45.5	54.8
richest 20% - poorest 20%	5.3	ND	6.7	13
Human Development Index (of 174)	170th	152nd	156th	153rd

Note: ND = No Data. (Source: UNDP 2000, World Bank 1999, GIS analysis based on ORNL 2003)

these statistics are in many cases several years old, they provide a general idea of the socio-economic situation faced by many citizens of the Lake Basin.

An estimated 10 million people reside in the Lake Tanganyika catchment (UNDP 2000) representing diverse ethnic groups of predominantly Bantu origins. Many Bantu languages are spoken – Swahili, a national language of Tanzania and DR Congo but also common in the lake regions of Burundi and Zambia, is the "lingua franca" on the Lake for commerce, transport and communications. Dating back to their respective Belgian and British colonial periods, Burundi and DR Congo both list French as an official language whereas Tanzania and Zambia similarly list English. Population growth rates range from 2.0-3.2% in Tanganyika's riparian nations, resulting in a rapid doubling time of 25–30 years (World Bank 1999). Population densities vary considerably in the Tanganyika Basin. In 1999 World Bank statistics, Burundi's population density was estimated at 250 persons per km^2, DR Congo was 21 persons per km^2, Tanzania 35 persons per km^2 and Zambia 13 persons per km^2. In the Tanganyika Basin, settlements are typically small and concentrated on areas of relatively flat topography.

The main lakeside urban settlements for the four countries are:

1. Bujumbura (population 400 000), Burundi, a capital city with an international airport and more than eighty industries (paint, brewery, textile, soap, battery etc.);
2. Kalemie (population unknown) and Uvira (population 100 000), DR Congo. Kalemie has some industries and a rail link to other centres in DR Congo, Uvira has cotton processing and sugar production industries but depends heavily on nearby Bujumbura for goods and services;
3. Kigoma (population 135 000), Tanzania, the largest transit point for goods and people entering/exiting the Lake region, with a rail link to other centres in Tanzania;
4. Mpulungu (population 70 000), Zambia the seat of the industrial fishing fleets.

Refugee movements and wars have ravaged the northern Tanganyika Basin during the last decade. Much of the Burundi and DR Congolese coastlines have experienced recurrent fighting and instability, dating back to October 1993 in Burundi and October 1995 in DR Congo. Consequently, 100 000 Burundians were internally displaced while 285 000 sought refuge in Tanzania. In DR Congo 700 000 people were internally displaced while 118 000 sought refuge in Tanzania (UNHCR 2000). Most refugees reached Tanzania via Lake Tanganyika. While some refugees (not reflected in these figures) settled in relatively unpopulated areas along the Tanzanian coast or in villages with family/friends, many camped within the Kigoma region in order to benefit from international assistance. While population movements are concentrated in the northern basin, all of Tanganyika's riparian nations have hosted refugees. These population movements have had repercussions on society, the regional economy and the environment. Population movements and ongoing civil wars have also affected the relationship between Tanganyika's riparian states.

Socio-economic activities

At population centres, people are often involved with administration and aspects of international trade between the four countries. Outside of these areas, subsistence and small-scale commercial fishing and farming dominate people's livelihoods (Quan 1996, Meadows & Zwick 2000). Flat, fertile land in the Tanganyika Basin is extremely limited and most farming occurs on steep slopes or narrow strips of land between the rift escarpment and the Lake. The principal crop is cassava, grown primarily for subsistence. Cash crops include oil palm and limited rice, beans, corn and banana production (Meadows & Zwick 2000). Historically, cattle-herding has not been widespread in the Basin due to tsetse flies, however, regional insecurities have caused some cattle owners in Burundi and DR Congo to move their cattle to nearby lakeside areas.

As a result of clearing land for agriculture and fuel-wood demands, there are fuel-wood shortages in many lakeshore villages (Meadows & Zwick 2000).

Lake Tanganyika is an important resource for its riparian nations. It provides freshwater for drinking and domestic use. Between 165 000 and 200 000 tonnes of fish are harvested annually from Lake Tanganyika (Reynolds 1999). This represents a significant source of protein in the local diet. Harvesting, processing, transporting and marketing these fish – some of which are sent to markets hundreds of kilometres away in Lubumbashi, the Zambian Copper Belt and Dar es Salaam - provides jobs and livelihoods for more than 1 million people (Reynolds 1999). Compared to other parts of these four countries, the Lake Basin is not endowed with significant mineral resources or especially fertile agricultural grounds. This, coupled with its distance from seaports resulted in much of the region being comparatively marginalised during colonial administrations. Except for Burundi, which has its capital on the Lake, the lakeshore regions of DR Congo, Tanzania and Zambia are remote,

Figure 11 Protected areas in the Lake Tanganyika Basin.

far from international airports, seaports and their countries' capital cities and economic centres. Except for a few large towns and one city, the Basin still lacks basic infrastructure (electricity, running water, communications) and little industrialisation has taken place.

The main lakeside urban settlements are all served by ports, which link people and cargo between Tanganyika's riparian nations. Landlocked Burundi and eastern DR Congo in particular, depend heavily on goods coming by rail from Dar es Salaam to Kigoma or by road from South Africa to Mpulungu. Railways link Kalemie and Kigoma to larger economic centres in DR Congo and Tanzania, respectively. Mpulungu links to other economic centres in Zambia by a paved and maintained road. Burundi has a good road extending the length of its coastline. DR Congo has a poor, unmaintained road extending from Uvira to Baraka. Most of the other roads run tangential to the Lake and are not well maintained.

Protected areas

Riparian governments have designated protected areas (PAs) in several locations bordering the Lake (Figure 11). Burundi has two PAs, the Rusizi Natural Reserve (recently downgraded from National Park) and Kigwena Forest; Tanzania has two PAs, Gombe Stream National Park and Mahale Mountains National Park; and Zambia has one PA, Nsumbu National Park. DR Congo currently has no protected areas along the Lake. The Rusizi Natural Reserve is a site of international ornithological interest as it hosts a diverse resident and migrant bird fauna. Gombe Stream and Mahale Mountains National Parks, hosting chimpanzees and other primates, are the sites of the longest-running primate studies. Nsumbu National Park harbours elephants, lions, leopards, gazelles and other game, but in low densities. Both Mahale Mountains and Nsumbu National Parks provide some protection to the Lake as their borders extend 1.6 km into the Lake. To date, tourism remains relatively undeveloped because of the remoteness, lack of infrastructure, regional insecurities, and competition from other locales.

Legal and institutional framework

Lake Tanganyika's riparian nations agreed upon a set of principles and values in their quest to ensure the conservation and sustainable use of the Lake's resources. Many of these principles are embodied in existing Conventions to which the four riparian countries are signatories, in particular the environmental and social principles that underlie the Convention on Biological Diversity, Agenda 21 and the Dublin principles. These principles include the: Precautionary Principle, Polluter Pays Principle, Principle of Preventive Action, Principle of Participation, Principle of Equitable Benefit Sharing, and Principle of Gender Equality.

Recognising that Lake Tanganyika is a special system, that it is threatened by a variety of destructive behaviours, and that existing national legislation regarding the Lake is inadequate, Tanganyika's riparian countries drafted the Convention for the sustainable use of the Lake (West 2001). This Convention was signed by the Ministers of the four countries on 12 June 2003. The convention is the result of five years of technical studies and expert evaluation, and charges member countries with controlling pollution, overfishing and other human activities in their territories that threaten the Lake, which supports the livelihoods of up to 10 million people in the four countries. The Convention provides the necessary rights, responsibilities, institutions and framework in international law which compel the countries to cooperate in managing Lake Tanganyika. Specifically, it creates a binding legal framework ensuring certain standards of protection, establishes the institutions for implementing the Convention, establishes the mechanisms for implementing the Strategic Action Programme (SAP) and establishes procedures for settling disputes. Simply stated, the SAP is a participatory strategic planning process to enable scientists and natural resource managers to identify and prioritise their management initiatives for the Lake.

The SAP is mandated to

- "Establish clear priorities that are endorsed at the highest levels of government and widely disseminated. Priority transboundary concerns should be identified, as well as sectoral interventions (policy changes, programmes development, regulatory reform, capacity-building investments, and so on) needed to resolve the transboundary problems as well as regional and national institutional mechanisms for implementing elements of the SAP."

Lake Malawi

Population

The countries of Malawi, Mozambique and Tanzania, with human populations of 10 million, 19.1 million and 31.2 million, respectively (WWF 2003), share Lake Malawi. The Lake Malawi Basin constitutes 70% of Malawi's land area, which is highly densely populated at 116 persons per km^2 (UNEP-IETC 2003). Indeed, 80% of the total lakeshore population is in Malawi (World Bank 2003). In Mozambique and Tanzania, the Basin area is sparsely populated due to its remoteness and isolation from the rest of the Basin (Figure 12) (Ribbink 2001). It is clear that most of the human impact on Lake Malawi is from Malawi which is highly populated and has the largest catchment area.

Socio-economic activities

The value of such a huge aquatic resource in semi-arid, drought-prone southern Africa cannot be overstated. For the people on the

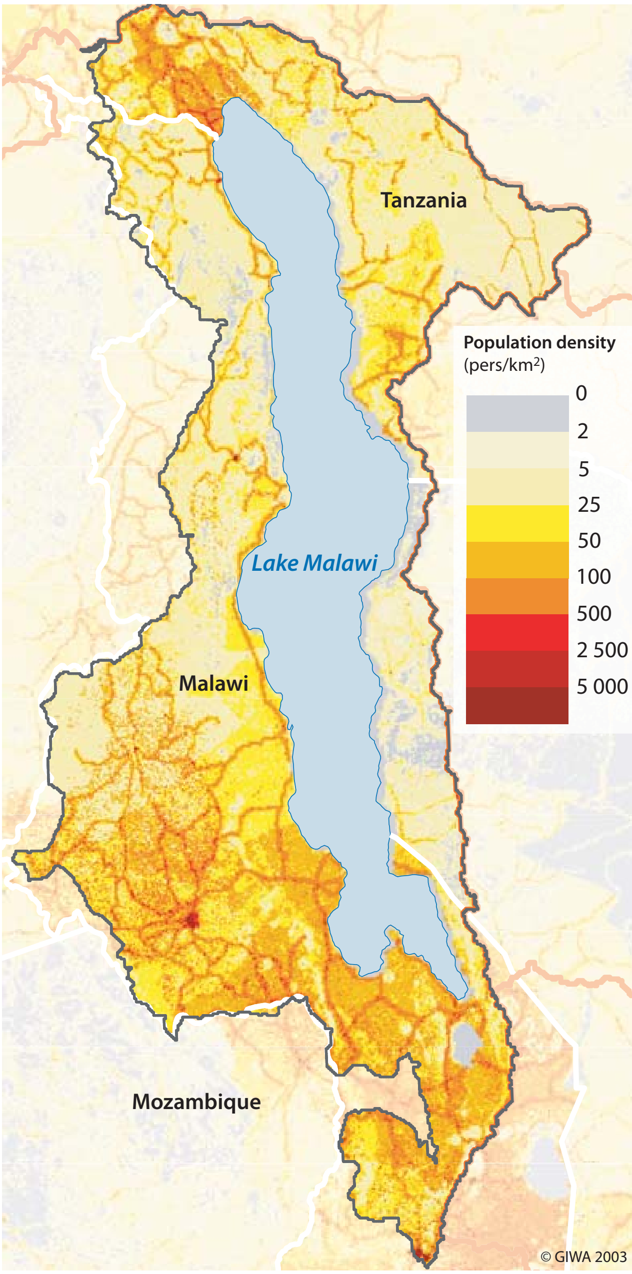

Figure 12 Human population density in the drainage basin of Lake Malawi.
(Source: data from ORNL 2003)

lakeshore, it provides the basis for life itself through abundant water for drinking and domestic uses, production of fish which provides the cheapest animal protein in human diets, easy transport for lake commerce, and possible use for irrigation of crops. In addition, for the country of Malawi currently, the Lake's catchment provides water for hydroelectric generation and exceptional opportunities for tourism. But the Lake is also renowned for its fabulous biodiversity, especially among the numerous cichlid fishes, the haplochromine subfamily being particularly species-rich and nearly completely endemic.

Land-based anthropogenic activities have an impact on the waters of the Basin, with direct or indirect consequences for the Lake (Ribbink 2001). Agriculture, deforestation, and biomass burning are all contributing to loss of fertility and sustainability of the land, while affecting the Lake through transport of the chemicals (mainly nutrient precursors) via the watershed and air (Ribbink 2001). The greatest agricultural development is in the basins of the Linthipe and Bua rivers in the south of the catchment (Eccles 1984).

Economic sectors and water-related engineering

The countries' GNP per capita is as follows: Malawi 220 USD, Mozambique 90 USD and Tanzania 210 USD (UNICEF 2003). The economies of the three countries are heavily dependent on international aid, and poverty remains deep and pervasive (WWF 2003). The economies depend heavily on the countries' natural resource base: agricultural production, almost 70% of which comes from smallholder farms, accounts for more than 90% of export earnings in Malawi and contributes 37% of GDP and supports more than 80% of the population (CIA World Fact Book 2002, World Bank 2003). In Mozambique and Tanzania, the contributions stand at 22% and 48% respectively (CIA World Fact Book 2002). Practically all the people living within the Lake Malawi catchment and along the shores of the Lake are involved in fishing and agriculture (WWF 2003). The key socio-economic indicators of the economies of the region are shown in Table 10.

Kabulo (in Perrings 2000) notes that the fisheries industry experienced rapid growth between the 1960s and 1980s where estimated landings in 1964 were 15 000 tonnes. Production peaked in 1987 at 88 000 tonnes whereas the 2000 landings average 70 000 tonnes. The importance of the fisheries sector in Malawi is given by its 4% contribution to the country's GDP, direct and indirect employment

Table 10 Some socio-economic indicators of the economies of the Lake Malawi Basin.

	Malawi	Mozambique	Tanzania
Population in the Basin (million)	6.5	0.2	1.4
Population density (km²)	98.3	21.8	38
Population growth rate (%)	2.21	0.82	1.72
GDP (billion USD)	7.2	19.2	22.5
GDP real growth rate (%)	1.2	8	5.2
GDP per capita PPP* (USD)	670	1 000	630
GDP by sector (%):			
Agriculture	37	22	48
Industry	16	23	15
Services	47	55	37
Population below poverty line (%)	54	70	36

**PPP=Purchasing Power Parity.*
(Source: CIA World Fact Book 2002, GIS analysis based on ORNL 2003)

of around 240 000 people, and nutrition. Fish provides between 60 to 70% of Malawi's animal protein supply and 40% of total protein supply. Export trade of ornamental fish grew between 1970s and 1980s. Major customers are North America, Germany, France, and Belgium.

An overriding problem is that poverty of the population within the Lake Basin and its dependence upon natural resources are making it increasingly difficult to maintain sustainable use of resources (Ribbink 2001). Orr and Mwale (2001) noted from their Rapid Rural Appraisal (RRA) study that the poor are becoming poorer while at the same time there were those who reported an improvement in their economic status. Livelihood improvement was attributed to market liberalisation with respect to income generation from agricultural crops like barley, tobacco, vegetables, grain legumes and micro enterprise output. Another study observed the rural poverty in Malawi was associated with the absence of household food security, which was in turn equated to household maize production (Orr et al. 2001). Initiatives are being set up to address the poverty problem in the region. The Mtwara Development Corridor is one such development initiative of the governments of Mozambique, Malawi, Tanzania and Zambia. It covers southern Tanzania, northern Mozambique, northern and central Malawi and eastern and northern Zambia. These are the most undeveloped regions within each country, particularly in terms of: low levels of infrastructure development, high incidence of poverty, poorly developed and integrated local economies, dependence of fragile small holder production regimes and deteriorating natural environmental resource base (Graham 2003).

The only prominent water-engineering project is the Shire Valley hydroelectric power plant on the Shire River. There are many irrigation schemes within the catchment particularly on the Malawi side. There is increased demand for water for crop irrigation as more and more irrigation schemes are being established (Government of Malawi 1998).

Health

Out of Malawi's 11 million people, 89% live in rural areas, where 25% of the males and up to 40% of the females have never attended school (UNEP-IETC 2003). An indicator of the low health status of these populations is the lack of amenities: only 1% of rural households has electricity; 67% use a well as a source of water (39% of which are not protected); up to 53% of the population use water sources that are classified as unsafe; and 34% of the rural households do not have access to either a flush toilet nor a traditional pit latrine (UNEP-IETC 2003). In Mozambique, 41 to 62% of the children under 5 years old living in the provinces, Niassa, Zambezia and Tete, that border Lake Malawi have chronic malnutrition (UNICEF 2003). The number of people with access to safe water ranges from 17% in Zambezia to 40% in Tete, while those with access to sanitation ranges from 6.6% in Zambezia to 66% in Niassa (UNICEF 2003). The incidence of water-borne diseases, such as schistosomiasis, occurs in coastal settlements along Lake Malawi and its principle outlet, the Shire River, but it is related mainly to lack of sanitation rather than agricultural or industrial effluent (UNEP-IETC 2003).

Legal and institutional framework

Open access conditions prevail in most circumstances in the three countries as the right to use natural resources is synonymous with survival (WWF 2003). At international level, some environmental conventions have been endorsed, e.g., Malawi is signatory to the Convention on International Trade in Endangered Species (CITES), Convention on Biological Diversity, Convention on the Conservation of Migratory Species of Wild Animals, and the Ramsar Wetland Convention. At regional level, there are a number of policies which guide the conduct of State Parties in relation to the use of natural resources: SADC Protocols on Fisheries, Shared Watercourse Systems, Mining, Wildlife Conservation, and Law Enforcement (Kasweswe-Mafongo 2003, WWF 2003). But due to the voluntary nature of their application and a lack of effective enforcement institution at regional level, they do not have notable impacts (Kasweswe-Mafongo 2003, WWF 2003).

Also, all three countries have passed a number of policies and legislation on fisheries, forestry, water, and soil, but these have been developed independently and without consultation, and they are, therefore, disjunct. In Malawi, the major statute for the regulation and control of fisheries is the Fisheries Act 1974 that is administered by the Department of Fisheries. The Act is charged with the prevention of depletion of fish resources and making harvesting of fish sustainable through licensing, gear restriction and seasonal closing of fisheries. Policing of these regulations, however, is constrained by lack of trained staff and patrol equipment, and also by inadequate penalties for non-compliance. In Tanzania and Mozambique, the fisheries policies focus more on marine fisheries rather than on inland water bodies such as Lake Malawi (WWF 2003). There is also some disagreement over political boundaries between Tanzania and Malawi.

The Lake Malawi Ecosystem Management Project (LMEMP) is an ecosystem management programme that is being prepared by the three riparian countries and is funded by GEF and other bilateral agencies. It aims to maximise the benefits to the riparian communities from improved fisheries management and the sustainable use of soils, forests, wetlands and other resources within the Basin to generate food, employment and income, while sustaining the ecosystem from which these benefits arise.

Assessment

This section presents the results of the assessment of the impacts of each of the five predefined GIWA concerns i.e. Freshwater shortage, Pollution, Habitat and community modification, Overexploitation of fish and other living resources, Global change, and their constituent issues and the priorities identified during this process. The evaluation of severity of each issue adheres to a set of predefined criteria as provided in the chapter describing the GIWA methodology. In this section, the scoring of GIWA concerns and issues is presented in Tables 11, 13, 15 and 18. Detailed scoring information is provided in Annex II of this report.

Table 11 Scoring table for Lake Turkana.

Assessment of GIWA concerns and issues according to scoring criteria (see Methodology chapter)

IMPACT 0 No known impacts; IMPACT 1 Slight impacts; IMPACT 2 Moderate impacts; IMPACT 3 Severe impacts

The arrow indicates the likely direction of future changes.
↗ Increased impact
→ No changes
↘ Decreased impact

Lake Turkana	Environmental impacts	Economic impacts	Health impacts	Other community impacts	Overall Score**	Priority***
Freshwater shortage	1.8* ↗	1.8 ↗	1.6 ↗	1.8 ↗	**2.2**	2
Modification of stream flow	2					
Pollution of existing supplies	1					
Changes in the water table	0					
Pollution	1.6* ↗	1.0 ↗	1.0 ↗	1.0 ↗	**2.0**	3
Microbiological pollution	0					
Eutrophication	1					
Chemical	0					
Suspended solids	2					
Solid waste	0					
Thermal	0					
Radionuclide	0					
Spills	0					
Habitat and community modification	1.5* ↗	2.6 ↗	2.3 ↗	2.5 ↗	**2.6**	1
Loss of ecosystems	1					
Modification of ecosystems	2					
Unsustainable exploitation of fish	0.7* ↗	0 ↘	0 ↗	0 ↗	**0.9**	5
Overexploitation	1					
Excessive by-catch and discards	1					
Destructive fishing practices	0					
Decreased viability of stock	0					
Impact on biological and genetic diversity	1					
Global change	1.4* ↗	2.0 ↗	2.4 ↗	3.0 ↗	**2.1**	4
Changes in hydrological cycle	2					
Sea level change	1					
Increased UV-B radiation	0					
Changes in ocean CO_2 source/sink function	0					

* This value represents an average weighted score of the environmental issues associated to the concern. For further details see Detailed scoring tables (Annex II).

** This value represents the overall score including environmental, socio-economic and likely future impacts. For further details see Detailed scoring tables (Annex II).

*** Priority refers to the ranking of GIWA concerns.

Lake Turkana Basin

Freshwater shortage

The only perennial river, and by far the most dominant source of water to the Lake (90%) (Cerling 1986), is the Omo River. The Omo River drainage basin lies mostly within Ethiopia, while the Lake lies within Kenya. Rainfall in the Lake Basin varies from more than 1500 mm in the Ethiopian plateau (Halfman & Johnson 1988), to less than 255 mm per year in the lake area (Survey of Kenya 1977). The Omo River discharge is about 19 billion m^3 of water each year (Beadle 1981). All the other rivers are seasonal or intermittent, thus there is little overland surface run-off into the Lake from the surrounding watershed.

The lake water itself is not suitable for drinking due to its high alkalinity and total dissolved solids concentration (cf. Yuretich & Cerling 1983), but the affluent river waters and shallow wells along the rivers are used as sources of potable water. The Turkwel River, entering the Lake from southwest, was dammed in 1991 for hydroelectric power generation at Turkwel Gorge, about 150 km west of the Lake (Figure 13). There is currently no evidence that abstraction of water from aquifers exceeds natural replenishment. Very little hydrogeological data is available for effective evaluation in the Lake Basin. Groundwater recharge zones and amount of groundwater recharge to the Lake are largely unknown. Nevertheless, on account of the land degradation and increasing number of settlements, it is likely that the groundwater recharge has, to some extent, decreased.

Environmental impacts

Modification of stream flow

The freshwater shortage in the Basin is due mainly to modification of stream flow. Along the Omo River in Ethiopia, there has been an extensive increase in small irrigation schemes diverting water from Lake Turkana. For example, in the Lower Omo Valley in Ethiopia (rainfall 300 mm/year), fodder and food crop production depends almost entirely on seasonal floodwater from the River Omo and recession farming in the old river channels (Kay 2001), and the delta (Raymakers 2003). Alexander (1990, in Haack & Messina 2001) estimates that the Omo River discharge has been reduced by 50% because of these activities. Development and commissioning of the large Turkwel River Dam in 1991 has also probably significantly impeded the flow of freshwater in the Turkwel River, and this may have impacted negatively on the fisheries in Ferguson's Gulf through lowered lake levels. Studies are, however, required to quantitatively determine the environmental effects of the dam construction.

Pollution of existing supplies

Heavy grazing along the lower Omo valley, especially along watering routes and overnight pastures, and settlement close to the rivers indicates that there is some pollution particularly from human and livestock wastes. In Marsabit District (Kenya), only 5.7% of the households (1700 out of 30 000 households) have access to potable water, and the average distance to the nearest potable water point is 25 km (Republic of Kenya 2002a). In Turkana District, the situation is somewhat better, with 28% of households (23 000 out of 80 921 households) having access to potable water, and the average distance to the nearest potable water point is 10 km (Republic of Kenya 2002b).

Socio-economic impacts

The people in the area are mainly pastoralists, and to a lesser extent, agro-pastoralists. Most of the lake drainage basin is used as pastureland (47.5%) compared to only 2.5% used as crop fields (World Lakes Database 2002). The main people affected by freshwater shortage due to abstraction of water for irrigation, and pollution, would be mainly those downstream close to the deltas of the Omo and Kerio-Turkwel Rivers (cf. Raymakers 2003). The degree of impact to these downstream users is probably fairly significant, particularly because water abstraction is a continuous activity, with resultant loss of agricultural uses (crops and livestock) and productivity, and increased effort to dig more water wells.

In Africa, nomads have the least access to any health services, and no satisfactory strategy has been devised to deliver proper health care to remote populations (Sheik-Mohamed & Velema 1999). Lack of access to safe water and adequate sanitation remains particularly acute in rural areas of Ethiopia (CIHI 1996) and Kenya (CIHI 1995) and are major underlying causes of several diseases. Common diseases related to quality of water and sanitation include diarrhoeal diseases, intestinal worms, schistosomiasis, common eye infections such as trachoma, and skin diseases (CIHI 1996, Republic of Kenya 2002a and b). Most watering points are, however, along the rivers and the delta area where permanent settlements and livestock populations are growing. Due also to lack of health care facilities in this remote region (the average distance to the nearest health facility in Turkana and Marsabit areas of Kenya is 50 km and 80 km respectively (Republic of Kenya 2002a and b), it is expected that more than 25% of the population are affected by bacterial-related gastroenteritic disorders. The freshwater shortage is an endemic, age-old situation because of the climatic setting, and the respective governments are continually making concerted efforts to improve the situation by digging new wells and boreholes in rural areas, as well as increasing access to piped water in urban settlements.

Figure 13 Turkwel River

Although there is no direct information on the impact of freshwater shortages resulting from human interventions on the communities, it is known that only 10% of the rural people in Ethiopia have access to potable water, while human waste disposal facilities are non-existent, and health services are limited and reach only 46% of the population (Waktola 1999). This situation likely reflects the prevailing conditions in the relatively poor and mainly nomadic regions of southwestern Ethiopia and northern Kenya. There would be increased potential for upstream/downstream conflicts that could be quite explosive, and population migration to areas not traditionally within the pastoralists normal range of movement. For example, there are some international conflicts (e.g. between the Turkana and the Merele of Ethiopia), and local ones as well, arising from livestock related issues such as grazing grounds and watering wells (Raymakers 2003); there have been several reports of armed conflict over ownership of water wells in the region. The government-supported irrigation schemes on the Turkwel River have impinged on traditional croplands of the Turkana, consequently, disputes have arisen between the traditional cultivators and the irrigation schemes (Barrow 1988).

Conclusions and future outlook

The freshwater resources of the Basin are critical for the livelihoods of the pastoralists and agro-pastoralists in the largely semi-arid drainage basin. River water is used for subsistence agriculture, but the rate of abstraction is currently unsustainable and is impacting Lake Turkana. The construction of dams in the region appears to impact negatively on the livelihoods of downstream river users and the lake ecosystem. Studies are, however, required to quantitatively determine the environmental effects of the dam construction. Most of the population rely on river and shallow water wells for water, and proper sanitation facilities are basically non-existent. Heavy grazing along the lower Omo valley, especially along watering routes and overnight pastures, and settlement close to the rivers indicates that there is some pollution particularly from human and livestock wastes, but incidences of water-borne diseases do not appear to have increased significantly. There is a need to establish groundwater resource value and to initiate its sustainable development as a source of potable water in the region. Food security is inextricably linked to the freshwater resources. With the very low rainfall in the region, an increasing number of people are shifting from pastoralism to agro-pastoralism and becoming more vulnerable as a consequence. The unsustainable abstraction of Omo River waters in upstream areas is beginning to impact on downstream users. Droughts in the past have exacted high costs in terms of loss of life of humans and livestock and the drought impact will likely increase as the freshwater resources dwindle.

Freshwater shortage is likely to become more acute as more and more water is diverted from the rivers to adjacent farms, and will be acutely accentuated during periods of drought. The higher populations close to the riverbanks are also likely to pollute the waters to significant levels, thus rendering the freshwater shortage more acute because of its reduced quality. Economic impacts on downstream settlers will become worse because it would become increasingly more difficult to maintain high agricultural productivity and gain relatively easy access to potable water (i.e. from relatively shallow wells) as more of the freshwater is diverted for use upstream. Health impacts will increase due to lack of sufficient and potable water supplies, and as well to unsanitary conditions in the increasingly settled downstream parts. These factors can lead to a host of diseases such as cholera and typhoid. The potential for upstream/downstream conflicts will further increase, as will population migration.

Pollution

Pollution generally is not a highly ranked problem within the Lake Turkana Basin. It is concentrated mainly in the relatively highly populated Omo River drainage basin. Little or no use of agrochemicals in the adjacent floodplain farms means that water pollution is mainly through contamination by human and livestock waste. The relatively low population density also suggests that pollution of the waters would be a gradual, rather than rapid process, partly constrained by the dilution and dispersion capacities of the rivers and Lake vis-à-vis the initial pollution load.

There is no evidence available to show that microbiological and chemical pollution, solid wastes, thermal, radionuclide, and spills are currently of any threat to the Lake and its rivers. There are basically no industrial, large-scale agricultural or other types of developments in the Basin that can singularly or collectively substantially contribute to pollution of the water bodies. As mentioned before, lack of access to safe water and adequate sanitation remains particularly acute in rural areas of Ethiopia (CIHI 1996) and Kenya (CIHI 1995), but there are no reports available in relation to microbiological pollution to indicate that there is above normal incidence of, or an increase in, bacterial related gastroenteritic disorders in fisheries product consumers. There have not been any fisheries closures or advisories due to outbreaks of gastroenteritic disorders. Most heavy metals are present in low and stable concentrations and are naturally derived: aluminium, iron and manganese fluctuate with rather large changes in concentration in connection with the influx of organic matter (Kallqvist et al. 1988). There is no evidence of significant fertiliser use in the agricultural activities being undertaken along the principal rivers banks (World Lakes Database 2002).

Environmental impacts

Eutrophication

Although fluvial activity is generally infrequent (only the Omo River is perennial), the sediment load is high, in common with other arid environments (up to 1600 tonnes/km^2/year), and delta construction is rapid (Frostick & Reid 1986). There is also increased soil erosion on the banks of the affluent rivers due to human activities (Waktola 1999, Haack & Messina 2001). This has partly contributed to the growth of the Omo River delta, reflecting a measurable shallowing of the depth range of macrophytes. Input of nutrients during the Omo River flood season has been noted as driving phytoplankton population dynamics (Ogari 1981), although there has not been any monitoring programme to determine whether there has been an increasing trend in abundance of epiphytic and planktonic algae with time. During surveys carried out from 1972 to 1975, nitrate and nitrites were frequently undetectable, with maximum concentrations of 17.7 µg/l being noted in the Omo delta and thought to be derived from the Omo River (Ferguson & Harbott 1982). From the low levels of nitrate and nitrite in the inshore and open water of the Lake, Ferguson & Harbott (1982) surmised that nitrates are very rapidly utilised; no nitrate was detected in the highly productive waters of Ferguson's Gulf despite a potentially abundant supply from the excreta of the rich avifauna, cattle and goats, and heterocystous blue-green algae.

Suspended solids

The principal pollution problem in Lake Turkana Basin is that of suspended solids. Yuretich (1979) observed that sediment plumes up to 100 km long extend southward from the Omo River delta during flood seasons. More recent imagery from Landsat and other spaceborne sensors clearly show the heavy sedimentation flow into the Lake (Haack & Messina 2001). The rapid and extensive growth of the Omo River delta over the past few decades reflects significant changes in sedimentation. Today the lake colour, especially in the north, is brown because of increased suspended solids (Haack & Messina 2001). The euphotic zone is about 6 m, and the Lake is always turbid (Kallqvist et al. 1988). Increased population pressure in the drainage basin of the Omo River in Ethiopia has caused increased soil erosion by removal of the vegetative cover for fuel and conversion to agricultural lands (Haack & Messina 2001), increasing the amount of sediment delivery to the River and Lake. Soil loss from the productive land in the upper reaches of the Omo River will take its toll on agricultural productivity. The sedimentation changes that have taken place in the deltas of the Omo and Turkwel rivers, as well as in the northern part of the Lake, have probably affected the local aquatic benthic and/or pelagic biodiversity (e.g. through sediment blanketing and increased turbidity), but studies are needed to ascertain the type and extent of change.

Socio-economic impacts

There are no known studies on the economic impacts of pollution in Lake Turkana. Economic impacts are related to costs incurred to treat diseases (both human and livestock) arising from lack of access to safe water and poor sanitation. There could also be a problem of reduced fish stocks since many of the fish that spawn in the inflowing rivers could be adversely affected by increased sedimentation and turbidity. Additionally, the food chain could have been disrupted as phytoplankton, and other pelagic or benthic organisms, may have been negatively impacted by increased turbidity.

The health impacts are similar to those mentioned under freshwater shortage above. An additional effect may be loss of traditional fishing grounds due to increased sedimentation and turbidity, and hence reduced fish catches and lower protein intake that could lead to malnutrition. Loss of a traditional protein source would increase the vulnerability of the people living in this area to food or essential nutrient shortages. Communities may migrate to areas where there is safe water and/or are suitable for agriculture, resulting in conflicts over land-based resources.

Conclusions and future outlook

The main pollution problem is that of high suspended sediment loads in the affluent rivers, particularly the Omo River. Conservation efforts should be directed at minimising soil erosion. Settlements within the area need to be planned and have proper sanitation facilities, better animal husbandry needs to be incorporated, and clean water sources of potable water, such as groundwater should be explored and harnessed to serve the communities.

If there are no intervention measures taken soon, then increased agricultural activities and land degradation along the rivers will result in increased suspended solids being transported to the Lake. There is a likely increase in the use of agro-chemicals as the land becomes less productive, and this will increase the nutrient loading to the Lake and thus increase the rate of eutrophication. Microbiological pollution which is currently not a major problem will increase due to sanitary problems that accompany the growth of settlements. Livestock waste would also significantly contribute to microbiological pollution of the water bodies. Economic impacts will become worse as sediment blanketing and increased turbidity influences changes in benthic and pelagic biodiversity, affecting the fisheries resources particularly in the riverine, shallow water and deltaic areas where subsistence fishermen fish. Health would be affected as a result of an anticipated increase in microbiological and chemical contamination from organic wastes (e.g. settlements and agro-chemicals). Other social and community impacts would increase as upstream/downstream conflicts increase. Oil exploration efforts offshore of Lake Turkana have been done by several oil companies, including Project PROBE, Amoco Kenya Petroleum Company and National Oil Corporation of Kenya. No economically viable oil deposits have been discovered so far, but this is a prospect which can significantly raise the threat of pollution in the region.

IMPACT Habitat and community modification

Lake Turkana Basin is characterised by arid and semi-arid type vegetation in the lowlands, and forest in highland areas of the Omo River. Grassy plains with Yellow spear grass and *Commuphera* and *Acacia* sp. characterise the vegetation of the lake region, while Acacia thorn scrub, with larger acacia trees along the river courses, grow around the Lake (Hughes & Hughes 1992). Galleries of forest occur along the affluent watercourses, being characterised by *Acacia elatior, Balanites aegyptiaca* and *Hyphaene coriacea* (Hughes & Hughes 1992). The Omo River is bordered by levee forest and the delta was forested in comparatively recent times (Hughes & Hughes 1992).

In the north Omo zone, deforestation is increasing as a consequence of rapidly growing population (Waktola 1999). Cleared lands are more and more being put under cultivation in the highlands, leading to rapid depletion of soil nutrients and forest resources (Waktola 1999). On the other hand, the pastoralists of the Lake Turkana region occupy arid and semi-arid environments where climatic variability causes distinct pulses of plant production followed by long periods of plant dormancy, but in which the pulses of production are not predictable in terms of time or magnitude (Ellis & Swift 1988). The pastoralists have, with time, developed rational sustainable land use systems based on the mobility of their livestock herds, and making optimal use of the land both geographically and ecologically (Barrow 1988). Thus, the major perturbations on the Turkana Basin ecosystem are droughts of a year's duration or longer (Ellis & Swift 1988) rather than human influence through, e.g. over-grazing and biomass burning.

Environmental impacts

Loss of ecosystems or ecotones

The habitats that are affected to varying degrees are the swamps, riparian belts, deltaic wetlands, river floodplains and the periodic standing water in Ferguson's Gulf. There have not been any comprehensive studies on the biodiversity and ecological structure of these ecosystems. It was concluded that loss of ecosystems is occurring in these areas through habitat fragmentation as a result of nutrient rich soils being cleared for agriculture and settlement, and some of the swamps with lush vegetation being used as grazing areas for livestock.

At the Omo River entrance to Lake Turkana, there has developed a highly complex and spatially fluctuating floodplain and delta (Haack & Messina 2001). Landsat imagery has provided spatial information on the extent of the deltaic growth (particularly significant since 1979) (Haack & Messina 2001). Aquatic vegetation has taken hold on the emerging delta at the possible expense of, e.g., shallow water benthic organisms.

Modification of ecosystem habitats or ecotones

Due to climate change and to the extensive land use changes in the region, particularly in the Omo River catchment, the amount of freshwater entering the Lake has declined steadily over the years, resulting in the growth of the Omo delta by about 380 km^2 between 1973 and 1989 as seen from Landsat images (Haack & Messina 2001). The expansion of the delta wetland is potentially maintaining or increasing the biodiversity of fauna and flora, both locally and regionally (Haack & Messina 2001). On the other hand, the good soil, lush vegetation and availability of water is also attracting permanent human populations, most likely in conflict with flora and fauna (Haack & Messina 2001). Similarly, the areas with gallery forest that occur along the affluent rivers (Hughes & Hughes 1992) are being cleared for cultivation.

The Lake has little-modified fauna and a low level of endemicity with few cichlids (Lowe-McConnell 1995). Shallow areas which are flooded during seasonal rises in lake level may be important for the reproduction of certain fish species e.g. tilapia (Kallqvist et al. 1988), and many of the fish retain the habit of spawning in the inflowing rivers (Lowe-McConnell 1995). Construction of artificial banks to create more room for agriculture, changes of the flow characteristics of the rivers due to diversion of water to irrigate adjacent farms, and increased turbidity, may place these fish at risk. It has been reported that there is a decrease in abundance of some species e.g. *Hydrocynus*, *Alestes* and *Schilbe*, and a decrease in individual mean size at first maturity of fish.

Socio-economic impacts

The economic impact of deforestation in this area has not been determined. However, the decline in fish landings due to the collapse of the tilapia fisheries in the Ferguson Gulf had a relatively high economic impact. The number of people estimated to be involved in commercial fisheries in Turkana District in 1982 was 30 000 to 40 000 (Kallqvist et al.

1988). This is a significant proportion of the districts total population of 230 000 in 1988 (lower in 1982) (Kallqvist et al. 1988). Reduced fish landings and marketing problems subsequently led to fisheries being much less profitable: the main reason for the decline in fish landings was the collapse of the tilapia fisheries in the Ferguson's Gulf area due to overexploitation and habitat change resulting from lowered lake levels (affecting spawning grounds), and today Lake Turkana has less than 3% of total fish catches in Kenya (Ikiara 1999). Loss of existing income in the only economic sector (fisheries) had therefore a severe effect, and the effects of the fisheries collapse due to habitat change have persisted over time. There are virtually no other employment opportunities for the local populations.

Fish is a primary source of protein in the area. Drastically reduced fish landings due to habitat change particularly in Ferguson's Gulf and reduced opportunities for fisheries in the Omo River delta area has negatively impacted on the nutritional status of the population. Although the food poverty level in some areas, e.g. Turkana District is high (81%) (Republic of Kenya 2002b), the degree of severity is not very high as there are alternative protein sources (primarily livestock). The lack of adequate protein supply is continuous, and its improvement is dependent on revival of the fisheries industry.

High rates of deforestation are recorded in the arid and semi-arid lands of Kenya (including the Lake Turkana Basin area), resulting in loss of indigenous biodiversity, destruction of vital ecosystems and habitats (Kirubi et al. 2000). Reduced capacity to meet the basic human need for food and fuel affects the welfare of the family unit. Global acute malnutrition rates in Turkana have increased to between 18–37% in May 2003 compared to 11–21% during the same time in 2002 (UN Kenya 2003). It is estimated that fuel wood and charcoal constitute 95-99% of the total energy demand for cooking, heating and lighting in the arid and semi-arid lands of Kenya (Kirubi et al. 2000). With the on-going destruction of vital ecosystems and habitats, the already acute situation is likely to get worse. Loss of alternative income has probably affected the family units' ability to afford education, health services, etc., although there is no quantitative information available on its impact.

Conclusions and future outlook

There have not been any comprehensive studies on the biodiversity and ecological structure of the wetland ecosystems that are being increasingly impacted by human activities including sedimentation and modification of river flow. Studies need to be carried out to establish what types of ecosystem habitats have been lost. The economic impact of deforestation in this area has not been determined. Fisheries offer a source of livelihood for the locals and attempts should be made to revive the commercial fishery. There are virtually no other employment opportunities for the local populations.

Better land use practices are critical for the conservation, sustainable use and management of habitats. There is a critical need to initiate studies to understand the natural and socio-cultural drivers of the habitat dynamics that have been observed in the region so that effective implementation policies can be drafted. In the absence of any interventions, it is expected that the economic impact would become more severe as a result of further ecosystem loss and habitat modification. Subsistence fisheries would be most affected as shallow aquatic areas are lost to land, reducing the local populations capacity to meet basic food needs. This, in turn, would increase health risks. The prospect of human conflict would also increase as populations migrate to areas which still retain their ecosystem integrity.

IMPACT Unsustainable exploitation of fish and other living resources

There are four fish communities in the Lake (Table 12): littoral, from the lakeshore to about 4 m deep; inshore demersal, from the littoral zone to 10-15 m deep; offshore demersal, from 8-20 m offshore and about 3-4 m above the lake bottom; epipelagic, subdivided into a superficial pelagic community above a midwater scattering layer and a deep pelagic community below this layer down to the demersal zone, extending down to some 60 m in the deepest part of the Lake (Lowe-McConnell 1995). The boundaries of the various communities shift seasonally, depending on the depth of light penetration (Lowe-McConnell 1995).

The Lake is currently largely unexploited but has the potential for fishing and tourist attraction (Republic of Kenya 2002a and b). There is no evidence of decreased viability of stocks through contamination and disease, nor of destructive fishing practices.

Environmental impacts

Overexploitation

Fishing takes place both in the unprotected Omo River delta (Hughes & Hughes 1992) and in the Lake. Based on measured primary phytoplankton productivity, an empirical model predicted a total fish yield of 22 000 tonnes per year for Lake Turkana, and the sustainable yield of traditionally exploited fish from the offshore areas of the Lake is estimated at 15 000 to 30 000 tonnes per year (Kallqvist et al. 1988). The fisheries of Lake Turkana are, today, operating way below their

Table 12 Fish species and habitats in Lake Turkana.

Community	Fish species	Habitat
Littoral	*Oreochromis niloticus, Clarias lazera*	Throughout littoral zone
	Sarotherodon galilaeus, Alestes nurse, Micralestes acutidens, Chalaethiops bibie	Over soft deposits
	Tilapia zillii, Leptocypris ('Barilius') niloticus	Over rocky or stony bottoms
	Haplochromis rudolfianus, Aplocheilichthys rudolfianus	Among emergent or submerged macrophytes
Inshore demersal	*Labeo horie, Citharinus citharus, Distichodus niloticus*	Over hard substrates
	Bagrus docmac	Over rocky areas
Offshore demersal	*B. bayad, Haplochromis macconelli* (endemic), *Barbus turkanae*	Deep water
Epipelagic	*Alestes minutus, A. ferox* (both endemic)	Pelagic zone - midwater scattering layer
	Alestes baremose, Hysrocynus forskahlii, postlarval *Neoboa stellae,* juvenile lake prawns	Superficial pelagic zone - above midwater scattering layer
	N. stellae, Lates longispinus, Schilbe uranoscopus, adult prawns	Below midwater scattering layer

(Source: Lowe-McConnell 1995)

sustainable yield limits. The impact of overexploitation is scored as slight based on the criteria that "commercial harvesting exists but there is no evidence of overexploitation".

Excessive by-catch and discards

Although there is no information on current excessive by-catch and discard, the issue was categorised as having a slight impact based on the fishing practices that partly led to the collapse of the fisheries sector in the 1980s and the under-recovery of the fish stocks in traditional fishing bays such as Ferguson's Gulf.

Impact on biological and genetic diversity

The introduction of alien stock (Nile perch) is considered as having a slight impact because there is, apparently, no evidence that it has caused major changes in the community structure of the Lake.

Socio-economic impacts

Fisheries is currently mainly a subsistence activity that is not contributing much to the economy of the area. Today, Lake Turkana has less than 3% of total fish catches in Kenya (Ikiara 1999), and most of the proceeds from fish sales are expatriated to other parts of the country. There are no known health impacts except those that may arise from consumption of naturally diseased fish (which has a very low probability). There are no social impacts as the current fish landing rates are far below the sustainable yield of the Lake's fisheries resource. Fishing is mainly at subsistence level.

Conclusions and future outlook

Although the Lake Turkana fisheries sector contributes little to the economies of Kenya and Ethiopia, it provides the riparian inhabitants with food options particularly during periods of drought. The remoteness of the site and lack of infrastructure is the major stumbling block in the development of a thriving fisheries sector in the region.

Fisheries is currently mainly a subsistence activity that is not contributing much to the economy of the area. The resurgence of commercial fisheries would have positive effects on the economy of the area. Because of the increasing density of settlements and population growth in the area, and the harsh environmental conditions that does not support high agricultural productivity, there may be increased consumption of fisheries products. Social conflicts are likely to flare up particularly between commercial and subsistence fishermen as fishing grounds for the latter have been reduced by freshwater shortage, pollution, ecosystem change and global change.

Global change

The Lake Turkana Basin is prone to frequent droughts. Drought is reportedly occurring more frequently (Waktola 1999), with elders in Turkana recalling recent droughts in: 1984, 1992-93, 1996, 1997, 1999, and 2000 (Hann et al. 2003). The rainfall pattern and distribution is erratic both in time and space, and it tends to fall in brief, violent storms that result in flash floods (Republic of Kenya 2002b). Lake Turkana responds drastically to climatic variability.

There is no evidence (no studies carried out) of increased UV-B radiation as a result of ozone depletion or of changes in lake CO_2 source/sink function. Some gas charged sediments are reported in Lake Turkana from seismic profiling, but no further work has been done to verify and quantify the flux.

Environmental impacts

Changes in hydrological cycle and lake circulation

The growth of the delta (Haack & Messina 2001) is partly a result of increased aridity. Both a decrease in precipitation within the catchment basin and an increase in temperature can be contributing factors. An increase in temperature would increase evaporation rates from the surface of the Lake and elsewhere in the region and decreased soil moisture would lessen run-off.

An annual cycle of stratification of the lake waters was observed in 1988: stable stratification from March to May and complete circulation in June to July (Kallqvist et al. 1988). The stratification influenced the distribution of fish in the deep water over as much as 20% of the lake area (Kallqvist et al. 1988). For the rest of the year, there is partly restricted vertical mixing with a temperature gradient of 1 to 2°C from the surface to the bottom at 70 m (Kallqvist et al. 1988).

Lake-level change

On a perennial basis the lake level fluctuates about 1 m every year from the seasonal flooding of the Omo River (Ferguson & Harbott 1982) and has fluctuated over 20 m in the past century (Butzer 1971). It was 15 m higher at the end of the 19th century and 5 m lower in the 1950s (Figure 14). These changes were climatic and to a lesser extent geomorphological in origin. The changes since then are more dramatic and more likely to be anthropogenic (Haack & Messina 2001).

Socio-economic impacts

Lack of potable freshwater and food during periods of drought have incurred high economic costs to the two countries at large in terms of resettlement and food aid (Waktola 1999, Hann et al. 2003). Declining water levels in Lake Turkana led to the collapse of the fishing industry at Kalokol as the catch declined and the shoreline moved 6 km away from the only cooling and fish-processing plant. Lack of potable water and food during periods of drought leads to malnutrition and even deaths. In southern Ethiopia, for example, during the famine in 1985-86, there was a 40% increase in mortality among children under five years old in "traditional and stable societies" and a three- to fourfold increase for those who were living in relief shelters (CIHI 1996). A lack of potable water and food during periods of drought leads to large-scale displacement of populations and fragmentation of family units. Most of the poorest people in Turkana District dwell in the northern part and central plains where there is recurrent drought and disease (Turkana District Development Plan 2003). Social conflicts increase over the sharing of limited resources (cf. Raymakers 2003). It takes a fairly long time to revert back to the normal way of life after such events. For example, during the severe drought that was experienced in 1999–2000 in the Lake Turkana area, there was heavy loss of livestock resulting mainly from lack of forage and disease outbreaks, reduced agricultural production, necessitating the remobilisation of resources to save the lives of both humans and livestock through the provision of water, relief food and food supplements, disease control, and provision of health services (Republic of Kenya 2002b). Cattle rustling, which is rampant in the area around Lake Turkana, is probably partly driven by the need to re-stock livestock herds that have been devastated by drought. Cattle rustling and bandit raids lead to loss of life, loss of property, displacement of families, destruction of infrastructure such as schools, health and water facilities, and disruption of education and farming (Republic of Kenya 2002b).

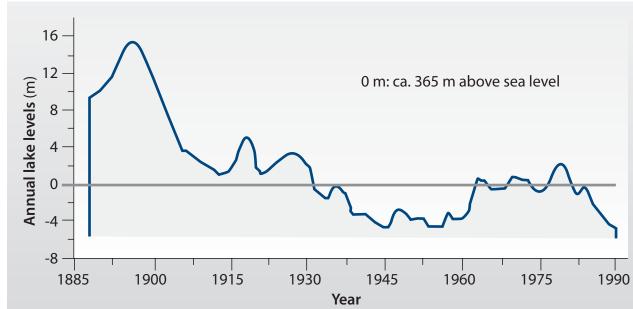

Figure 14 Fluctuations in the level of Lake Turkana, 1888-1990.
(Source: World Lakes Database 2002)

Conclusions and future outlook

The projected increases in global temperatures are expected to lead to significant local changes in precipitation and evaporation. The volume and level of Lake Turkana is likely to continue fluctuating widely, with a probable overall downward trend due to global warming and to the intensification of land and water use in the catchment (Nyamweru 1992). These changes in lake level will have significant effects on the lacustrine wetlands (Nyamweru 1992) and biodiversity, e.g., upstream of the Omo River delta is an extensive floodplain: the existing combined wetland (4°28'-5°13' N; 35°44'-36°13' E) covers 120 000 ha (Hughes & Hughes 1992). Higher temperatures may also result in longer periods of stratification in lakes with reduced dissolved oxygen contents. During periods of stable stratification, there can be conditions where reduced dissolved oxygen will affect fishes, as was noted in May 1988 when stable stratification influenced the distribution of fish in the deep water over as much as 20% of the lake area (Kallqvist et al. 1988). Reduced lake levels will also result in increased salinity and pH of the water, which would have adverse effects on phytoplankton, zooplankton, fish biodiversity and fish stocks. Changes in water quality will also affect the avian fauna, particularly water-edge and migrating birds.

Priority concerns

The concerns that are recommended for further analysis based on the outcome of the GIWA assessment are: Habitat and community modification and Freshwater shortage. The concerns were ranked in descending order of severity:

1. Habitat and community modification
2. Freshwater shortage

3. Pollution
4. Global change
5. Unsustainable exploitation of fish and other living resources

Habitat modification is a result of all the other four GIWA concerns, although Unsustainable exploitation of fish and other living resources is the least significant in this case and is not discussed further. With respect to Global change, the trend of reducing precipitation and higher temperatures can result in increased concentrations of pollution in the Lake due to reducing lake level (and volume). However, global change is more important in its influence on freshwater through the hydrological cycle. It can also drive habitat change but this, as a naturally occurring process, would be on the order of decades to millennia. Pollution, which in this case is due mainly to suspended sediments that originate from habitat change (land clearance, degradation and increased erosion rates) in the principal river catchments, can affect natural habitats in the Lake by limiting light penetration and smothering benthic organisms. High microbiological load also reduces the availability of potable water. Freshwater shortage is most closely linked to habitat modification. The freshwater shortage arises primarily due to abstraction of river water for irrigation, and damming. This has, in part, led to rapid delta growth and hence modification (e.g. loss of ecosystems and changes in population structure) of the wetland areas in the deltaic and floodplain areas of the principal rivers, as well as in the littoral waters of the Lake. The linkages between the GIWA concerns are shown in Figure 15.

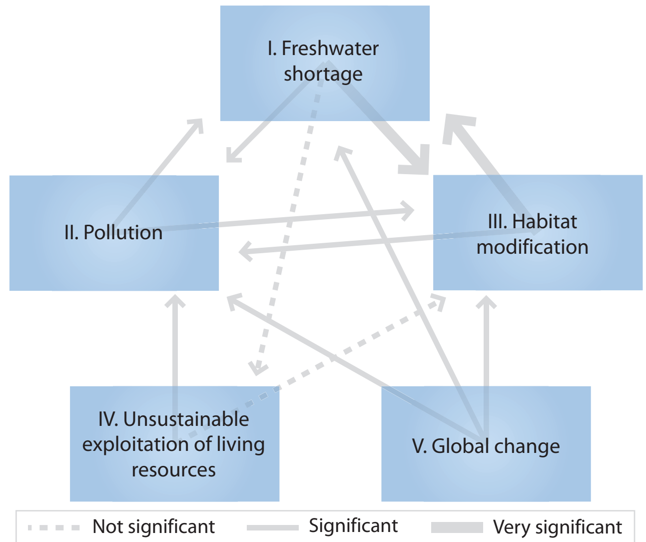

Figure 15 Linkages between the GIWA concerns in Lake Turkana.

Lake Victoria Basin

Table 13 Scoring table for Lake Victoria.

Assessment of GIWA concerns and issues according to scoring criteria (see Methodology chapter)

IMPACT 0 No known impacts; IMPACT 1 Slight impacts; IMPACT 2 Moderate impacts; IMPACT 3 Severe impacts

The arrow indicates the likely direction of future changes.

↗ Increased impact
→ No changes
↘ Decreased impact

Lake Victoria	Environmental impacts	Economic impacts	Health impacts	Other community impacts	Overall Score**	Priority***
Freshwater shortage	1.7* ↗	0.1 ↗	0.6 →	1.0 →	**1.3**	5
Modification of stream flow	1					
Pollution of existing supplies	2					
Changes in the water table	2					
Pollution	2.6* ↗	2.0 →	2.0 ↘	2.0 ↘	**2.1**	1
Microbiological pollution	3					
Eutrophication	3					
Chemical	2					
Suspended solids	3					
Solid waste	1					
Thermal	0					
Radionuclide	0					
Spills	0					
Habitat and community modification	2.5* ↗	1.1 ↘	1.2 ↘	1.0 →	**1.5**	3
Loss of ecosystems	2					
Modification of ecosystems	3					
Unsustainable exploitation of fish	2.6* ↘	2.4 ↘	2.2 ↘	2.1 ↘	**1.9**	2
Overexploitation	3					
Excessive by-catch and discards	2					
Destructive fishing practices	3					
Decreased viability of stock	2					
Impact on biological and genetic diversity	2					
Global change	1.0* ↗	1.3 ↗	1.4 →	1.0 →	**1.3**	4
Changes in hydrological cycle	1					
Sea level change	1					
Increased UV-B radiation	0					
Changes in ocean CO_2 source/sink function	0					

* This value represents an average weighted score of the environmental issues associated to the concern. For further details see Detailed scoring tables (Annex II).

** This value represents the overall score including environmental, socio-economic and likely future impacts. For further details see Detailed scoring tables (Annex II).

*** Priority refers to the ranking of GIWA concerns.

Freshwater shortage

The waters of Lake Victoria and its shoreline are shared between three countries; Kenya (6%), Uganda (43%) and Tanzania (51%). Additionally, the catchment of the principal affluent river, the Kagera, runs through the countries of Rwanda and Burundi. There are 11 main rivers draining into Lake Victoria: Nzoia, Yala, Nyando, Sondu-Miriu, Gucha, Mara, Gurumeti, Duma, Simiyu, Magoga, Isonga and Kagera (Figure 16, Table 14) (Shepherd et al. 2000). Of these, only two are shared; the Kagera by Tanzania, Rwanda, Burundi and Uganda; and the Mara by Kenya and Tanzania. The only surface outlet is the Nile River, which has the Owen Falls hydroelectric power station at its source.

Freshwater shortage has only slight impact in Lake Victoria Basin. The freshwater shortage in the Lake Basin, most of which is due to pollution of existing supplies, is driven principally by pollution as a major concern. This issue is, therefore, tackled in more detail in the section on Pollution.

Environmental impacts

Modification of stream flow

Some of the inflowing rivers from the catchment have been modified by activities involving irrigation (Nyando, Yala and Kagera rivers), valley dam construction (Sondu-Miriu and Yala rivers) and for others, the flood plains and wetlands have been degraded (most of the affluent rivers). This leads to reduction of inflow (Scheren et al. 2000, Lowe-McConnell 1994, Awiti & Walsh 2002), but the effects are constrained mostly in the specific river drainage basins where water is being abstracted, since direct precipitation on the Lake is by far the dominant principle source of water in the lake system. Out of the total irrigation potential of 469 400 ha in Kenya, 214 000 ha (46%) lies within the Lake Victoria Basin where the unexploited potential is still large (Marenya & Nyaguti 2000).

Table 14 Demographic and biophysical characterisation of the inlet drainage basins of Lake Victoria.

River basin	Countries sharing basin	Basin size (km²)	Population density 2000 (people/km²)	Total population 2000	Mean annual rainfall (mm)	Sediment transport capacity index*	Average % slope
Nzoia/Yala	Kenya	15 143	221 (±154)	3 346 000	1 306	0.14	2.3
Nyando	Kenya	3 517	174 (±127)	611 000	1 360	0.30	5.0
Sondu Miriu	Kenya	3 583	220 (±148)	788 000	1 415	0.14	2.3
Gucha	Kenya	6 612	224 (±183)	1 481 000	1 300	0.16	2.0
Mara	Kenya Tanzania	13 915	46 (±56)	640 000	1 040	0.15	2.0
Gurumeti	Tanzania	12 290	21 (±26)	258 000	879	0.12	1.6
Mbalaget	Tanzania	5 702	37 (±22)	211 000	766	0.05	0.6
Duma/ Simiyu	Tanzania	9 702	50 (±26)	485 000	804	0.06	0.5
Magoga/ Muame	Tanzania	5 104	88 (±47)	449 000	842	0.05	0.4
Isonga	Tanzania	8 972	48 (±22)	430 000	897	0.04	0.3
Kagera	Tanzania Uganda Rwanda Burundi	59 158	181 (±196)	10 711 000	1 051	0.24	3.0
Lake edge	Kenya Tanzania Uganda	40 682	133 (±175)	5 411 000	1 077	0.21	1.4

** Areas with high indices are those with higher potential for erosion.*

(Source: Shepherd et al. 2000)

Figure 16 The major drainage basins of Lake Victoria.

Pollution of existing supplies

Lake Victoria provides freshwater supply for domestic, agricultural, livestock and industrial use. Tropical lakes are at particular risk from pollution hazards, owing to the lower oxygen saturation levels and high oxygen consumption rates which occur at high temperatures (Cohen et al. 1996). In Lake Victoria, pollution is a major problem. Since the 1960s, the Lake has experienced a serious decline in water quality (microbiological and chemical contamination, increased suspended solids, etc.) negatively impacting on dependent communities. Several chemical pollution studies have detected low levels of trace metals and pesticides in the water, sediments, plants, and fish species of the Lake (Wandiga1981, Wandiga & Onyari 1987, Ejobi et al. 1994, Ruud 1995, Wasswa 1997, Ssentongo 1998, Henry & Kishimba 2000, Tole & Shitsama 2000, Kituyi et al. 2001, Kasozi 2001). However, though the concentration levels are below the acute toxicity level they may be of concern to the food chain (Wandiga 2002).

Many rivers and even sewerage outlets drain through swamp areas before discharging to the open waters of Lake Victoria. When flowing slowly through the swamp, the biological oxygen demand (BOD), nutrients, pathogens and other pollutants in the water generally reduce (Kansiime & Nalubega 1999, LVEMP 2001). The wetlands environmental function as a sink for pollutants is, however, potentially in danger through loss of ecosystem function as a result of harvesting, clearing, cultivation and diversion of water for irrigation agriculture (Balirwa 1998, Chapman et al. 2001, LVEMP 2001).

Changes in the water table

Groundwater stored within the Lake Victoria catchment was estimated in 1979 to be of the order of 70 000 million m^3, while the total annual groundwater discharge was about 18 million m^3, of which 7.5 million m^3 was discharge to streams and 4.9 million m^3 was that extracted by pumping (Ongwenyi 1979). These are broad estimates in view of the fact that no quantitative assessment has been attempted (Ongwenyi 1979). In the Kenya sector, the groundwater is of excellent chemical quality (total dissolved solids concentration is of the order of 500 ppm and rarely exceeds 1000 ppm) and can be put to a variety of uses (Ongwenyi 1979). The only problem is that in places the groundwater contains excessive fluoride concentrations far in excess of the 1.5 ppm stipulated for drinking water purposes (Ongwenyi 1979). The expansive and continual land degradation, soil erosion and deforestation that has been taking place over the past few decades within Kenyan sector of the catchment (Swallow et al. 2002), provides indirect evidence that there is declining base-flow in rivers. There have been reports of over-abstraction of water in some wells within the region, but the regional extent of this is not known. Studies are required to quantify base-flow in rivers and to establish the regional nature of the groundwater aquifers in the Lake Basin, their quantity and yield, in order to be able to sustainably manage the resource.

Socio-economic impacts

There are no significant economic impacts arising from freshwater shortage in the Lake Basin. Treatment of common water-borne diseases and loss of income due to incapacitation has some effect on economic activities and livelihoods in the Basin, and is particularly exacerbated by the generally high poverty levels. Many of the people living in villages along the shoreline and close to the rivers in the catchment area as a whole draw their water directly from these sources for domestic use and consumption without any treatment (Bwathondi et al. 2001, Thompson & Cairncross 2002). Except for the urban centres, the rural settlements do not have any treated water supply networks nor sanitation infrastructure. Although more homes are today supplied with piped water, the supply is irregular and unevenly distributed (Thompson & Cairncross 2002). Nzoia, Yala, and Nyando rivers (Shepherd et al. 2000) and the lake area around the large urban centres such as Kisumu, Kampala and Mwanza, are the most polluted. Along the lake edge, the problem has become worse because the water is often dirty and smelly because of the rotting mats of hyacinth weed (NEMA 1998, Mailu 2001), even in areas that are far removed from urban centres. Groundwater development projects conducted by NGOs in these areas have somewhat mitigated the impact of use and consumption of polluted water. Polluted water supplies compel the affected communities to search farther away from their villages for sources of clean water. These sources are normally groundwater wells and boreholes that have been constructed by NGOs and national governments.

Conclusions and future outlook

Other than the pollution of existing supplies, freshwater shortage is not yet a critical problem in the Lake Basin. The Kenya National Water Master Plan includes plans for dams and water transfer projects from the Basin to other river basins or sub-basins in the country (UNECA 2000). There are several localities within the Lake Basin in Kenya where dams have been proposed, and recently the Sondu-Miriu Dam on Sondu-Miriu River has been built mainly for hydroelectric power supply. Tanzania also plans to transfer water from the Lake to the Vembere Plateau in the Manonga River Basin in central Tanzania to irrigate between 88 000 and 230 000 ha of land (UNECA 2000). The effects of this structure and others proposed may lead to freshwater shortages. Land degradation and deforestation in the watershed regions and the catchment as a whole will steadily lead to the depletion of natural water supply (both surface and groundwater) in the drainage basin, with adverse consequences.

Interventions are required to initiate sustainable development within the catchment to protect the critical watershed areas and aquatic systems. Maintenance of the status quo would have adverse impacts in the long run. Economic impacts will arise due to loss of; agricultural uses and productivity (crops, livestock, aquaculture), hydroelectric power production, and industrial uses. There would also be increased costs of intake treatment and damage to water-related equipment. Freshwater shortage would also lead to loss of human drinking water supplies, recreational use and aesthetic values, and waste assimilative capacity. There will be increased potential for upstream/downstream conflicts, and reduced availability of fish as food.

IMPACT Pollution

In Lake Victoria and its influent rivers, pollution is a major problem. From the catchment areas, there are: diffuse pollution sources such as silting and agrochemicals which increase biological oxygen demand (BOD) and fertilise the Lake; and point pollution sources including industrial wastewater effluents and solid wastes, domestic sewage and organic and microbial loads (Wandiga & Onyari 1987, Kansiime & Bugenyi 1996, Kansiime & Nalubega 1999, Scheren et al. 2000).

Most of the farming systems in the Lake Basin are associated with slash and burn land management practices. Burning residues left in forest timber harvesting produce an even greater increase in the release of ions from the forest litter and mineral soil than the harvesting operation itself. The impact of these ions (most of which are nutrients like nitrate, phosphate and sulphate) on the Lake has been an increase in eutrophication (Hecky 1993). Nutrient loads to the Lake are associated mainly with atmospheric deposition (natural and biomass burning) and land run-off (e.g. agriculture), and these together account for about 90% of phosphorus and 94% of nitrogen input to the Lake (Scheren et al. 2000). Other nutrient sources include riverine input, nitrogen fixation, the upward flux of nutrients from the water layers below (Hecky 1993), and sewerage effluents from urban centres. Millions of litres of untreated sewage sludge flow into the Lake every day from major urban centres along the lake shore (Scheren et al. 2000). In Uganda for example, expired chemicals as well as drugs and partially treated domestic sewage from the Kampala area is dumped into public waterways, which finally ends up in Lake Victoria (Kiremire 1997).

Environmental impacts

Microbiological

Microbial pollution is a big problem with many incidences of epidemics of cholera, dysentery and intestinal problems (e.g. Karanja 2002). There are major urban centres located near the Lake, such as Kampala and Entebbe in Uganda, Bukoba and Mwanza in Tanzania, and Kisumu in Kenya. Large sectors of these and other urban-periurban centres either do not have, or are poorly served by a public sewerage system; raw sewage is discharged directly into the Lake (Nriagu 1992). Pit latrines are the most common method of on-site sanitation in Mwanza. This leads to seepage of sewage to low-lying areas and streams. In 1995, with the exception of the Mwanza Tanneries, which had a wastewater treatment facility, all the industries in Mwanza drained their wastewaters into Lake Victoria without any treatment (Kishimba & Mkenda 1995), and the situation remains significantly unchanged to date.

Eutrophication

Eutrophication has increased drastically within the last four decades due to high levels of nutrients (Hecky 1993). Landscape disturbance from the 1930s onwards, and the resulting increase in soil erosion and sedimentation is the dominant cause of the ongoing eutrophication (Verschuren et al. 2002). Algal blooms have increased since the 1960s (Mugidde 1993). The filamentous and colony forming blue-green algae, known for causing hypoxic conditions that occasionally lead to fish kills is now very dominant in Lake Victoria (Kling et al. 2001). Domestic biological oxygen demand exceeds industrial loads in all regions (Scheren et al. 2000). The use of agrochemicals is increasing in the Lake Basin where there are large-scale farms of coffee, tea, cotton, rice, maize, sugar and tobacco (Ntiba et al. 2001). Consequently, nearly half of the lake floor currently experiences prolonged anoxia for several months of the year, compared to the 1960s when anoxia was localised and sporadic (Talling 1965 and 1966, Hecky 1993). Algal concentrations are three- to fivefold greater in the surface waters today than in the 1960s, reflecting higher rates of photosynthesis (Mugidde 1993). In consequence, dissolved silica concentrations in the water column have plummeted to 10% of their 1960s values (Hecky 1993, Verschuren et al. 2002). Enhanced denitrification has lowered the N:P ratio and blue-green algae have replaced diatoms as the dominant phytoplankton in the Lake (Hecky 1993, Verschuren et al. 2002).

From satellite imagery, it has been observed that nutrient-rich sediment plumes originating from agricultural run-off and the low-lying, deforested riparian zones and other areas surrounding the Lake are feeding the water hyacinth (Wilson et al. 1999). For instance, in September 1998 the water hyacinth mat covered 400 000 ha of the Kavirondo Gulf in Kenya (Figure 17). In the same year, four-fifths of Uganda's shoreline was covered by the hyacinth mat. Its spread has disrupted fishing activities, transportation, and has threatened the functioning of various lakeshore-based installations such as water purification and hydroelectric power plants (e.g. Twongo 1996). Proliferation of the water hyacinth leads to reduced oxygen levels, and hence reduced floral and faunal diversity (Kudhongania et al. 1996). A study in the Ugandan part of Lake Victoria has shown that in the vicinity of the water hyacinth mats, fish species number, biomass and diversity are reduced, the former two very significantly (Willoughby et al. 1996). It, however, provides a protective habitat for some of the endangered haplochromine species, hippopotamus, crocodiles, snakes, as well as bilharziasis carrying snails and mosquitoes.

Figure 17 Water hyacinths.
(Photo: Still Pictures)

The extinction of the haplochromine species have been attributed to occurrence of seasonally persistent deep-water anoxia since the late 1970s (Kaufman & Ochumba 1993, Hecky et al. 1994); decimation of demersal haplochromine fish stock by Nile perch since the former deep-water refugium that protected them from predation had been destroyed by lack of oxygen; and historical land use that resulted in massive nutrient load with subsequent algal production in Lake Victoria (Verschuren et al. 2002). The last cause indicates that landscape disturbance rather than food-web alteration or climate change is the dominant cause of the ongoing eutrophication. All the three factors have contributed to species decline with the major cause being attributed to land management whose control remains the significant remedy for saving the Lake.

Chemical

The use of agrochemicals is increasing in the Lake Basin where there are large-scale farms of coffee, tea, cotton, rice, maize, sugar and tobacco (Ntiba et al. 2001). In the industrial sector, the polluters include e.g. breweries, sugar refineries, soft drink and food processing factories, oil and soap mills, leather tanning factories and mining companies (Ntiba et al. 2001). Pollution has also been reported in feeder rivers and streams (e.g. Wandiga & Onyari 1987, Kishimba & Mkenda 1995). Beer brewing, pulp and paper production, tanning, fish processing, agro-processing and abattoirs discharge raw/untreated waste to feeder rivers and lakes (e.g. Wandiga & Onyari 1987, Ntiba et al. 2001). All these have contributed to the degradation of river and lake water quality for habitat and drinking use (Wandiga & Onyari 1987, Ntiba et al. 2001).

Several chemical pollution studies have detected low levels of trace metals and pesticides in the water, sediments, plants, and fish species of the Lake (Wandiga & Onyari 1987, Wasswa 1997, Ejobi et al. 1994, Kasozi 2001, Ssentongo 1998, Henry & Kishimba 2000, Wandiga 1981, Kituyi et al. 2001, Ruud 1995, Tole & Shitsama 2000). However, though the concentration levels are below the acute toxicity level they may be of concern to the food chain (Wandiga et al. 2002). The increase of small-scale gold mining in Tanzania in particular (gold mining also takes place in Kenya) is leading to some contamination of the local waterways by mercury which is used to amalgamate and recover the gold; some traces of heavy metals such as chromium and lead are also found in the Lake, although the problem has not yet reached major proportions. Expired pesticides are disposed of in the Lake, for example, used chlorine has been dumped into the Lake killing a lot of aquatic organisms. Some companies have stockpiles of banned substances such as DDT and may potentially dispose of these in the Lake.

Suspended solids

Lake Victoria Basin is mainly (80%) an agricultural catchment (Majaliwa et al. 2000). The current population pressure (more than 30 million people in the catchment) on forests, wetlands, rangelands and marginal agricultural lands as well as inappropriate cultivation practices, forest removal and high grazing intensities (that, in extreme cases, leave barren environments) lead to unwanted sediment and stream flow changes that impact mainly the downstream communities (Magunda & Majaliwa 2000, Botero 1986). Forests and bush are cleared, and wetlands are encroached to create space for human settlement, roads construction and to satisfy wood fuel energy demands. Similarly, pastoral areas are subjected to growing human and livestock populations, leading to land degradation, soil erosion and to an increase in the load of non-point pollutants. Land use activities that alter the type or extent of vegetative cover on watersheds frequently will change water yield and in some cases, maximum and minimum stream flow. The overall effect of deforestation/change of plant species because of population pressures has increased sediment loading to rivers and lakes in the Basin (Swallow et al. 2002). The sediment loads from such areas are normally high in nutrients and organic matter (Ffolliot & Brooks 1986).

Solid waste

Solid waste pollution is localised in areas with high population densities, such as the downstream sections of the rivers, and around the lake edge close to urban centres or settlements (personal observations). These waterways are used for dumping of various types of solid wastes such as plastics, scrap metals, paper, wood and other types of waste from cottage industries, etc. (personal observations).

Socio-economic impacts

The costs are related to wastewater treatment, the cost of alternative supplies and the costs of removing invasive weeds (Twongo 1996) plus the costs of treating diseases (Karanja 2002). The cost of treating the water before supplying it to the public is high because of the diverse range and high concentrations of pollutants in the water. Suspended solids also raises cost in relation to reduced output capacity and cleaning of turbines at the hydroelectric power stations, and reduces the lifespan of dams. The fish kills, migration of fish from certain areas because of anoxic conditions (Hecky 1993) and the cyanotoxins (Mugidde 1993) negatively impact on the output from the fisheries industry. An additional effect on this sector is due to loss of income from fishing because of e.g. fish gill clogging by the suspended solids (Awiti & Walsh 2002, Kairu 2001). Pollution and unhygienic conditions resulted in great economic loss (estimated at 300 million USD) after the European Union temporarily banned fish imports/exports to Europe from East Africa in 1997 because of the fear of the contaminated fish.

There are many people affected by pollution through using and bathing in dirty Lake Victoria water or influent river waters. Dumping untreated sewage in the Lake and nearby rivers exposes people to water-borne diseases, water-related vector borne diseases, faecal/orally transmitted diseases, and health issues related to exposure to agro-chemical residues (Karanja 2002). These health problems include malaria, cholera, schistosomiasis, typhoid, and dysentery. In several towns around the shores and in the vicinity of the Lake, many epidemics of cholera, dysentery and other water-borne diseases have been experienced. The cyanotoxins make the drinking water unpalatable to animals and affect the people who drink and bathe in this water. The algal blooms become unsightly after sometime, and have a foul odour. The effects of the deteriorating state of the Lake on fish productivity also has negative implications on the dietary needs of the riparian communities.

Cockburn & Cassanos (1960) first addressed the association of the bacterium *Vibrio cholerae* with plankton, observing a correlation between the incidence of cholera and presence of increased numbers of blue-green algae in the water. Cholera and bacillary dysentery have become endemic within the lake population in recent years. During an outbreak of cholera in western Kenya between June 1997 and March 1998, there were 14 275 cholera admissions to hospitals in the Nyanza Province, and a total of 547 cholera-related deaths reported (Shapiro et al. 1999). A case-control study to identify major risk factors was conducted at seven sites in the Asembo region, a rural area bordering Lake Victoria. Drinking water from Lake Victoria was found to be one of the independent risk factors for illness. A larger geographical analysis showed that diarrhoeal patients who had V. cholerae were more likely to live in a village bordering Lake Victoria than were those with other pathogens identified. The authors speculate that infestation of the Lake with water hyacinth may lead to improved survival of *V. cholerae* and provide a reservoir of endemic infection (Shapiro et al. 1999).

The Lake Victoria region in Kenya has long been described as one of the major endemic areas of schistosomiasis in the world (Nelson et al. 1962 in Karanja 2002). This situation is unlikely to have changed since the number of people infected or at risk of being infected with schistosomiasis in many areas has reportedly increased over the last 50 years. The snail vectors that transmit both the intestinal *Schistosoma mansoni* and urinary form *S. haematobium* are widely distributed throughout the Lake Victoria Basin. Schistosomiasis has been shown to be very closely associated with Lake Victoria in the three East African countries of Uganda, Tanzania and Kenya (Kabatereine et al. 1996, Karanja 2002, Masaba 1980, McClelland & Jordan 1962). Lake Victoria Basin is characterised by stable endemic malaria (Bloland et al. 1999) with malaria-associated anemia being a serious cause of morbidity and mortality (Lackritz et al. 1992). The prevalence of malaria in children in Kisumu district ranges from 70-90% (Githeko et al. 1992).

The riparian communities have relied on the Lake as a steady source of fish protein. In recent years the Lake has provided a near constant amount of about 20 000 tonnes of harvestable haplochromine fishes. In the last 40 years the Lake's ability to provide fish has been severely compromised by a host of human impacts. These range from increased soil erosion estimated at 690 million to 19 800 million tonnes per year (Verschuren et al. 2002) with high nutrients, fertilisers and pesticides loads from farming and deforestation activities; increased urban run-off and sewage spills; accidental introduction of water hyacinth; planned introduction of Nile perch; industrial and chemical wastes; and the destruction of wetlands with contaminant sink potential.

Conclusions and future outlook

Microbiological pollution, eutrophication, suspended solids and chemical pollution are the most important issues in this GIWA concern and occur over a significant proportion of the Lake Victoria Basin. All these pose many problems of an economic, social and/or health nature. The certain population increase will increase demand for freshwater and other land-based resources, leading to greater pressure to modify the stream/river flows and higher rates of land degradation. The governments of the region and international agencies such as GEF and the World Bank have provided funds for water quality assessments with a view to mitigate pollution.

Failure to address the pollution concern immediately would have far reaching and adverse consequences. Pollution in its various forms would lead to increased risks to human health, with attendant increased costs of human health protection, costs of medical treatment, cost of water treatment and clean-up, etc. Aquatic species would become increasingly endangered if pollution is not controlled. Because of the increase in population, increase in urbanisation, and with no poverty alleviation programme, there will be a measurable number of people whose health and livelihoods will be impacted, even if there is a general increase in awareness of the problem. Other economic impacts would include increased costs of weed control (hyacinth), intake cleaning and maintenance of monitoring programmes. Improvement in technology would make operations cheaper, despite the high capital cost of investment. The problem of pollution will have to be addressed within the context of a transboundary integrated land and water management plan. Critical habitats such as watershed areas, river banks and wetlands need to be urgently protected, and a quantitative assessment of sources, pathways and fluxes of various types of pollutants needs to be carried out in order to initiate effective interventions. Rules and regulations governing pollution at national and international level need to be reviewed and enforced, while governments need to put in more money into the provision of safe water and the enhancement of sanitation infrastructure in the Basin.

Habitat and community modification

Degraded and deforested lands (including wetlands) are becoming increasingly characteristic features in the Lake Victoria catchment (e.g. Shepherd et al. 2000, Swallow et al. 2002). Land use activities that alter the type or extent of vegetative cover on watersheds frequently will change water yield and in some cases, maximum and minimum stream flow. The overall effect of deforestation/change of plant species because of population pressures is increased sediment loading to rivers and lakes in the Basin. The sediment loads from such areas are normally high in nutrients and organic matter (Ffolliot and Brooks 1986). Most of the farming systems in the Lake Basin are associated with slash and burn land management practices. The estimated extent of change of land cover as a result of human activities has been outlined in the Regional definition section.

Lake Victoria is believed to have been invaded by water hyacinth in the late 1980s (Freilink 1991), through the Kagera River (Twongo 1996), and since then a constant stream of the plant to cover 3 ha per day has entered the Lake. On entering the Lake it found a fertile environment for its multiplication. The weed thrives in bays and inlets which are sheltered from strong offshore and along-shore winds; have flat or gently sloping, relatively shallow shores (rarely deeper than 6 m); and have a muddy bottom rich in organic matter (Twongo 1996).

Environmental impacts

Loss of ecosystems or ecotones

Land degradation and deforestation in the lake catchment area and along the river banks is probably contributing to loss of ecosystems (e.g. Shepherd et al. 2000, Swallow et al. 2002). The acreage under cultivation for cash and food crops (namely tea, tobacco, rice, beans, coffee and sugar cane) in Nyanza province, for example, has increased from about 15 400 ha in 1968 to 157 000 ha in 1991-1992 (Kairu 2001). Studies are, however, needed to quantify the level of ecosystem loss.

Much of the lake margin is swampy, and islands of *Cyperus papyrus*, with its typical associates, detach from the fringing swamps (Hughes & Hughes 1992). The continuous cropping of papyrus along the lake shore could have very serious ecological effects, including the loss of large quantities of nutrients removed with the harvested papyrus biomass that would otherwise be recycled (Muthuri et al. 1989). The interface of papyrus swamps and the open water is also often a chemically rich habitat that harbours a high diversity and biomass of aquatic organisms. The Lake itself contains submerged species such as *Ceratophyllum demersum* and *Potamogeton* spp. around the margins, waterlilies and *Pistia stratiotes* are found floating in quiet spots, and there are many animals including water turtles, aquatic snakes, monitor lizards, crocodiles, numerous birds, rodents, otters and *Hippopotamus amphibius* (Hughes & Hughes, 1992).

Ecosystem changes in the catchment area include, for example, the large-scale draining of the Yala swamp in Kenya to create land for agriculture and settlement (Grabowsky & Poort 1987). Also, clearing of riparian vegetation has led to erosion and loss of vegetation that acted as filters (Lowe-McConnell 1994). Indications are that the on-going and unregulated wetland conversion may contribute to a decline of floral and faunal diversity through loss of habitat, destruction of refugia, and floral/faunal mixing. Studies do, however, need to be conducted to estimate the loss of ecosystems in the swamps.

Modification of ecosystems or ecotones

As recently as the 1960s, Lake Victoria supported an endemic cichlid fish species flock of between 300 and 500 members, but these have progressively disappeared from the catches to become poorly represented today. The losses are attributed to habitat degradation in the catchment, introduction of alien species (particularly Nile perch), heavy fishing pressure (Ogutu-Ohwayo 1990, Witte et al 1999), proliferation of filamentous and blue-green algae, and development of anoxic conditions within the Lake (Kling et al. 2001). This indeed reflects a most startling loss of fish species that has resulted from modification of an ecosystem.

Land use change can potentially lead to extreme impacts on food security in the region. For example, approximately 46% of the 3 516 km^2 Nyando River Basin (or 1 624 km^2) has experienced severe soil physical erosion, and it is estimated that only 868 km^2 remains unaffected by soil physicochemical degradation or soil nutrient deficiencies of one form or another (Swallow et al. 2001). The most degraded parts of the Nyando River Basin, both in terms of nutrient deficiencies and soil physical degradation, are areas currently used for open grazing and extraction of fuel wood; areas currently used for subsistence agriculture are also characterised by both types of degradation but at lower prevalence rates than grazing areas (Swallow et al. 2001). In the Mara, Mwanza and Kagera basins, clearing of forests has resulted in deforestation, a dominant feature in most parts of the area where land is left bare following the expansion of settlements, livestock keeping and agriculture (Hongo 2000). Further research is, however, required to establish the linkages between land degradation, and biodiversity and ecosystem change in the rivers and lake.

The wetlands of the Lake Victoria region have recently witnessed increased pressure from exploitation due to the need for land to produce more food, space to settle the rapidly growing population and for other development projects. The full extent of wetland use and its impacts are not well known (Kairu 2001), but satellite imagery suggests that it is substantial, based on observed erosion from shoreline zones (Wilson et al. 1999). The current degree of modification of the littoral belt wetlands still needs to be quantified. Some data from the inland wetlands provides some clues. For example, the Nakivubo Urban Wetland close to Kampala, Uganda, is being reclaimed for agricultural, industrial and residential expansion; already, slightly over half of the total area (2.9 of 5.29 km^2) has been modified or reclaimed for agriculture, industry and settlement, and the danger exists that the entire wetland will be modified and converted for urban expansion purposes (Schuijt 2002). The Yala valley swamp in Kenya (along Yala River) is host to many fish species, plants, invertebrates and birds as well as mammals and reptiles. Currently, part of the swamp has been reclaimed for agricultural use, and more recently, the government of Kenya has put aside about 2.66 million USD to drain the swamp for agricultural purposes (Aloo 2003). Before the construction of a diversion canal, the Yala River used to flow through the eastern swamp into Lake Kanyaboli before dispersing into the main swamp. After 1970, the Lake was separated from the swamp by a silt-clay dyke but connected to it by a drainage channel: recent reports indicate that the canal has been destroyed by livestock and very little water now reaches Lake Kanyaboli (Aloo 2003).

Recent invasion of the Lake with water hyacinth (Twongo 1966, Twongo et al. 1995) exemplifies Lake Victoria as an interesting area for lake-wide scientific studies for years to come. The usually anaerobic conditions under which the decay process takes place lead to production of noxious gases like ammonia and hydrogen sulphide. Together with the light shading effects of the dense weed mats, which interfere with photosynthesis, the water environment under the weed mats influences changes in the diversity and distribution of aquatic biodiversity. The maximum water hyacinth cover in Lake Victoria was reached between 1994 and 1995 when 80% of the Uganda shoreline was covered with about 4 000 ha of water hyacinth, there was 6 000 ha coverage in Kenya, and about 2000 ha in Tanzania (Mailu 2001). The situation in June 2002 showed much reduced, disintegrated, and stunted water hyacinth cover along the shorelines of all three countries (Mailu 2001). It is argued that this reduction in water hyacinth is mainly due to the biological control method, achieved through the introduction of *Neochetina weevils* in 1996, but further studies are required to make a conclusive statement on this. Recent reports from the LVEMP Secretariats (Nyirambu, personal communication), indicate that about 80% of the hyacinth infestation has been cleared from the Lake.

Socio-economic impacts

The negative economic impact of the loss of fertile agricultural soils in the Lake Basin as a result of erosion could be fairly high, as described above. The immediate effect of wetland modification is somewhat mixed: although the economic benefits of wetland resources could be high as a result of income from agricultural activities, harvested papyrus sales, brick making, etc. (Schuijt 2002), wetland loss adversely affects the flora, fauna, and the natural buffering and other functions of the system. The economic costs of controlling the water hyacinth invasive weed (Twongo 1996, Twongo et al. 1995) and for restoration of the modified ecosystems are high. Costs related to hyacinth clean-up are substantial but they are in localised areas, for example the shipping harbours and water intake points. There have also been losses of earning opportunities when fishermen could not access fishing and fish landing sites, and through interference with fishing gear and clogging of pumps, as a result of water hyacinth infestation (Mailu 2001). Reduced access to water resources, possibly enhanced occurrence of diseases such as schistosomiasis, malaria, increased risk of snake bites etc., are important health outcomes that are in part contributed to by loss or modification of habitats, particularly as a result of the water hyacinth infestation. The negative health knock-on effects of water hyacinth are inconclusive (see Mailu 2001). Studies need to be carried out to determine the relationship between habitat modification or loss vis-à-vis human health.

Other social and community impacts include losses of aesthetic values of these ecosystems, risks to human populations and capital investments, and reduced capacity to meet basic human needs. For example, the high export demand for the introduced Nile perch (which forms about 80% of total fish catch) has driven the price of fish to levels which cannot be afforded by many local consumers; this has diverted cheap protein food from local consumers, threatening their nutritional status as the consumption of fish declines (World Bank 1996).

Conclusions and future outlook

Although there is general land degradation and deforestation in the Lake Basin as a whole, there are some critical habitats that need to be urgently protected. These include the watershed areas, riparian zones along river banks, river deltas, and wetlands along the lakeshore. The lake habitat itself also needs to be protected from further degradation to protect the human populations, fisheries sector and other industries that rely on it for transportation, tourism, agriculture, etc. Sustainable agricultural practices and soil conservation activities need to be instituted immediately. There is also a need to measure the spatial extent of the land degradation under different land use/land cover scenarios and to assess the effect of human land uses on vegetation community structure over the last several decades, in order to understand how the landscape can be better managed to reverse the negative trends and mitigate hotspots (Swallow et al. 2002).

Methods for controlling the water hyacinth weeds need to be developed through more scientific studies. Water hyacinth is very mobile and is moved by the wind easily from one corner of the Lake to the other. Therefore, its removal may require special tools. However, its shredding in the Lake as was done by the Kenya government results in seed dispersion. In addition, shredding adds organic matter to the lake bottom that further depletes the oxygen content. Water hyacinth seeds once dispersed in the lake bottom may take up to 15 years to germinate. This makes the weed management preferred over weed elimination. It has been noted, for example, that ecological succession has made a major contribution to the control of fringing water hyacinth in the Ugandan portion of Lake Victoria: pure mats of water hyacinth are invaded initially by aquatic ferns and/or sedges, often followed progressively by Hippograss (*Vossia cuspidator*) that eventually dominate and shade out the water hyacinth (Mailu 2001). Surveys conducted in 1999 indicated that water hyacinth showed increased weed stunting and disintegration of original mats, reflecting severe environmental stress including that occasioned by the weevils already released into the Lake (Mailu 2001).

Unsustainable exploitation of fish and other living resources

Fisheries resources of Lake Victoria have been the main concern of the riparian states since the early 1950s when a number of introductions took place in order to boost the decreasing level of biomass of fish (Fisheries Department 1950). Introductions of tilapiine species took place around 1954 to boost the production of the endemic *Oreochromis esculentus* and *O. variabilis* that were already on the downward trend. Thus the following species were introduced into Lake Victoria; *Oreochromis leucostictus*, *Tilapia rendalli* and *T. zillii*. Experimentation towards Nile perch (*Lates niloticus*) in Lake Victoria accidentally led to a full introduction of the fish to the Lake. Hamblyn (1960) noted the first appearances of Lates niloticus in the fishermen catches. Full blast introductions took place thereafter with Uganda restocking from Lake Kyoga and Lake Albert while Kenya reciprocated by introductions from Lake Turkana. Since the introductions of Nile perch, the fishery of Lake Victoria has never been the same (Figure 18). The fishery of the Lake was boosted at a much higher level than previously, the economic level of the fishery rose beyond the traditional level of tilapiine fishery, economic and social activities around the fishery improved tremendously (Reynolds & Greboval 1995). The higher level of economic production proved only transient, as the usual overexploitation of the fishery continued after the post-Nile perch boom. Other endemic species of Lake Victoria have similarly been undergoing stressful exploitation.

The historical trends in the fish catches in Lake Victoria have shown that for each of the East African Community Partner States (through the 1970s to the late 1990s) a salient feature in the pattern of the fish output is that it is very low. In the 1960s and the 1970s the combined annual catch for the three countries was only 150 000 tonnes. The catch of the days that followed up to the early 1980s was dominated by haplochromines which were/are small-sized fish of the cichlid family of very limited commercial value. Other species comprising the catch were the mudfish (*Clarias* sp.), the native tilapia (*Tilapia esculentus*), *Bagrus* sp., the African lungfish (*Protopterus* sp.), and a mixture of other tilapia species. During this period the haplochromines formed a species flock of many closely related species renowned for their great evolutionary significance and scientific value. Morphological, behaviour and taxonomic studies (Barel et al. 1985, Greenwood 1951, 1981, 1984 and 1994) distinguished hundreds of separate species of haplochromines, of which different groups colonised different bottom types and inlets.

Hydroacoustic surveys indicated that the total biomass in the Lake is fairly constant at about 2 million tonnes, but the components of the biomass during 1999 and 2001 have changed, with Nile perch decreasing from an estimated 1.5 to 0.9 million tonnes while the small pelagics (*R. argentea* and haplochromines) increased concurrently from an estimated 0.5 to 1.2 million tonnes (Bwathondi et al. 2001). Bottom trawl surveys in Kenyan waters of Lake Victoria (1997-1998) revealed that areas with relatively consistent high fish catches extend from west of Maboko Island up to Mbita Channel in the depth range of 5 to 22 m (Getabu & Nyaundi 1999). This area is outside major urban and riverine influence and is where most of the fishing effort by artisanal fishermen is currently concentrated (Getabu & Nyaundi 1999).

The Universities of Northern England Consortium for International Activities (UNECIA) has reported on the indicators of overfishing exhibited by *Lates niloticus* as reduction in age/length at maturity, higher mortality caused by fishing pressure, reduction in catch per unit effort (CPUE), reduction in mesh size of nets used and increased proportion of immature fish in the catches. It was noted that similar trends were observed for *Oreochromis niloticus* and *Rastrineobola argentea*. Of all the changes occurring in Lake Victoria, the impacts on the fish species, and thus the fishery and its trends, have immediate significance to the East

Figure 18 Fishermen weighing Nile perch.
(Photo: Corbis)

Africans, particularly the riparian population. What did it mean for East Africa when the fishery changed from one made up of haplochromines and other multi-species fishery to one, after 1980s, principally dominated by the Nile perch? This new fishery has opened export markets and has thus turned the fisheries sector in Lake Victoria into one of the main foreign exchange earners for the riparian peoples and the East African countries. What are the challenges and prospects of the Lake Victoria fisheries sector for the East African peoples?

Environmental impacts

Overexploitation

In the late 1950s, the Nile Perch was introduced to Lake Victoria from Lake Kyoga. During the early 1980s the Nile perch exploded in numbers causing serious predatory impacts on the Lake's native species (Ogutu-Ohwayo 1990). *Oreochromis niloticus* (Nile tilapia) also thrived as an introduced species (Lehman 1996). The population of haplochromines was collapsing due to these introductions (Ogutu-Ohwayo 1990). Signs of overfishing were reported as early as 1927 when catch rates for tilapia dropped from 50-100 fish per 50 m long net with 127 mm stretched mesh (Wothington & Worthington 1933) to less than 5 fish (Ssentongo 1972). Many food fish species such as *Oreochromis esculentus* (Graham), *Bagrus docmak* (Forsskål), *Clarias gariepinus* (Burchell), *Labeo victorianus* (Boulenger) and the haplochromines (once important for fishmeal) have almost disappeared (Mkumbo 1999). More recently, even *L. niloticus*, the most important fish in the fishery, shows signs of declining (Othina & Osewe-Odera cited in Mkumbo 1999). There are indications that the fishery yield in Uganda has declined from 135 000 tonnes in 1993 to 107 000 tonnes in 1997 (Odongkara & Okaronon 1999).

The introduction of Nile perch, overfishing, unregulated gill net mesh sizes and exploitive fishing techniques have led to the decline of nearly all endemic species, most notably the cichlid fish species (Bugenyi & Magumba 1996). These practices led to the removal of the phytophagous haplochromines and native tilapiines (Goldschmidt & Witte 1992). Indicators of overfishing in the Nile perch fishery are: reduction in age/length at maturity, high mortality (especially caused by fishing pressure), reduction in catch per unit effort, reduction in mesh size of nets used, and an increased proportion of immature fish in the catches (Bwathondi et al. 2001).

Despite a continuous decline in main endemic food species, there has been a rapid increase in total landings from early 1980 to a peak in the early 1990s (Figure 19). By the late 1980s the Nile perch and Nile tilapia dominated the fish catch to near exclusion of all native species except for *Rastrineobola argentea* (Ogutu-Ohwayo 1990). The total catch in the late 1980s and early 1990s reached close to 500 000 tonnes. This attracted many more fishermen into the lake fishery. An export market, associated with fish processing, turned the low-keyed fishery sector of the Lake into one of the main foreign currency earner for the riparian countries. Overall, a fishery that was multi-species before 1980 is now a three species fishery dominated by the Nile perch, *Rastrineobola* and Nile tilapia, respectively. There are currently 31 licensed fish processing factories in the Lake Victoria Region (Ntiba et al. 2003).

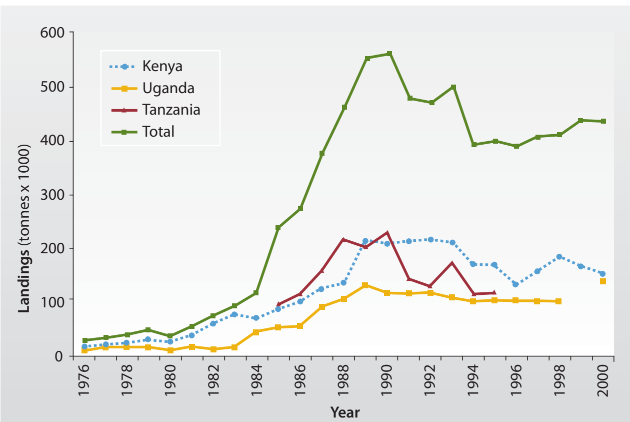

Figure 19 Total landings of fish in the three riparian countries of Lake Victoria.
(Source: Knaap et al. 2002)

Excessive by-catch and discards

Quantitative information on actual by-catch and discards is generally not available, but this aspect of overexploitation is reflected in the increasing number of juveniles caught, as well as by reduction in size at first maturity. In other words, excessive by-catch and discards has come about mainly through the destructive fishing practices which are outlined below, particularly the use of undersized mesh nets.

There has been a progressive decline in the modal length of Nile perch caught by experimental trawling: in 1988 the modal length was 7080 cm (Ligtvoet & Mkumbo 1991), and it decreased to 50-60 cm in 1992, and even further to 40-50 cm in 1994 and it remained around the same level to the end of the 1990s (Nisinda et al. 1999). Similar trends are found in tilapia and *Rastrineobola*, and the fishing mortality on *Rastrineobola* stocks from the mosquito seine fishery is very high (Bwathondi et al. 2001). Catch rates from the 5 mm and 10 mm mosquito nets for *Rastrineobola* argentea in Tanzanian waters show exploitation of a high proportion of immature fish (Bwathondi et al. 2001). For *Oreochromis niloticus*, fishing mortality has increased dramatically in Kenyan waters since the early 1990s (M. Njiru, unpublished data, cited in Bwathondi et al. 2001). Often the lusenga nets and beach seines are fitted with small mesh netting, even mosquito netting, which is thought to be especially destructive to stocks since it catches everything, including juveniles (personal observations). Trawling using undersized mesh nets for target species and indiscriminate fishing gears or poisons are considered serious and in most cases result in indiscriminate catches including juvenile fish.

Destructive fishing practices

From as early as 1905 to 1916, gill nets were introduced into the Lake to exploit the tilapiine cichlids, *Oreochromis esculentus* and *O. variabilis* (Katunzi 1996), and catches declined with time as the fishing activity increased (Graham 1929 cited in Katunzi 1996). As traditional fishing methods are now often considered inadequate for landing a sufficient catch, fishermen increasingly resort to deploying illegal fishing gear such as cast nets, fish poison and weirs to improve their catches (Ntiba et al. 2001). The recommended mesh size for gill nets is 5 inches (~ 127 mm), but around 36% of the nets in use are below this recommended size and this has increased from around 9% in 1990 (NRIL 2002). Gill nets below the minimum legal mesh size (5 inches) constituted about 15% of the gill nets in the fishery in Lake Victoria in 2000. Uganda had the highest number of gill nets followed by Tanzania and Kenya. Other types of gear in operation does not augur well for the sustainability of the fisheries within the Lake particularly within the Kenya part of Lake Victoria that had the highest number of beach seine and mosquito seine (Asila 2001).

The introduction and success of the nilotic species followed an episode of nearly unregulated reduction of gill net mesh sizes and collapse of the traditional tilapia fisheries, and was contemporaneous with initiation of commercial trawling for demersal haplochromines (Lehman 1996). Mesh sizes have progressively declined over the past 10 years with 24% of the nets (LVFO 2000, Kulindwa 2001) in Uganda now below the recommended mesh size of 5 inches, and now more recent beach surveys (Muhoozi cited in Bwathondi 2001) suggest that this is now as high as 50%. In Kenya and Tanzania, 3 and 18%, respectively, of the gill nets are below the legal mesh size limits (Bwathondi et al 2001). Trawling using undersized mesh nets for target species and indiscriminate fishing gears or poisons are considered serious and in most cases result in indiscriminate catches including juvenile fish. Trawling does have adverse biological implications. Bottom trawling disturbs the substrate, the water column and interferes with the breeding ground and the spawning process especially for tilapiines and other cichlids. It also destroys larvae and eggs of fish, macro- and micro-invertebrates at different strata of the Lake. Thus, trawling using non-selective mesh nets may cause overfishing by taking away both adult and juvenile fish and therefore reducing their productive potential. Further to that it may result into mass unemployment by displacing artisanal fisherfolk (Mbuga et al. 1998). With the near disappearance of many food fish species (Mkumbo 1999) and signs of decline in *L. niloticus* (Othina and Osewe-Odera cited in Mkumbo 1999), a number of management measures were effected including a ban on beach seines and undersized mesh nets (<127 mm stretched mesh) in 1994, and a ban on trawlers in 1996 (Mkumbo 1999). The use of poison led to a ban on fishing and the sale of fish in March 1999 (Ntiba 2003).

Decreased viability of stock through contamination and disease
Recent studies have shown high incidence of infection of *Rastrineobola argentea* by *Ligula* sp., an endoparasite (Ntiba, pers. comm.). *Salmonella* spp. were detected by the Spanish Veterinary Authorities in February 1997, resulting in the imposition of compulsory and systematic checks on Nile perch fillets for Salmonella in the EU countries (Knaap et al. 2002). A cholera outbreak which occurred in 1997 led to a six-month ban of fish exports to the EU from January to June 1998, but this ban was considered to be unjustified in the region because fish products are expected to be further processed at their export destination (Knaap et al. 2002).

Impact on biological and genetic diversity
The Nile perch, introduced in the Lake during the middle to late 1950s, exploded in numbers during the early 1980s (Ogutu-Ohwayo 1990 and 1992, Ntiba & Ogana 2003) causing serious predatory impacts on the Lake's fish species assemblages. At the same time another introduced species of tilapia, Nile tilapia (*Oreochromis niloticus*), and a native sardine-like cyprinid locally known as Omena/Dagaa/Mukene (*Rastrineobola argentea*) proliferated. According to Witte et al. (1992) a huge proportion of 400 endemic species of haplochromine cichlids were almost approaching extinction in Lake Victoria in the 1980s. The time and the cause of these dramatic shifts in the lake environmental conditions and biotic assemblages is subject to various scientific studies. Whether the answers can be attributed solely to the introduction of the Nile perch and subsequent changes in the trophic relationships in the ecosystem, or are due to environmental dynamics associated with increased human population growth, resulting in increased deforestation and agriculture in the Lake Basin, urbanisation and the setting up of towns around the Lake, is not conclusive.

Socio-economic impacts

The EU ban on the fisheries had a negative impact on the economics of the fishery. However, in 1999 with the fish ban and water hyacinth infestation, Kenyan fishermen still managed to catch and sell fish worth about 100 million USD (8 billion Kenyan Shilling). Tanzania was allowed to resume the export of perch products from Lake Victoria to the European Union in January 2000, followed by Uganda and Kenya in August and December 2000, respectively (Knaap et al. 2002). Other economic impacts of overexploitation include higher costs of management of fisheries, fuel costs of moving to new fishing grounds, and the loss of fisheries revenue.

A number of deaths were reported among fish consumers on the Lake because of the use of illegal poisoning to catch fish (Knaap et al. 2002). Consequently, the Uganda government self-imposed bans on fishing, consumption of fish from the Lake, and export in March 1999 which were eventually lifted in November 2000 (Knaap et al. 2002). The cholera outbreak of 1997, which resulted in an EU ban on fisheries, has not been clearly linked to the fisheries sector, but unhygienic conditions in this sector can easily trigger such outbreaks that can lead to high loss of human life. The high demand for fisheries products in export markets has resulted in a decline of available fish for local consumption (Jansen 1997), and thus contributes to malnutrition in the region (World Bank 1996).

The fisheries sector is important in all three riparian countries in terms of food security, employment and livelihoods, as well as foreign exchange earnings (NRIL 2002). Fish has traditionally been the most affordable source of animal protein (World Bank 1996, Jensen 1997) with an average regional per capita consumption of around 12 kg, and in recent years much of the contribution to economic development and employment has been associated with the export of Nile perch (NRIL 2002). The long-term decrease in the commercial viability of fishing operations has resulted in unemployment, increasing poverty and decreasing food security in the region (World Bank 1996). This is reflected in the increasing fish prices over time, declining per capita fish consumption, decreasing size of fish caught and decreasing average incomes (Abila personal communication).

Conclusions and future outlook

There is an immediate need to quantify the actual resource base in order to establish what would be the actual sustainable level of exploitation of Lake Victoria fish as the small-scale fishermen greatly depend on the sustainability of the fisheries for their livelihoods (Katunzi 1996). Mechanisms for the regulation of the fisheries sector, including the export markets and processing factories, the eradication of use of destructive fishing practices, and the creation of alternative avenues for income to sustain the livelihoods of the riparian communities is required if the overexploitation of fisheries is to be effectively addressed. For example, the high demand for the Nile perch from filleting factories, and their preference for fillets from juveniles of 0.1-1 kg for some export markets, will inevitably lead to a collapse of stocks because too few fish will reach spawning size (Bwathondi et al. 2001). The domestic market is equally open for undersized fishes and thus urgent remedial measures have to be considered (Bwathondi et al. 2001).

Currently, projects such as the Lake Victoria Environmental Management Project (LVEMP) and the Lake Victoria Fisheries Organisation (LVFO) are addressing some of the issues, but these need to be nested within the wider framework of integrated land and water management, taking into consideration issues like population growth, and other development programmes that can diversify the economic base of the region. The introduction of new regulatory laws governing fisheries (e.g. restrictions on free access to fisheries), and participatory management of fisheries and other resources may lead to a sustainable use of the resources. This may lead to potentially new employment possibilities, and improved catch and earnings. There may, however, be conflicts between user groups for shared resources including space. Community participation and government policies may help to improve the current situation.

Global change

The climatic characteristics of the region have been outlined in the section on Physical characteristics. Lake Victoria is sensitive to climate change as its water balance is dominated by rainfall on the Lake and evaporation, with river inflow and outflow making minor contributions (Spigel & Coulter 1996). Global warming will lead to higher temperatures estimated to be between 0.2 and 0.5°C per decade for Africa (Hulme et al. 2001). The major effects of climate change on African water systems will be through changes in the hydrological cycle, the balance of temperature, and rainfall (IPCC 2001). Lake Victoria, is now 0.5°C warmer than in the 1960s (Hecky et al. 1994, Bugenyi & Magumba 1996), in harmony with changes in surface temperature at tropical elevations above 1 000 m world-wide. There have been no studies on increased UV-B radiation as a result of ozone depletion, or on changes in lake CO_2 source/sink function in the region.

Environmental impacts

Changes in hydrological cycle and lake circulation

Changes in the hydrological cycle and lake level are intricately intertwined as the water balance of the Lake is dominated by rainfall and evaporation. The lake level is therefore particularly sensitive to climatic and hydrological change. All the current impacts of global change are related to the El Niño phenomenon or unusually heavy rains in the region. These are recurrent features of the climate system that occur with some measure of predictability. The frequency of El Niño Southern Oscillation (ENSO) episodes in East Africa has become irregular and shorter. Through the hydrological cycle, it tends to disrupt mainly agricultural activities and food production.

Lake-level change

The observed lake-level changes in the past few decades have not shown any significant departure from the mean trends. The strong El Niño years such as the 1982/1983 and the 1997/1998 events tend to rapidly raise the lake level and causes widespread flooding along the lake shore and rivers (Birkett et al. 1999, Conway 2002). For example, the El Niño phenomenon in 1997/1998 resulted in the water level rise by 1.7 m in Lake Victoria, 2.1 m in Lake Tanganyika and 1.8 m in Lake Malawi (Birkett et al. 1999). The widespread heavy rainfall and flooding produced adverse wide-ranging agricultural, hydrological, ecological and economic impacts in east Africa (Conway 2002).

Socio-economic impacts

Besides the wide-ranging economic effects the health is also important with respect to global change. One of the effects of El Niño-related flooding is the widespread dispersal and elevated concentration of biological contamination of water resources from surface run-off, domestic and municipal sewage wastes and other organic pollutants. This leads to sporadic higher incidences of water-borne diseases. For example, malaria is the most climate sensitive vector-borne disease. In the two warming periods in the 1930s to 1940s and the late 1980s (IPCC 1996), malaria epidemics were observed in the East African region (Roberts 1964, Githeko & Ndegwa 2001). In 1997, during the El Niño, a cholera epidemic occurred in western Kenya. Between June 1997 and March 1998, 14 275 cholera admissions to hospitals in Nyanza Province in western Kenya were reported (Shapiro et al. 1999). According to WHO (1999) similar events occurred in Kenya, Mozambique, Somalia, Uganda, Tanzania, Zambia and Zimbabwe.

A common problem with flooding in the Lake region is related to the displacement of people from their villages, the disruption of normal day to day routine because of lack of exit and access to marooned areas, lack of shelter and food.

Conclusions and future outlook

El Niño is a recurrent phenomenon in the region, but, due to global changes, the frequency and perhaps the intensity of these events will increase. The current impacts that it has on the communities of the Lake Basin are basically as a result of lack of investment in flood control measures, and lack of disaster preparedness by the governments.

The social, economic and health impacts of El Niño can be drastically reduced if the afore-mentioned measures are put in place.

Malaria and cholera epidemics have occurred to varying degrees in the eastern African in the last decade. It is critical to know what to expect in the future in terms of disease trends so that adaptive measures can be put in place. Equally it is important to establish the population's adaptive capacity in terms of the ability to prevent and treat climate related illnesses.

Priority concerns

The concerns that are recommended for further analysis are: Pollution and Unsustainable exploitation of fish and other living resources. The concerns were ranked in descending order of severity:

1. Pollution
2. Unsustainable exploitation of fish and other living resources
3. Habitat and community modification
4. Global change
5. Freshwater shortage

Dramatic and highly adverse changes that have enormous ramifications for the tens of millions of inhabitants of the Lake Victoria Basin have taken place in the fisheries sector because of overexploitation of fishery resources. These changes have been spurred by various unsustainable practices within the catchment and the Lake itself. The adverse interactions have been related to environment, economy, society, governance and legislation at national, regional and global levels. Many of the consequences of Unsustainable exploitation, which has emerged as a principal GIWA concern for the region, have worked through various pathways that are linked to the other GIWA concerns, namely, Pollution, Habitat modification, and Freshwater shortage. Unsustainable exploitation may cause pollution and/or habitat modification through the use of pesticides or other chemicals to increase fish catches, or via deforestation which exposes soil to erosion. The linkages between the GIWA concerns are shown in Figure 20.

Pollution emerged as another important GIWA concern that merits further analysis. Pollution poses many problems of an economic, social and/or health nature. The problem of pollution will have to be addressed within the context of a transboundary integrated land and water management plan.

Although current climate scenarios project small increases in tropical temperatures, small changes in temperature and water balance can dramatically alter water levels, as well as mixing regimes and productivity (IPCC 1996). High temperatures would increase evaporative losses, especially if rainfall also declined (IPCC 1996). Minor declines in mean annual rainfall (10–20 %) for extended periods would lead to the closure of the African lake basins even if temperatures were unchanged (IPCC 1996). There is also likely to be an increase in the frequency and or severity of extreme events such as El Niño. Severe droughts and floods would adversely impact the socio-economic activities and livelihoods of the inhabitants of the lake basins.

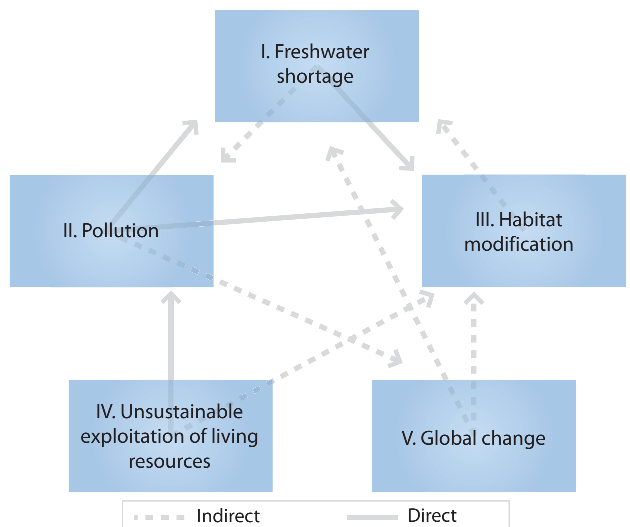

Figure 20 Linkages between the GIWA concerns in Lake Victoria.

Lake Tanganyika Basin

Table 15 Scoring table for Lake Tanganyika.

Assessment of GIWA concerns and issues according to scoring criteria (see Methodology chapter)	The arrow indicates the likely direction of future changes.
0 No known impacts; 1 Slight impacts; 2 Moderate impacts; 3 Severe impacts	↗ Increased impact; → No changes; ↘ Decreased impact

Lake Tanganyika	Environmental impacts	Economic impacts	Health impacts	Other community impacts	Overall Score**	Priority***
Freshwater shortage	1.0* ↗	0.2 ↗	0.2 ↗	0.2 ↗	1.0	5
Modification of stream flow	1					
Pollution of existing supplies	1					
Changes in the water table	0					
Pollution	2.4* ↗	1.4 ↗	1.0 ↗	1.3 ↗	2.2	3
Microbiological pollution	1					
Eutrophication	1					
Chemical	2					
Suspended solids	3					
Solid waste	0					
Thermal	0					
Radionuclide	0					
Spills	1					
Habitat and community modification	2.0* ↗	2.6 ↗	0.9 ↗	2.0 ↗	2.4	2
Loss of ecosystems	2					
Modification of ecosystems	2					
Unsustainable exploitation of fish	2.1* ↗	2.9 ↗	1.3 ↗	2.5 ↗	2.5	1
Overexploitation	3					
Excessive by-catch and discards	0					
Destructive fishing practices	2					
Decreased viability of stock	0					
Impact on biological and genetic diversity	1					
Global change	0.9* ↗	1.3 ↗	1.0 ↗	1.0 ↗	1.5	4
Changes in hydrological cycle	1					
Sea level change	2					
Increased UV-B radiation	1					
Changes in ocean CO_2 source/sink function	0					

* This value represents an average weighted score of the environmental issues associated to the concern. For further details see Detailed scoring tables (Annex II).

** This value represents the overall score including environmental, socio-economic and likely future impacts. For further details see Detailed scoring tables (Annex II).

*** Priority refers to the ranking of GIWA concerns.

Freshwater shortage

Lake Tanganyika has a water volume of 18 800 km³; precipitation on the lake surface and surface run-off represents about 63% and 37% of water input, respectively, while evaporation at 94% accounts for the major loss of water (Beadle 1981, Haberyan & Hecky 1987). The surface outflow through the Lukuga River controls the maximum and present lake level. Lake Tanganyika receives water from different rivers with different chemical compositions, the most important one is the Rusizi River in the north which supplies more than 50% of the total dissolved salts. Except for rice production, agriculture in the region is rain-fed. Irrigated rice production is seasonal and small-scale and currently does not have a significant impact on water levels in the Rusizi River or Lake Tanganyika. Power companies utilise the Rusizi River for hydroelectric power generation and have been exploring possibilities to expand the network. There is little modification or diversion of Tanganyika's affluent water supply and the Lake, consequently, has relatively few problems with respect to freshwater shortage. There is currently no evidence that abstraction of water from aquifers exceeds natural replenishment.

Environmental impacts

Modification of stream flow

Due to diversion of water for irrigation purposes, there is significant but localised loss of wetlands in some areas (e.g. Burundi) (personal observations). Dams and irrigation channels are not, however, common in affluent rivers (personal observations). Hydroelectric power production on the Rusizi River also has limited impact on Lake Tanganyika.

Pollution of existing supplies

The Lake provides freshwater for drinking and domestic use, but only between 32 and 62% of the population has access to safe water, while 14 to 49% do not have access to sanitation (Table 9) (UNDP 2000, World Bank 1999). This suggests that, within localised settlements, pollution of existing supplies is a significant threat. Increasing land use, particularly in the north, is affecting the quality of river water. The salinity of input from the Rusizi River (0.65‰) may in part influence the slightly elevated salinity of the Lake (0.5‰) (Hughes & Hughes 1992). The very large volume of Lake Tanganyika may provide a temporary buffer against deterioration of water quality (Spigel & Coulter 1996), but there have been several significant fish kills in localised areas, especially in Bujumbura and Kigoma Bays (personal observation, reported in the media). Nevertheless, the observed pollution has not compromised the overall quality of the water supply due to the large size of the reservoir.

Socio-economic impacts

There has probably been a slight reduction in stream flow owing to conversion of wetlands, but it is not possible to obtain quantitative data and there are no known socio-economic or health impacts linked to this issue. The localised pollution that has been observed has not compromised the overall quality of the water supply due to the large size of the reservoir, hence the health impact is generally very small. Freshwater shortage is not significant enough to affect (periodically or continuously) more than a very small proportion of the riparian community, and only in localised areas.

Conclusions and future outlook

Modification of stream flow is not considered a serious problem in Lake Tanganyika Basin. Even though power companies utilise the Rusizi River for hydropower generation, their activities currently have only limited impact on the Lake. More generally, dams and irrigation channels are uncommon. Pollution of existing supplies can be significant in localised areas, but the large volume of Tanganyika acts as a buffer, diluting to insignificant levels the amount of pollutants in the Lake. Consequently, the Lake Basin has relatively few problems with respect to freshwater shortage.

Increased agricultural activities in the catchment, abstraction of water for irrigation, denser settlements with poor sanitation, and possibly damming of the Rusizi River and increased abstraction of water for irrigation, coupled with a trend of decreasing precipitation projected for the region, may result in future freshwater shortage and increased pollution. Due to the Lake's long residence time, pollution resulting from the effects of human activities and development in its catchment is potentially catastrophic to the Lake's water quality, economic fish stocks and overall biodiversity (West 2001, Duda 2002). In addition, it is less likely that damage can be reversed once it occurs (Spigel & Coulter 1996). Economic impacts will likely become worse because of increased demand for water for potable use and irrigation. Health impacts will also increase due to lack of sufficient and potable water supplies, and as well to unsanitary conditions in the increasingly settled shoreline. These factors can lead to a host of diseases such as cholera and typhoid.

Pollution

Of many serious environmental threats that Lake Tanganyika faces, the most immediate are excessive loads of sediment and nutrients caused by deforestation and erosion in the watershed, and industrial and urban pollution. The three most important issues of pollution in the Lake and influent rivers are suspended solids, chemical pollution and eutrophication. Increased deforestation and consequently erosion in the catchment has caused an increase in suspended sediment entering the rivers and the Lake (Cohen 1991, Bizimana & Duchafour 1991, Tiercelin & Mondeguer 1991). The dynamics and behaviour of river-borne and run-off sediment entering the Lake are complex and not well understood. It appears, however, that much sediment deposition occurs in the littoral zone, precisely where most of the Lake's biodiversity is concentrated. Increased sedimentation rates are manifested in the Lake by sediment inundated rocky habitats, common along the Burundi coast, and prograding river deltas, such as the Rusizi River delta. The Rusizi River delta is the major drainage in the northern basin and appears to have prograded by an order of magnitude during the past 20 years (Cohen 1991).

The Lake as a whole has a large nutrient reservoir in the anoxic layer. Relatively strong gradients in concentrations of nutrients and dissolved oxygen approximate a persistent thermocline which divides clear, impoverished surface water layers from reservoirs of nutrients resident within the anoxic hypolimnion (Langenberg et al. 2002). In the pelagic zone at the northern and southern end of the Lake, mean turbidity values (NTU) ranged between 0.3 and 1.4 (mean=0.6 NTU) in August 1995 to July 1996 (Langenberg et al. 2002). The impact of land-derived nutrients is, therefore, constrained to littoral zones within the influence of sediment inputs.

Pollution abatement facilities in the Basin are extremely limited (West 2001). Untreated wastewater discharge, including; industrial waste from large cities (e.g., Bujumbura in Burundi, Uvira in DR Congo, Kigoma in Tanzania and Mpulungu in Zambia); agricultural run-off particularly from Malagarasi and Rusizi catchments due to increase in the use of agro-chemicals concomitant with agricultural expansion; and mining waste containing mercury, are major chemical pollution sources (West 2001). While the condition lake-wide is generally satisfactory, some areas, like Kigoma Bay, show cause for local concern (Chale 2000, Bailey-Watts et al. 2000). Perhaps because of its greater water volume and lower human population density in its watershed, Lake Tanganyika appears to be more resilient to different forms of environmental impact than Lake Victoria (Beeton 2002).

Environmental impacts

Microbiological

Microbiological pollution is an issue, from time to time, on a localised scale, evidenced by water quality issues in Kigoma Bay and cholera outbreaks in Burundi and Zambia (Chale 2000).

Eutrophication

Kigoma Bay, which is about 4 km long, 3 km wide and 25 m deep, is surrounded by Kigoma Town (population 135 000) which draws its domestic water supply from the Bay (West 2001). A comparison of water quality between Kigoma Bay and offshore waters, showed that Kigoma Bay waters were significantly higher in nutrients and 2.23 times less transparent than offshore waters (nitrogen 56 μg/l vs. 36 μg/ l; phosphorus 12.55 μg/l vs. 6.47 μg/l) (Chale 2000). A similar trend was found in comparisons with un-impacted nearshore areas, suggesting that nutrient input into the Bay from external sources is considerable. These values are elevated enough to render Kigoma Bay 'meso-eutrophic' on the classification of lake productivity levels (West 2001).

Kigoma lacks a wastewater treatment facility; many households have diverted their plumbing to enter the town's storm drains. These drains thus act as conveyers for domestic effluents to enter the bay, which may ultimately be responsible for the high nitrogen and phosphorus concentrations and enrichment in plant nutrients (West 2001).

Chemical

Of the four riparian countries, Burundi, with the largest population density and the most industries in the Basin, poses the greatest pollution threat. Bujumbura hosts a variety of industries and potential pollution sources within several kilometres of the lakeshore, including a textile-dying plant, a brewery, paint factories, soap factories, battery factories, fuel transport and storage depots, a harbour and a slaughterhouse. Fuel depots, Kigoma's harbour and electricity-generating facilities, industrialised fishing in Mpulungu, and cotton and sugar processing plants in DR Congo present other cases of potential industrial pollution. The wastes from these enterprises typically are not treated before they are discharged and ultimately make their way to the Lake. The same is true for domestic waste. Even in highly populated areas, no municipal or household wastewaters are treated before they are discharged.

Run-off of agricultural pesticides may also be an important source of pollution. There is significant use of pesticides in the catchment, other contaminants are also present (water quality studies summarized in Bailey-Watts 2000). Pesticide residues have been detected in molluscs and in the fish that are the main targets of the commercial fishing industry (Foxall et al. 2000, Deelstra et al. 1976), indicating that pesticides have entered the food chain, although the values are within WHO acceptable tolerance ranges. Mercury and other chemicals used in small-scale gold and diamond mining in the catchment represent other potential lake pollutants. Leaks and accidents in the Lake's cargo/shipping industry, executed by a fleet of ancient vessels, is another potential environmental hazard. Finally, although no production is occurring yet, petroleum exploration has been conducted on the Rusizi Plain and the Kalemie Trough while plans for nickel mining in Burundi are well underway. Table 16 summarises the various types and sources of pollution identified in the Tanganyika catchment.

The impact of these various discharges is poorly understood. While Environmental Impact Assessments (EIAs) have not been conducted, some studies suggest that pollution has altered, in some areas, the composition of phytoplankton communities (Cocquyt et al. 1991).

Suspended solids

Cohen (1991) reports that Landsat image analysis revealed that 40–60% of original forested land in the Lake's central basin, and almost 100% in the northern basin, had been cleared, as evidenced by headward erosion, stream incision and gully formation, all features associated with deforestation. Much of this land was probably cleared for fuel wood, burned and converted for subsistence agriculture or grazing. Analyses of sedimentation rates from ^{14}C dated cores (Tiercelin & Mondeguer 1991) confirmed the high sediment impact in the northern basin with the southern and central basins receiving <1 500 mm/1 000 years and <500 mm/1 000 years respectively, compared to the northern basin which received about 4 700 mm/1 000 years. Bizimana and Duchafour (1991) have estimated soil erosion rates in the deforested and steep sloping Ntahangwa River catchment in northern Burundi to be between 20 and 100 tonnes/ha/year. More recent studies by Sichingabula (1999) and Kakogozo et al. (2000) show that annual lake-wide sediment input into Lake Tanganyika is enormous (Table 17). In addition, three significant landslides that occurred near Gatororongo show that, especially in the rainy season, significant amounts of sediment (estimated at more than 11 280 tonnes at this site alone) can be introduced into the Lake without transiting through rivers (West 2001).

Excessive sedimentation resulting from high sediment yields from catchments threatens the diversity of nearshore fishes (Cohen et al. 1996). There is evidence of increased turbidity, and large sediment

Table 16 Sources of pollution in the Tanganyika catchment.

Type of pollution	Sources within the catchment
Industrial wastewater	More than 80 industries in Bujumbura, Burundi
Urban domestic wastewater	Bujumbura, Uvira, Kalemie, Kigoma, Rumonge, Mpulungu
Chlorinated hydrocarbons, pesticides	Rusizi Plain, Malagarasi Plain
Heavy metals	North basin waters from industrial wastes
Mercury	Malagarasi River
Ash residues	Cement processing in Kalemie
Nutrients associated with fertilisers	Rusizi Plain, Malagarasi Plain and other catchments
Organic wastes, sulphur dioxide	Sugarcane refining plant near Uvira
Fuel, oil	Ports, harbour and shipping and boats in all four countries

(Source: modified from Patterson & Makin 1998)

Table 17 Some water and sediment discharge rates into Lake Tanganyika.

River	Country	Water discharge rate (million m^3/year)	Sediment discharge rate (tonnes/year)
Kalimabenge	DR Congo	36.5	25.3
Kavimvira	DR Congo	9.2	18.8
Mulongwe	DR Congo	34.1	21.3
Izi	Zambia	44.9	456
Kalambo	Zambia	580	14 445
Lucheche	Zambia	51.4	510
Lufubu	Zambia	3.1	76 140
Lunzua	Zambia	427	9 478

(Source: Sichingabula 1999, Kakogozo et al. 2000)

plumes. Significant stretches of coastline have been transformed from rocky substrates to mixed rocky/sandy substrate or entirely sandy substrates (refer to several studies on sedimentation in Lake Tanganyika summarised in West 2001). Increased water turbidity as a function of sediment load and sediment deposition thwart algal growth, which may have profound effects upon other components of the food web. In studying ostracods across a variety of habitats that were lightly, moderately or highly disturbed by sediment, Cohen et al. (1993b) found that ostracods from highly disturbed environments (both hard and soft substrate) were significantly less diverse than those from the less disturbed environments with differences in species richness in the range of 40–62%. Species richness for deepwater ostracods followed the same general pattern, though the differences were not as great. These data suggest that sediment input may have already had an important role in altering ostracod community structure. Benthic algae productivity studies show that sediment inputs from deforestation probably reduce the amount of available habitat for colonisation, decrease the nutrient value of the food source, and reduce the feeding efficiency of the primary consumers (O'Reilly 1998).

Spills

There have been serious accidental spills, e.g. of DDT in Kigoma harbour (Alabaster 1981) and fuel oil leakages in Mpulungu harbour, although DDT is no longer used except near the shoreline in the Zambian side of the Lake (Cohen et al. 1996). Occasional fish kills suggest that spills exist, but they are not common (personal observation, media reports and local knowledge).

Socio-economic impacts

There are chemical and microbiological pollution impacts in the economic sector, however the score is low overall because few people are actually contaminated, taking preventative measures or seeking medical treatment. In addition, sedimentation and eutrophication have indirect economic impacts that are difficult to quantify. These processes are continuous, and given that the Lake operates as a nearly closed system due to long residence and flushing times, these impacts are cumulative. However, occasional fish kills due to spills have significant, but short-lived, impacts. Sedimentation has a significant effect on the social sector in terms of global biodiversity, but this is not weighted heavily compared to other criteria and therefore the overall evaluation is low in terms of impact.

Conclusions and future outlook

Suspended solids, chemical pollution and eutrophication are the most important sources of pollution in the Lake. Pollution abatement facilities in the Basin are extremely limited. Currently, however, the effects of pollution in Lake Tanganyika seem to be buffered by the enormous size of the reservoir. High sediment loading due to deforestation and erosion in the catchment, particularly in the northern basin where deforestation is almost 100%, has contributed to the rapid growth of the Rusizi River delta over the past 20 years (Cohen 1991). In the lake proper, much of the sediment deposition occurs in the littoral zone where most of the Lake's biodiversity is concentrated, thus affecting the food web and reducing species diversity (Alin et al. 1999, West 2001). There are various sources of chemical pollution particularly in the northern basin area resulting from industry, agriculture, municipal sources etc., but the impacts of these various discharges is poorly understood.

While the Tanganyika Basin is not nearly as industrialised or populated as other parts of sub-Saharan Africa, pollution is a threat to Lake Tanganyika because the Basin's population is rapidly increasing and little legislation exists to protect the environment (West 2001). Given the Lake's fluid medium for transport and that it is a nearly-closed system, with long water residence and flushing times, pollution is potentially catastrophic to the Lake's water quality, economically important fish stocks and overall biodiversity. Increased agricultural and industrial activities in the catchment, coupled with denser settlements with poor sanitation, will result in further pollution. Petroleum exploration is being undertaken west of the Lake - if oil were discovered and produced in the region, risks of oil spills would arise from well accidents, cross-lake transport and harbour spills (Cohen et al. 1996).

Economic impacts are likely to become worse as sediment blanketing and increased turbidity cause changes in benthic and pelagic biodiversity, affecting the fisheries resources. Health would be affected as a result of an anticipated increase in microbiological and chemical contamination from organic wastes (settlements, agrochemicals). Other social and community impacts would increase due to increased demand for increasingly limited resources.

IMPACT Habitat and community modification

Human activities in the catchment, especially agriculture and fuel wood gathering, have greatly decreased the original forest cover in the catchment. *Cyperus papyrus*, *Phragmites mauritianus* and *Typha domingensis* dominate the delta swamps (Hughes & Hughes 1992). *Potamogeton* species are the predominant macrophytes around much of the shoreline, with occasional rafts of *Nymphaea caerulea* and *N. capensis* in shallow sheltered bays (Hughes & Hughes 1992). *Phragmites* *mauritianus* swamps accompany the Rusizi River (Hughes & Hughes 1992). The Rusizi River has formed a substantial delta at the north end of Lake Tanganyika. *Ceratophyllum demersum* is abundant in the vicinities of affluent river mouths (Hughes & Hughes 1992). In the deltas of several rivers, *Azolla pinnata* forms immense floating mats, green or brown in colour, and there are great submerged beds of *Myriophyllum spicatum*, *Najas marina*, *N. pectinata*, *Ottelia ulvifolia*, *Potamogeton pectinatus* and *P. Schweinfurthii* (Hughes & Hughes 1992).

There are extensive wetlands associated with the Rusizi River and its tributaries. *Phragmites mauritianus* swamps accompany the Rusizi River in a belt up to 3 km wide (Hughes & Hughes 1992). Some reptiles are present including various swamp snakes, as well as several bird species and some small mammals such as otters, mongooses and water rats (Hughes & Hughes 1992). The floodplains are intensively cultivated, and the wet areas are frequented by domestic cattle in the dry season when large areas of wetland are burned (Hughes & Hughes 1992). The littoral zone of Lake Tanganyika includes sandy, rocky, mixed sandy-rocky and mud substrates. The Lake contains a large fish fauna comprising some 193 species from 13 families; 98% of the cichlids and 57% of the non-cichlid species are endemic (Hughes & Hughes 1992).

Environmental impacts

Loss of ecosystems

Deforestation is essentially complete within the Burundi and northern DR Congo portions of the watershed (Cohen et al. 1993b) and land clearing using uncontrolled large fires is proceeding at an alarming rate further south (Cohen et al. 1996). Intense cultivation of floodplains, grazing by cattle and burning during the dry season (Hughes & Hughes 1992) has led to significant loss of wetland for example in Burundi. Land degradation and deforestation has increased the sediment flux to the Lake and altered habitats, particularly in the littoral zone. Sediment input has transformed extensive stretches of coastline from rocky habitats to mixed sandy and rocky or even wholly sandy habitats (refer to several studies on sedimentation summarised in West 2001). This phenomenon has not been studied quantitatively or rigorously in Lake Tanganyika, but there are two sources of data that underscore the significance of habitat modification. Comparisons between recent biodiversity surveys and lake-wide ecological studies by Belgian expeditions in the 1940s revealed that many sites had been transformed within the past forty years. Also, underwater observations and mapping of littoral substrates (West, unpublished data) has shown that significant stretches of rocky shoreline in Burundi have been transformed to mixed sandy-rocky or wholly sandy substrates since 1986. In some cases more than 1 m of sediment has accumulated at these sites.

Modification of ecosystems

As a result of the modification of ecosystems particularly by sedimentation and overfishing, the structure of fish communities has changed over time as well as some populations of cichlids and molluscs becoming locally extinct during the past 30 years (West 2001, Lake Tanganyika Research project reports, and personal observation). For example, Alin et al. (1999) have noted that sediment inundation of lacustrine habitats has reduced species richness and density of molluscs, and the species richness of ostracods. The changes in ostracod (Cohen et al. 1993b) and benthic algal (O'Reilly 1998) communities have an impact on ecosystem structure and function, affecting all levels of the aquatic food chain.

Socio-economic impacts

Loss of ecosystems has indirect links to the economic sector in terms of loss of spawning grounds for fish and severe impacts on the ornamental fishing industry, but perhaps the greatest impact is in terms of loss of global biodiversity. The population structure of the economically important fish stocks has changed, with some difficult to assess impacts on the economic sector.

About 70% of all fish species are found in all three sub-basins of Lake Tanganyika (West 2001). While the commercial fishery is based on only six species, the artisanal and subsistence fisheries have over 100 species in their catches and their activities are concentrated in varied habitats along the rocky and sandy shoreline, where biodiversity in the Lake tends to be concentrated (BDP 2003). Habitat modification through sedimentation, nutrient loading, destructive fishing practices and overfishing are leading to reduced fish catches: fish are important to the livelihoods of the numerous artisanal fishers and their dependants in terms of food security and employment. In addition, the loss of biodiversity is of great concern. Possible impacts of biodiversity loss include e.g. loss of traditional food sources, fuel wood energy sources, medicinal plants, and tourism. However, research is required to quantify the rate of loss of biodiversity in the Lake and its catchment, and its impact on the local, regional and global communities.

There are no known health impacts other than reduction in protein sources for the population due to reduced fish yields.

Conclusions and future outlook

Land use change, land degradation and deforestation in the catchment have had profound impacts that are propagated through the rivers, by the land surface and atmosphere to the lowland wetlands and Lake. Intense cultivation of floodplains, grazing by cattle and biomass burning during the dry season (Hughes & Hughes 1992) has led to significant loss of wetland e.g. in Burundi. Land degradation and deforestation has increased the sediment flux to the Lake and has dramatically altered habitats, particularly in the littoral zone. Sediment input has transformed extensive stretches of coastline from rocky habitats to mixed sandy and rocky or even wholly sandy habitats. Partly in relation to this, the structure of fish communities has changed over time and some populations of cichlids and molluscs have become locally extinct during the past 30 years.

The pressure on land-based resources is likely to increase with the rapidly increasing population. In addition, a perceived lack of sustainability thinking by farmers cultivating the steep slopes of Lake Tanganyika catchment may have more to do with the present political insecurity than with an inherently short-term view or ignorance of the environmental consequences of a failure to prevent soil erosion (Allison 2002). If this is indeed the case, then rapid population growth and political instability in the region does not augur well for sustainable land management, soil conservation, and biodiversity in the future. The rate of loss of ecosystems and/or their modification will increase as result of increased sedimentation and reduction in water covered areas, leading to loss of wetland and littoral vegetation, fish spawning grounds, local reduction in species diversity, loss of biodiversity, etc. There is already significant loss of wetlands, local extinction of fishes and changes in population structure of vertebrate and invertebrate organisms in the Lake. Economic impact would become more severe as a result of further ecosystem loss and habitat modification. Subsistence fisheries would be most affected as shallow spawning grounds and fisheries are lost due to sedimentation, reducing the local populations' capacity to meet basic food needs. This, in turn, would increase health risks and result in the loss of jobs.

IMPACT Unsustainable exploitation of fish and other living resources

Fishing activities on Lake Tanganyika include commercial fishing by both industrial and artisanal fishermen, subsistence fishing, and ornamental fish extraction for export. Commercial fishermen target the sardine and *Lates* species and work further offshore in the pelagic zone. Commercial fishers, both artisanal and industrial, have usually made a significant financial investment in gears and motors to access the pelagic zone. Artisanal fishing relies on canoe-catamarans that use lights to attract fish and deploy lift-nets to collect them. Industrial fishing typically employs 15 m purse seines and a number of smaller vessels to attract the fish and deploy seines. Industrial fishing has been limited to a few areas (Bujumbura, Uvira, Kigoma and Mpulungu) which have access to larger markets. The subsistence fishermen primarily target the sardines and Lates species, though in their efforts they catch and utilise many other species. They operate close to shore, from small canoes. Each of Tanganyika's riparian nations hosts one or more companies which export ornamental fish to markets in Europe, America and Japan. A variety of fish, predominately cichlids, are targeted by divers and snorkellers, captured alive and exported to aquarium enthusiasts abroad. There are six non-cichlid species that are targeted by artisanal and industrial fisheries, and whose potential yield has been estimated at 380 000-460 000 tonnes per year. There is no evidence for decreased stock viability in the Lake.

Environmental impacts

Overexploitation

Fish production is estimated at 555 130 tonnes per year, while fish catch is at 178 486 tonnes per year: catch per production ratios for the whole Lake remain relatively low (average 0.30), but for *Lates stappersi*, it is extremely high in all countries, being lowest in Tanzania (0.76) and highest in DR Congo (1.12, i.e. clearly unrealistic) (Sarvala et al. 2002). Present fishing pressure in the Lake is very high. According to FAO (2001), the realised catch of planktivorous fish in the whole lake was about 23-28%, and in the most heavily fished Burundi waters it was 43.52% of estimated production. For piscivorous fish in the whole lake the corresponding figure was 61-73%.

The Lake is fished intensively from Bujumbura and other ports in all four countries that border it; the fishing intensity for all species is higher in the southern and northern parts of the Lake than in any other areas (Hughes & Hughes 1992). Several studies (Petit & Kiyuku 1995, Pearce 1995, Coulter 1999) have suggested that commercial fisheries have already drastically reduced the fish stocks, and the impact of ornamental fishing on population and community structure could be considerable as the rare and alien species are extracted in as high a number as possible because of the high mortality rates in shipping (West 2001).

Burundi once hosted a large industrial fishing fleet, but by the early 1990s they could no longer make a living and all the vessels were dormant or had been sold to companies in Congo or Zambia (Petit & Kiyuku 1995). Pearce (1995) calculates that the fishing effort in Zambia had tripled by the early 1990s and catches had been decreasing since 1985. These efforts have apparently affected the community structure of the stocks in Zambia for initially the catch was 50% sardines, 50% *Lates* (Coulter 1970) whereas since 1986 the catch has been 62–94% *Lates stappersi* (West 2001). The fishery has evolved from a six-species fishery (two sardines, four *Lates* spp.) to a single species fishery (*Lates stappersi*) (West 2001).

Excessive by-catch and discards

There is little by-catch or discards; the economically important fish live in the pelagic zone and few other species are present. Inshore fisheries occasionally have cichlid by-catch but these, though they are not targeted, are consumed (from Lake Tanganyika Research project reports, personal observations, reports from Lindley 2000a and b).

Destructive fishing practices

Beach seining and fishing with mosquito netting are common (though illegal) (summarised in Lindley 2000a and b). Long-term studies of fisheries statistics for Lake Tanganyika signal that fishing practices have altered the population structure of fish communities, especially for the economically important species. Some studies suggest that, in some areas, pollution has altered the composition of phytoplankton communities. Subsistence fishermen primarily target the sardines and *Lates* species, though in their efforts they catch and utilise many other species (West 2001). They operate close to shore, from small canoes, using lusenga nets (large, conical scoop nets), bottom-set gill nets, beach seines, basket traps and hand-lines. Often the lusenga nets and beach seines are fitted with small mesh netting, even mosquito netting, which is thought to be especially destructive to stocks, as it catches everything, including juveniles. In addition to disrupting population structure in this way, beach seines are additionally harmful because they drag along the bottom, turning-over the substrate, and thus obliterating food sources and cichlid nests (West 2001).

Impact on biological and genetic diversity

Invasive species exist in the Tanganyika Basin, including water hyacinth (*Eichhornia crassipes*), cattail (*Typha* spp.), and the fish *Oreochromis* (from West 2000). There is no available data to quantify their impact.

Socio-economic impacts

Fishing activities include commercial fishing by both industrial and artisanal fishermen, subsistence fishing, and ornamental fish extraction for export. Overfishing and fishing with destructive methods have led to loss of jobs and livelihoods even at country scale, e.g. the collapse of the Burundi industrial fishing fleet in the early 1990s (West 2001). Sample surveys show that fishers and post-harvest operators are very pessimistic in their appraisals of catch trends over recent years: majorities in all the national sectors take the view that they have been on the decrease (FAO 2001). Fish accounts for 25-40% of total animal protein supply in the Lake Tanganyika Basin (FAO 2001). At the same time, rapid population growth in the Basin has fuelled an ever increasing demand for fish products, so that over the last several decades, the per capita supply has barely kept pace with overall fish production despite increases in the latter (FAO 2001). Thus, local livelihoods are affected as the principal source of protein in the local diet is reduced due to overexploitation and destructive fishing practices. The global species diversity is reduced as a result of overexploitation and destructive fishing practices. Prolonged political unrest in the region (Burundi, DR Congo and Rwanda), has compounded the effects of population growth and drought in increasing the demand for the Lake Tanganyika fisheries products (FAO 2001).

Conclusions and future outlook

Fishing activities on Lake Tanganyika include: commercial fishing by both industrial and artisanal fishermen, subsistence fishing, and ornamental fish extraction for export. Several studies (summarised in West 2001) have suggested that commercial fisheries have already drastically reduced the fish stocks. Increased fishing effort has apparently affected the community structure of the stocks in Zambia, changing the fishery from a six-species fishery to a single species fishery (*Lates stappersi*). Destructive and illegal fishing practices such as beach seining and fishing with mosquito netting are common. These practices have contributed to an altered population structure of fish communities and degradation of shallow water habitats.

Without intervention and legislation, unsustainable exploitation of fish would severely affect fish stocks, the food web and biodiversity of the Lake, with negative ramifications on the local populations and world markets. Declining catches per unit of fishing effort have been noted (e.g. Roest 1992). In addition to impacting biodiversity by altering population and community structures of fish stocks and food webs, overfishing and fishing with destructive methods have negative repercussions on the socio-economic circumstances of riparian communities through loss of jobs and livelihoods. For example, collapse of entire segments of the fishing industry has occured e.g. the industrial fishing fleet of Burundi in the early 1990s (Vrampas in Cohen et al. 1996). Collapses in the fishing industry are likely to increase in frequency lake-wide. Since fish stocks are already drastically depleted, the industry could face a total collapse in the near future, with severe impacts on the mainstay fisheries economy of the region. Because of the increasing density of settlements close to the Lake, microbiological pollution is expected to increase in these proximal areas. There may be a minor increase in the incidence of bacterial-related gastroenteric disorders in fisheries product consumers due to consumption of fish from these areas. Social conflicts are likely to flare up between commercial and subsistence fishermen as fishing grounds for the latter are being reduced.

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IMPACT Global change

Changes in the hydrological cycle and lake level are intricately intertwined as the water balance of the Lake is dominated by rainfall and evaporation (with river inflow and outflow making minor contributions). Lake Tanganyika enhances rainfall by about 20% compared to that in the catchment (Nicholson & Yin 2002). The lake level is therefore particularly sensitive to climatic and hydrological change. The effects of lake level change, CO_2 source-sink function, etc. remain uninvestigated. Significant ENSO teleconnections have been found, with average air temperature, maximum and minimum air temperature, humidity, rainfall, winds, pressure and radiation, through research conducted by the ENSO Project (1997-2000). The strongest teleconnections were found between monthly air temperature anomalies with the sea surface temperature anomalies in the west equatorial Pacific Ocean. A time lag of 4–6 months generally gave the strongest correlation (ENSO Project 2003). ENSO events over the past approximately 50 years were characterised by an average air temperature increase of +0.26°C while extreme air temperature could reach ±0.8°C during a strong El Niño. During ENSO events, winds decreased but air pressure and radiation increased; this seems to impact mixing of the Lake (ENSO Project 2003).

Besides ENSO, a warming was observed in the recent decades in the air temperature at Lake Tanganyika (>0.7–0.9°C). This was apparently linked to a water temperature increase and a higher stability of the Lake. Decreased winds and changes in fish catches were observed during the same period for the clupeid fishes and *Lates stappersi*. Those observations suggest that the Lake is sensitive to other climate variability such as the recent global temperature increase besides ENSO (ENSO Project 2003). It has recently been discovered that local temperature rises, less windy conditions and climate change have dramatically altered the nutrient balance of the Lake (O'Reilly et al. 2003, Verburg et al. 2003): the surface of the Lake is getting warmer, reducing mixing of essential nutrients such as nitrogen and sulphur between the epilimnion and hypolimnion, and thus cutting off fish production. Catch per unit effort of the main pelagic fishes was partially correlated with ENSO for the last 30 years in two stations of Lake Tanganyika, and changes in hydrodynamic and upwelling intensity were presented to explain this (ENSO Project 2003). More wind and lower temperature seem favourable for clupeid fishes (and possibly phytoplankton and zooplankton) while *Lates stappersi* catches are lower maybe because of lower transparency unfavourable to this visual predator (ENSO Project 2003). The observed decline of primary productivity by about 20% implies that the fish yields have decreased by about 30% over the past 30 years or so (O'Reilly et al. 2003). This suggests that the impact of regional effects of climate change on the aquatic ecosystem functions and services can be larger than that of local anthropogenic activity or overfishing (O'Reilly et al. 2003).

Environmental impacts

Changes in hydrological cycle and lake circulation

Changes in the hydrological cycle are related to changes in rainfall. These are ultimately reflected in lake-level changes as described below. During El Niño events, river discharge and sediment load tends to be high, and the rivers breach their banks in the lower reaches. These floodwaters affect the communities living along the river belts.

Lake-level change

Relatively small changes in rainfall and evaporation may lead to shifting between closed- and open-basin status as has happened in historic times for Lake Tanganyika (Spigel & Coulter 1996). The effects of global climate change in the Tanganyika Basin are reflected mainly in the Lake's nutrient dynamics (described above) and in increased frequency and intensity of El Niño phenomenon. The El Niño phenomenon in 1997–1998 saw water levels increase, lake-wide, by 2.4 m, but otherwise variability is limited (West, Cohen et al. field observations). Such flooding had a serious impact on low-lying urban riparian centres.

Socio-economic impacts

Economic impacts of El Niño are largest in the agricultural sector, where droughts and floods can significantly affect the GDP of the riparian countries, as they are mainly dependent on the agricultural sector for economic growth and food security. Flooding during El Niño years may also lead to increased incidences of water-borne diseases and may have an impact on low-lying lakeshore centres, e.g. by inundation of settlements and disruption of daily activities.

Conclusions and future outlook

El Niño is a recurrent phenomenon in the region, but due to global change the frequency and perhaps the intensity of the event is likely to increase (IPCC 2001). The current impacts that it has on the communities of the Lake Basin are basically a result of lack of investment in flood control measures, and lack of disaster preparedness by the governments. The social, economic and health impacts of El Niño can be drastically reduced if the afore-mentioned measures are put in place. Malaria and cholera epidemics have occurred to varying degrees in the East African region in the last decade. It is critical to know what to expect in the future in terms of disease trends so that adaptive measures can be put in place. Equally it is important to establish the population's adaptive capacity in terms of the ability to prevent and treat climate related illnesses.

Although current climate scenarios project small increases in tropical temperatures, small changes in temperature and water balance can dramatically alter water levels, as well as mixing regimes and productivity (IPCC 1996). Further, and more immediate and potentially catastrophic impacts are the changes in nutrient dynamics and mixing regimes within the Lake as a result of increased thermal stability as they affect fisheries production and can completely alter the trophic structure of the food chain (O'Reilly et al. 2003, Verburg et al. 2003, ENSO Project 2003). High temperatures will increase evaporative losses, especially if rainfall also declines (IPCC 1996). Slight decreases in precipitation or increases in either temperature or average wind speeds could convert Lake Tanganyika to a closed basin (Owen et al. 1990, IPCC 1996), cause significant changes in the thermal stability of the Lake's water mass and mixing dynamics (Hecky & Bugenyi 1992), and change the lake's water chemistry (Cohen et al. 1996) etc., affecting many aquatic organisms. Global change would affect the riparian communities by perhaps an increase in the frequency of extreme events e.g. El Niño. Severe droughts and floods would adversely impact the socio-economic activities and livelihoods of the inhabitants of the Lake Basin. High economic costs due to impact of droughts are unlikely to decrease. Health impacts of drought, such as malnutrition and deaths are however likely to increase in frequency.

Priority concerns

The GIWA concerns are prioritised as follows:

1. Unsustainable exploitation of fish and other living resources
2. Habitat and community modification
3. Pollution
4. Freshwater shortage
5. Global change

The priority concerns that were selected by the Task team for Lake Tanganyika are Habitat and community modification and Unsustainable exploitation of fish and other living resources. The linkages are shown in Figure 21 and are described below.

Habitat modification arises primarily as a result of all the other four concerns. Unsustainable exploitation of fish and other living resources has been shown to be inextricably linked to habitat modification. This has led to loss of ecosystems and changes in population structure of the wetland areas in the deltaic and floodplain areas of the principal rivers, as well as in the littoral and standing waters of the Lake. Pollution, which in this case is due mainly to suspended sediments that originate from habitat change (land clearance, degradation and increased erosion rates) in the principal river catchments, contributes to habitat modification, which in turn also affects the living resources. Natural habitats and living resources are affected by e.g. limitation of light penetration in the lake water due to increased turbidity and sediment blanketing of benthic organisms. Global change (reducing precipitation and higher temperatures) can result in increased concentrations of pollution in the Lake due to reducing lake level (and volume), but is more important by its influence on freshwater resources through the hydrological cycle.

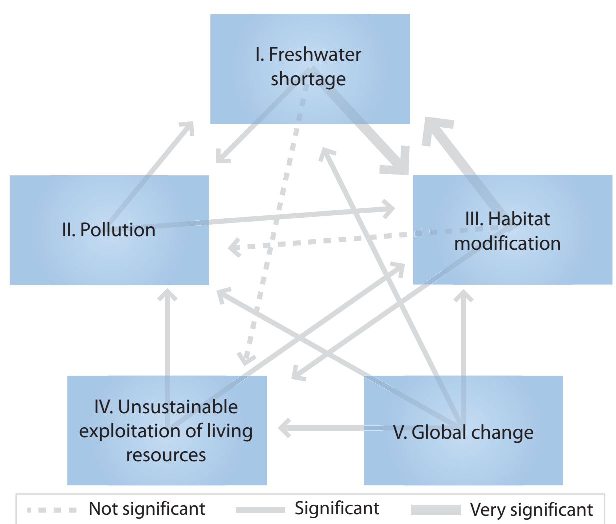

Figure 21 Linkages between the GIWA concerns in Lake Tanganyika.

Lake Malawi Basin

Table 18 Scoring table for Lake Malawi.

Assessment of GIWA concerns and issues according to scoring criteria (see Methodology chapter)

- 0 No known impacts
- 1 Slight impacts
- 2 Moderate impacts
- 3 Severe impacts

The arrow indicates the likely direction of future changes.

- ↗ Increased impact
- → No changes
- ↘ Decreased impact

Lake Malawi	Environmental impacts	Economic impacts	Health impacts	Other community impacts	Overall Score**	Priority***
Freshwater shortage	2.0* →	1.1 ↗	2.0 →	0.8 ↗	1.8	4
Modification of stream flow	2					
Pollution of existing supplies	2					
Changes in the water table	0					
Pollution	2.0* ↗	1.2 ↗	0.6 ↗	2.0 →	2.0	3
Microbiological pollution	2					
Eutrophication	2					
Chemical	1					
Suspended solids	3					
Solid waste	0					
Thermal	0					
Radionuclide	0					
Spills	1					
Habitat and community modification	2.0* ↗	1.7 ↗	2.3 ↗	2.5 ↗	2.5	2
Loss of ecosystems	2					
Modification of ecosystems	2					
Unsustainable exploitation of fish	2.6* ↗	1.7 ↗	1.6 ↗	2.0 →	2.5	1
Overexploitation	3					
Excessive by-catch and discards	0					
Destructive fishing practices	2					
Decreased viability of stock	0					
Impact on biological and genetic diversity	1					
Global change	1.0* ↗	1.9 ↘	1.3 →	1.4 →	1.4	5
Changes in hydrological cycle	1					
Sea level change	1					
Increased UV-B radiation	0					
Changes in ocean CO_2 source/sink function	0					

* This value represents an average weighted score of the environmental issues associated to the concern. For further details see Detailed scoring tables (Annex II).

** This value represents the overall score including environmental, socio-economic and likely future impacts. For further details see Detailed scoring tables (Annex II).

*** Priority refers to the ranking of GIWA concerns.

Freshwater shortage

The lake surface area is about 28 800 km² and the catchment area is 126 500 km² (Bootsma & Hecky 1993). The land catchment can be divided into a number of short coastal streams and six major river basins, of which four and part of the fifth lie within Malawi (Eccles 1984). Although only 28% of the Lake's total drainage basin area lies within Tanzania, the country provides 53% of the total inflow into the Lake, mainly through the Songwe (shared with Malawi), Kirire, Lafirio, Ruhuru and Rumakali rivers: annual mean run-off exceeds 10 000 m³/km² in many areas (World Bank 2003). The total inflow into the Lake is calculated to be 920 m³/s out of which 400 m³/s are from Malawi, 486 m³/s are from Tanzania and 41 m³/s are from Mozambique, while the average annual outflow is estimated to be 395 m³/s (Government of Malawi 1998). Most of the inflows are rather short from the escarpments and nearby mountains, and their volumes depends directly on the rainfall in the catchment of each stream or river. The hydrology is delicately balanced. The level of the Lake and the volume of the outflow react rapidly to changes in local rainfall between wet and dry seasons as well as to longer term fluctuations. The outlet via the Shire River to the Zambezi River is intermittent, with seasonally dependent flow rates. The rise and fall of the Lake is seasonal but also exhibits longer-term trends (Eccles 1974, Beadle 1981, Bootsma & Hecky 1999). Outflow may increase or decrease quite substantially, depending on the annual rainfall (Beadle 1981).

Environmental impacts

Modification of stream flow

Catchment disturbance through land clearance has resulted in greatly increased sediment loads and run-off (Calder et al. 1995), and diversion of water for irrigation in some rivers has resulted in reduced flow (Government of Malawi 1998). This is a significant issue due to its basin-wide pervasiveness and long-term impact on other aquatic aspects such as fisheries and habitat modification. Cattle grazing and agricultural activities (sugar and cotton growing under irrigation) are common in the marginal areas of the Shire swamps in the lower part of the course of the Shire River that supports one of Malawi's most important fisheries (Hughes & Hughes 1992). For example, the Dwanga River is completely closed off during the dry season and diverted to sugar cane fields; the River was originally an important locality for potamodromous fish runs, these spawning runs have now ceased completely with the annual diversion (Tweddle 1992).

Pollution of existing supplies

A survey of the water resources of Malawi concluded in 1980 that industrial pollutants and partly treated wastes from sewage had reduced the quality of water in many streams too far below acceptable levels (UNEP-IETC 2003). Today, with the rapidly rising population, lack of sanitation infrastructure, lack of sewage treatment facilities, increased numbers of informal settlements, rampant deforestation, etc., the situation must be far worse. The principal rivers, used to abstract potable water, carry suspended loads exceeding WHO guidelines in the range of 100 mg/l to over 400 mg/l (Kasweswe-Mafongo 2003).

The very large volume of Lake Malawi may provide a temporary buffer against deterioration of water quality (Spigel & Coulter 1996) but pollution of existing supplies in rivers and localised shoreline areas does occur. This problem is particularly associated with the western shoreline of Lake Malawi which is densely populated, and where the largely rural population relies on surface waters from the rivers and lake for domestic consumption without any treatment (Government of Malawi 1998).

Socio-economic impacts

The high silt load in surface water run-off has recently led to significant problems in downstream water quality, such as increased suspended solids, organic matter pollution and water treatment costs, decreased hydroelectric power generation capacity, water flow problems and siltation of ports (Government of Malawi 1998). This has most likely been associated with increased costs of human health protection, but there is no data to evaluate this.

The largely rural population is involved in continuously utilising untreated water, resulting in adverse health impacts that are localised and confined largely to densely populated settlements (Government of Malawi 1998). Up to 53% of the population use water sources that are classified as unsafe, and 34% of the population have no access to flush toilets nor traditional pit latrines (UNEP-IETC 2003). As a result, the people suffer from common ailments such as diarrhoea and malaria; these diseases are common in coastal communities (UNEP-IETC 2003). It has been noted that there has been an increased incidence of bilharzia (schistosomiasis) in the last two decades, and outbreaks of cholera are common near the lakeshore in the rainy season (Bootsma, pers. comm.).

Loss of human drinking water supplies, loss of recreational use, reduction in future use options and transboundary implications are the identified social and community impacts brought about by pollution of water. The possibility of contracting schistosomiasis in Lake Malawi and the negative travel advisories abroad in relation to this disease have deterred tourists from visiting the Lake's attractions (Bootsma, pers. comm.).

Conclusions and future outlook

Freshwater shortage has only slight impact in Lake Malawi, but a much greater impact on the rivers that flow into the Lake in terms of available water for consumption, domestic and livestock use, and irrigation of crops. Catchment disturbance through land clearance has resulted in greatly increased sediment loads (Tweddle 1992), and diversion of water for irrigation in some rivers has resulted in reduced flows. Most of the rivers are now polluted and are unsafe for use as potable water; this is prevalent mostly in rivers that flow through urban settlements and along the largely unplanned coastal settlements that lack proper sanitation infrastructure. The various forms of pollution have had diverse impacts: siltation threatens the production capacity of the hydroelectric power plant and operations of irrigation systems; reduced water quality and quantity has increased the costs of water treatment and water supply, respectively; and agricultural productivity is facing a decline due to soil loss and inadequate water supply for irrigation. It has been suggested that pesticide pollution in the rivers and the Lake itself may have played a role in the decline of the Ntchila (*Labeo mesops*) population (Government of Malawi 1998).

Increased agricultural activities and land degradation in the catchment will result in increased suspended solids being transported to the rivers and lake. Pollution of both surface and groundwater resources due to excessive use of agro-chemicals in catchment areas is likely to increase (Government of Malawi 1998). The very large volume of Lake Malawi may provide a temporary buffer against deterioration of water quality (Spigel & Coulter 1996), but its long residence time makes it more vulnerable to damage from the effects of human activities and development in its catchment. Because of the rapid population growth, high level of poverty, e.g. 46% of Malawi's population are currently facing severe poverty (Government of Malawi 1998), and high dependence on subsistence rain-fed agriculture and to a lesser extent irrigation, demand for the water resources, whose quantity and quality are increasingly being diminished by abstraction and pollution, will increase. Since the riparian countries are very poor, they will not be able to meet the associated rising costs of water treatment, sanitation and sewerage infrastructure. Nor will they be able to introduce the necessary sustainable land management practices that will ensure sustainability of the quality and quantity of freshwater resources.

IMPACT Pollution

Most of the pollutants in Lake Malawi come from the Malawi watershed which is by far the most densely populated;Tanzania and Mozambique watershed areas are lightly populated particularly because most of the lakeshore on the eastern and northern side is inaccessible due to the steep topography. Microbiological, chemical and spill pollution are largely local in extent. On the other hand, eutrophication and suspended solids are much more widespread due to increased run-off and erosion from the degraded and deforested watershed areas and large-scale biomass burning during the dry seasons that convey nutrient elements to the Lake via the atmosphere (Bootsma & Hecky 1999). As early as 1960, the high population density of Malawi had led to extensive alteration of the natural vegetation of the catchment (Eccles 1984).

Environmental impacts

Microbiological

Microbiological pollution is an issue, at various localities, but there are few reports that document its severity, particularly in Tanzania and Mozambique. The bacteriological quality of major rivers in Malawi is poor due to effluent discharges, with the worst quality being found in rivers that flow through the cities of Blantyre, Lilongwe, Zomba and Mzuzu (Government of Malawi 1998). Most rivers contain faecal coliforms exceeding 500 per 100 ml in the dry season: the faecal coliforms are largely from unplanned settlements and improper waste disposal (Kasweswe-Mafongo 2003). Counts as high as 20 000 faecal coliforms per 100 ml have been observed in Linthipe River downstream of the sewage plant during periods when the plant has broken down (Government of Malawi 1998). In low-income areas of the above cities, pit latrines are usually constructed without consideration to their potential for water resource pollution. Poor sanitation in the more densely populated areas around the Lake can potentially result in serious disease transmission problems, particularly via lake fish. For example, the practice of drying fish directly on beaches that are also used as untreated effluent disposal points can lead to outbreaks of cholera as outlined above.

Eutrophication

There are three major sources of nutrient inputs to Lake Malawi; land-based discharge, atmospheric deposition, and upwelling return (Lam et al. 2002). The nutrient and sediment loading to the Lake from its rivers is likelyto have increased by 50% within the past few decades with a few rivers such as the Linthipe, Songwe and Dwanga accounting for much of that increase (World Bank 2003). The likely factors influencing increased sediment deposition (Calder et al. 1995) and nutrient input (Bootsma & Hecky 1999) in the southern catchments are deforestation, increased agriculture, erosion and biomass burning. The environmental degradation is driven by the need to sustain the growing population.

The prominence of the blue-green algae *Planktolyngbya tallingi* in the southern region of the Lake (where it has replaced the previously dominant *Planktolyngbya nyassensis*) and the reported occurrence of *Cylindrospermopsis raciborskii*, a filamentous blue-green algae which is often a climax species in highly eutrophic situations and which has toxic forms are indicative of increasing eutrophication (Bootsma & Hecky 1999). The increased nutrient inputs (including phosphorus which is likely to be influencing changes in plankton composition) are from both the atmosphere and rivers resulting from deforestation, increased agricultural erosion and burning (Bootsma & Hecky 1999). They are not linked to fertiliser application, but are the result of nutrient mobilisation in terrestrial biomass and soils.

The water hyacinth is now encroaching into Lake Malawi from a variety of sources including its infested Shire River outlet and rivers, such as Bua and Linthipe, that drain the watershed (UNEP-IETC 2003). Some pockets along the Lake already show signs of infestation, e.g. at Chembe, Cape Maclear, where clusters of hyacinth were observed in 1996 (UNEP-IETC 2003).

Chemical

Chemical pollution from urban domestic and industrial sources, and from fertilisers, herbicides and pesticides used in agriculture has been increasing (Coulter & Mubamba 1993). Mercury in fish is a potential health hazard for humans, while organochlorines are unlikely to have any health impacts (Bootsma & Hecky 1999). Very heavy application of copper fungicides is reported near Nbozi, in the Tanzanian portion of the watershed (Alabaster 1981).

Suspended solids

Changing patterns of land use and erosion resulting from forest clearance (Calder et al. 1995) for agriculture to sustain the growing population in the southern catchments are the likely factors influencing increased sediment deposition in southern Lake Malawi (Bootsma & Hecky 1999). The inshore quality of water along Lake Malawi depends on the effect of river effluent, some of which has high sediment loads (UNEP-IETC 2003). River catchments with very high deforestation rates have led to increased turbidity and river discharges high in suspended solids. The increasing soil loss poses the greatest threat to sustainable agricultural production and negatively impacts on water quality (Kasweswe-Mafongo 2003). High sediment loads smother nearshore rocky habitats, reducing algal growth and habitat diversity, which in turn reduce fish abundance and, possibly, diversity. The sediment decreases water clarity and light penetration, further reducing benthic algal growth (which is the food base for the species-rich nearshore cichlid communities), and may reduce species diversity by preventing females from recognising con-specific males. Phytoplankton, and other pelagic or benthic organisms, will be affected by increased turbidity. In addition, many of the fish retain the habit of spawning in the inflowing rivers, and thus high sedimentation and turbidity may reduce fish stocks in the Lake.

Spills

There are no reported spills in the Lake, but these are likely to occur from time to time in the maritime transport industry.

Socio-economic impacts

Pollution has led to increased costs of human health protection, water treatment, preventive medicine and loss in fisheries.

Microbiological pollution is widespread in the Basin's rivers, particularly in those that pass through urban settlements, but is more localised along the lake shore where it results from poor sanitation infrastructure and unhygienic handling of fish, leading to increased incidence of water-borne diseases, particularly in densely populated settlements (Government of Malawi 1998, UNEP-IETC 2003). Pollution leads to increased risks to human health. In addition, loss of traditional protein sources (decline in fisheries) would increase the vulnerability of the people living in this area to food or essential nutrient shortages (Government of Malawi 1998, Kasweswe-Mafongo 2003).

Pollution has to some degree led to loss of potable water supplies, loss of tourism or recreational values, loss of aesthetic values, change in fisheries value, loss of wildlife sanctuaries, and avoidance of amenities and products due to perception of the effects of contamination (Government of Malawi 1998, Kasweswe-Mafongo 2003).

Conclusions and future outlook

The problem of eutrophication and increased suspended solids is widespread and is related to deforestation, agriculture, erosion and biomass burning in the catchment (Calder et al. 1995, Bootsma & Hecky 1999). This is leading, for example, to changes in phytoplankton communities particularly in the southern region of the Lake (Bootsma & Hecky 1999). There is also reported occurrence of *Cylindrospermopsis raciborskii*, a filamentous blue-green algae, which is often a climax species in highly eutrophic situations (Bootsma & Hecky 1999). The water hyacinth is now encroaching Lake Malawi from a variety of sources including its infested Shire outlet and rivers that drain the watershed (UNEP-IETC 2003). There are no reported spills in the Lake, but this is likely to occur from time to time in the maritime transport industry. Pollution (as defined in this section) is perhaps the greatest threat to Lake Malawi (Tweddle 1992). Eutrophication, pesticides, alteration of biological communities and possible consequences of petroleum extraction are of concern to the Lake Malawi Basin (Hecky & Bugenyi 1992).

Pollution will continue to increase as the human population grows and natural landscapes are converted for agriculture, habitation and transportation (Beeton 2002). Suspended solids and eutrophication are the primary pollution issues in Lake Malawi. Soil is declining in fertility due to soil erosion and degradation, and is evidenced by increased rates of soil loss, declining yields from unfertilised crops, declining responses to fertiliser application, and impaired watershed performance (World Bank 2003). While the concentration of solutes and particulates in rainwater near Lake Malawi are not particularly high relative to industrial regions or some other parts of Africa, higher than average ammonium-cation ratios, nitrate-anion ratios, and potassium concentrations suggest that burning is having a significant effect on atmospheric chemistry around the Lake (Bootsma & Hecky 1999). Although the direct effect of the deposition of these solutes on the Lake may not be deleterious, the burning and soil exposure that these observations reflect may potentially result in detrimental impacts on the Lake, such as siltation, accelerated flux of nutrients from soil to the Lake, and a decreased and more variable water supply from rivers (Bootsma & Hecky 1999). Phosphorus loading resulting from catchment disturbance could have some of the following consequences: reduced water clarity, resulting in a shallower benthic trophogenic zone; and a shoaling of the oxic-anoxic boundary and reduction of available fish habitat (Bootsma & Hecky 1999).

Soil conservation measures will need to be urgently implemented in order to protect both the rivers and lake, and to preserve or improve upon current agricultural productivity in the catchment. Because of its high contribution to total river inflow to Lake Malawi, land management within the Tanzania catchment area has a significant impact upon the level of nutrients, sediments and other land-based pollution entering the Lake. It is clear that further land clearance in the more mountainous northern areas will have relatively greater negative impacts on the Lake due to steeper slopes and higher rainfall (World Bank 2003). Pressure on the Lake is expected to increase as a direct result of declining agricultural productivity (World Bank 2003) and increasing pollution of rivers, etc., and this has the potential effect of adversely affecting fisheries, the lake ecosystems and water quality.

Habitat and community modification

There is a high rate of deforestation within the catchment. The total land areas under cultivation in the northern and central regions of Malawi were estimated to be 17% and 22% respectively in 1964-1965; these increased to 22% in the north and 41% in the central region by 1978 (Eccles 1984). Together, these two regions form almost 64% of the land catchment and 49% of the total catchment of the Lake, so it is evident that a large proportion of the natural *Brachystegia-Julbernardia* woodland has been cleared.

The fast-flowing upper reaches of the numerous rivers that drain into Lake Malawi support unique communities of animals and plants that are not found elsewhere in the system (Jackson et al. 1963, Tweddle & Skelton 1993). Small deltas with freshwater swamps occur at the mouths of some streams entering the Lake on the Tanzania shore. Larger swamps include: the Linthipe River delta, 22 km long and 15 km wide, mainly swampy; the Karonga Lakeshore Plain, much of which is under cultivation, along the northwest shore at the Malawi side; Nkhotakota Lakeshore Lowlands, a strip extending for 125 km along the western shore of Lake Malawi, containing a number of seasonally flooded areas; and Salima Lakeshore Plain, a very wet plain about 90 km long, with large marshes and the swampy delta of Linthipe River (Hughes & Hughes 1992). Water-level changes as a result of abstraction or natural fluctuations in the hydrological balance can have marked impacts on fish catches because the floodplains act as very productive nursery areas (Ribbink 2001). The Shire swamps in the lower part of the course of the Shire River support one of Malawi's most important fisheries. Cattle grazing and agricultural activities (sugar and cotton growing under irrigation) are also common in the marginal areas (Hughes & Hughes 1992).

The only area which currently protects the cichlid fishes is the 94 km^2 Lake Malawi National Park in the southern part of the Lake, declared by UNESCO as a World Heritage Site in 1982, but the continuous nature of the lake environment leaves this part vulnerable to large-scale changes in the Lake and its basin (Figure 22) (World Bank 2003).

Environmental impacts

Loss of ecosystems

The widespread deforestation within the catchment to pave way for agriculture and settlements has resulted in loss of some floral and faunal ecosystems. In addition, the rich genetic pool of flora and fauna in protected areas such as national parks, game and forest reserves is diminishing due to habitat destruction and poaching (Kasweswe-Mafongo 2003). Habitat degradation of rivers and overfishing threaten riverine and potamodromous fish species (Chapman et al. 1992, Tweddle 1992, Ribbink 2001). In the Bua River, the largest river to enter the Lake from the Malawi side, fishes e.g. *Opsaridium microlepsis* have now been largely eliminated from Malawian waters through a combination of siltation and fishing pressure (Cohen et al. 1996). In addition, the Ntchila (*Labeo mesops*) stocks, which migrate in groups into rivers to spawn and which used to be abundant in the Lake and formed the basis of an important fishery in the 1950s and l960s, have declined to less than 1% of their former levels (based on gill net catches) (Government of Malawi 1998). Although no studies have been done, anecdotal comments suggest that seine netting has reduced substantially the vegetated regions, and hence the amount of habitat for use as nurseries and for species that are adapted to living among macrophytes (Ribbink 2001). The habitats of the inshore regions support the richest, most diverse and most stenotopic cichlid fish communities (Ribbink 2001). The rocky shores harbour a wealth of invertebrates (e.g., harpacticoid copepods, chironomids, ostracods), molluscs and the crab *Potamonautes lirrangensis*, while sandy shores support an almost entirely different invertebrate fauna (copepod and ostracod Crustacea, the prawn *Caridina nilotica*, chironomid larvae, gastropods, bivalve Mollusca) (Hughes & Hughes, 1992). These communities are under threat from sediment inundation of the habitats, and overfishing (Ribbink 2001). Studies are, however, necessary to establish the extent of ecosystem loss and its impacts.

Modification of ecosystems

Available evidence indicates that the most seriously threatened fish species are the riverine and potamodromous species as a result of both habitat degradation of rivers and overfishing (Tweddle 1992, Ribbink 2001). The Bua River, for example, is important since it supports huge breeding runs of the migrating cyprinid fish *Opsaridium microlepsis*, which is endemic to Lake Malawi and is one of the major commercial species in its northern and central parts (Hughes & Hughes 1992). These fishes have now been largely eliminated from Malawian waters through a combination of siltation and fishing pressure (Cohen et al. 1996). They are still common in lightly populated areas of the Mozambiquan coast, but even there spawning grounds are beginning to show signs of serious deterioration (Massinga 1990). Within the Lake itself, it appears that some of the "key" fish stocks are declining. In the area south of Boadzulu Island, an area of intensive demersal trawling, many of the larger cichlid species have declined with some species becoming locally extinct. More generally, the fish community compositions are changing within the Lake as a result of overfishing.

Socio-economic impacts

In Malawi, 85% of the population is below the absolute poverty line: the major source of income for the population is agricultural production at subsistence level, and this is increasingly threatened by soil degradation (ADB 1997). It is estimated that 230 000 (ATF 1997) to 290 000 people (World Bank 2003) are employed directly or indirectly in the fishing industries, and these jobs are now being threatened by declining fish stocks (ATF 1997). The declining fish yields (Mapila 1998, Ribbink 2001), partly resulting from habitat change, has contributed to increased effort per catch unit. Given that the number of fishermen in the Lake is increasing against this decline in fish yields, the effective income per individual in the fisheries industry has declined. Fish is a primary source of protein in the area, so habitat change that results in lower fish yields leads to declines in nutritional status of the population.

Widespread poverty within the population plays a significant role in environmental degradation (ATF 1997). More than 90% of energy requirements are met from biomass supplies, and national wood consumption stands at double the sustainable production (WWF 2003). Reduced capacity to meet the basic human need for food and fuel affects the welfare of the family unit. Loss of species in Lake Malawi is a serious problem caused by a combination of high population growth, rampant poverty and other economic factors (ATF 1997). The harvest of large quantities of fish has altered the ecological balance in the Lake, reducing the number and species of fish and affecting other wildlife such as birds which feed on fish (ATF 1997). Loss of alternative income has affected the family units' ability to afford e.g. education and health services. This has been compounded by disruption of living patterns due to commercial fisheries opening up wider markets and fostering increased demand for fish, resulting in increased fish prices. This has forced the local people to modify their cultural ways in order to find alternative food sources (ATF 1997). Reduction of the diversity of the genetic pool reduces the available materials for extraction of medicines, for agriculture and research (Kasweswe-Mafongo 2003). Human conflicts (e.g. between subsistence and commercial fishermen) are likely to increase due to competition for diminishing resources, and loss of habitats leads to intergenerational inequities. Because of the endemicity of the Lake's cichlid fishes and rich speciation in haplochromines, the global community has only one chance at effective management of this unique resource (World Bank 2003).

Conclusions and future outlook

The Lake Malawi Basin has numerous swamps/wetlands that are important in terms of plant species diversity and nursing grounds for fish. Conversion of these swamps/wetlands for cultivation and cattle grazing, as well as the use of their waters for irrigation, has adverse impacts on their biodiversity. Increased sedimentation resulting from land degradation and deforestation in the catchment is also changing riverine and lacustrine habitats that again impacts on biodiversity. Overfishing and destructive fishing practices, acting in concert with human-induced wetland conversion and increased sedimentation, has grave impacts on the fish stocks and species diversity, particularly in the wetlands and littoral zones of the Lake. For example, the cyprinid fish *Opsaridium microlepsis*, which is endemic to Lake Malawi and is one of the major commercial species in its northern and central regions (Hughes & Hughes 1992) has now been largely eliminated from Malawian waters through a combination of siltation and fishing pressure (Cohen et al. 1996). In addition, water level changes in the floodplains can have marked impacts on fish catches because the floodplains act as very productive nursery areas (Ribbink 2001).

Figure 22 Lake shore of Lake Malawi near Money Bay in Lake Malawi National Park.
(Photo: Corbis)

Water hyacinth has been introduced into the rivers of the Basin and through them has entered the Lake. It is currently not a problem as the Lake does not have sufficient nutrients to sustain it, but may become so with increased eutrophication. The rate of loss of ecosystems and/or their modification will increase as result of changes (reduction) in the surface area currently under water, human activities in the catchment and aquatic system as a whole. Changes in salinity due to decreasing water levels and increasing temperatures will also affect the current ecosystem and could result in changes in community structure and species composition, though this is very unlikely in the near future. Economic impact would become more severe as a result of further ecosystem loss and habitat modification. Subsistence fisheries would be most affected, as shallow aquatic areas are lost to land, reducing the local populations capacity to meet basic food needs. This, in turn, would increase health risks. The prospect of enhanced lake deterioration would also increase as populations migrate to areas which still retain their ecosystem integrity in search for unpolluted fish food, water, agricultural land and fuel wood resources.

IMPACT Unsustainable exploitation of fish and other living resources

Malawi has about 800 different species of fish (Ribbink 2001). Many of these fishes are colourful and highly sought after by the aquarium trade. The inshore distribution of these fishes and their inquisitive behaviour make them attractive to view and adds immeasurably to the tourism potential of the Lake.

By the 1930s, commercial fisheries had begun in Malawi (Ribbink 2001), and in the 1940s the first concerns over overfishing were raised (Ricardo-Bertram et al. 1942). The growth of the artisanal fishery was accompanied by the development of a mechanised fishery which started in 1943 with the introduction of open plank boats with engines. Fishing pressure increased in the 1960s when artificial twines replaced natural fibres, plank boats with outboard engines became popular and the first demersal trawlers were introduced (Tarbit 1971). Since then, the number of small, open vessels has increased progressively, with a growth of more than 80% since 1980 in Malawi, to almost 9 400, of which 1 700 are planked boats (Malawi Fisheries Department, cited in Ribbink 2001). In Mozambique and Tanzania, the remoteness of the Lake from regions of high population density meant that the scale and intensity of fishing never reached a level comparable to that in Malawi (Ribbink 2001). Nevertheless, fishing pressures grew along the lakeshore in both countries, despite the relatively low population densities (Booth 2000). In Malawi, the artisanal fishery land 80–90% of the catches, while in Tanzania and Mozambique, the artisanal fisheries account for all landings (Ribbink 2001).

All the fishes in the Lake are edible, consequently, by-catch is not wasted as all fish that are caught are eaten, whether targeted or not (Ribbink 2001). There is no evidence of decreased viability of stock through increased incidence of fish contamination and disease.

Environmental impacts

Overexploitation

Fish production in Malawi rose dramatically from annual catches of 20 000 tonnes in 1965 to 84 000 tonnes in the 1970s and has declined since then to give fluctuating yields, sometimes dropping to 60 000 tonnes per year (Mapila 1998). In Mozambique, there was a decline in fishing effort due to the civil war but since then there has been an increase in fishing activity. In Tanzania, the fishery has shown steady growth. An increase in the number of boats and in fishing effort has resulted in a decline in catches (Ribbink 2001). The soft substratum-associated fish communities have been more heavily impacted than the rocky fish-associated communities in the shallower parts of the Lake. Overfishing does not occur throughout the Lake, and the deep pelagic waters of the Lake are probably under-exploited. However, deep water demersal communities (50-100 m depth) are harvested by offshore trawlers in particular and have shown changes in species composition and standing stock, but nearshore, shallow demersal communities are under the greatest pressure (Ribbink 2001). The cichlid fish communities of the inshore regions are the richest, most diverse, most stenotopic, and hence the most vulnerable to fishing pressure, yet it is these vulnerable communities that are subjected to the greatest fishing effort; the artisanal fishery land about 85% of the catch and is restricted to the nearshore habitats (Ribbink 2001). There are indications that local overfishing has taken place because Catch Per Unit Effort (CPUE) and standing stocks have decreased (Ribbink 2001). In the artisanal and commercial fisheries, species composition of catches has changed, with the larger fishes disappearing from the catches (Ribbink 2001). Partly as a result of overfishing, the most seriously threatened fish species are the riverine and potamodromous species, some of which have now been eliminated (Tweddle 1992, Cohen et al. 1996, Ribbink 2001).

Destructive fishing practices

Although no studies have been done, anecdotal comments on fishing in the littoral belt suggest that seine netting has reduced substantially the vegetated regions, and hence the amount of habitat for use as nurseries and for species that are adapted to living among macrophytes (Ribbink 2001).

Impact on biological and genetic diversity

There is no evidence of deliberate or accidental introductions of alien stocks or genetically modified species (Cohen et al. 1996). However, there have been many unintentional species translocations within the Lake, mostly by the aquarium trade industry. The translocations disrupt existing nearshore species, and may result in the extinction of species at certain locations, and/or homogenisation of the gene pool and loss of genetic diversity (Bootsma, pers. comm.).

Socio-economic impacts

Fisheries is an important economic sector, supporting thousands of permanent inhabitants who are largely dependent upon fish for their livelihood (Ribbink 2001). The commercial fisheries from Lake Malawi are currently estimated to contribute 1–2% to GDP and provides employment, directly or indirectly, to up to 290 000 people (World Bank 2003). The ornamental fishery provides foreign exchange, and employment to several hundred people (Ribbink 2001). The per capita consumption of fish fell in Malawi from 12.3 kg in 1972 to 7 kg in 1991 (Mapila 1992), and is believed to have continued to fall, suggesting that supply cannot keep up with demand (Ribbink 2001). Overexploitation and destructive fishing methods would lead to reduced economic returns, loss of employment and livelihood, and reduced earnings in one area by destruction of juveniles in another (migrating populations).

Fish is particularly important to the people during times of drought (Mapila 1992) as it combats malnutrition when crops fail. Unsustainable exploitation can therefore lead to malnutrition due to loss of protein sources for human consumption. In Malawi, for example, fish from the Lake and rivers provides about 70% of animal protein consumption in the country (Nyambose 1997, World Bank 2003). The poor who rely on fish for their daily needs lose out as fish stocks decline, and demand and prices increase (Nyambose 1997). However, it is not too severe due to the existence of protein options.

The Lake is one of the world's major biodiversity hotspots. The ornamental fishery stimulates the interest in the biodiversity of the Lake and focuses international attention on the Lake, which is of benefit to promoting donor interest and the tourism industry (Ribbink 2001). On the other hand, trawlers sometimes fish inshore, creating conflict between them and the artisanal fishermen. With the introduction of commercial large-scale fishing, the lakeshore people are finding it difficult to continue their traditional way of life: in some cases, living patterns have been dismantled and cultural practices have been modified in order to find alternative sources of food (Nyambose 1997). Intergenerational equity issues also arise due to the environmental degradation and loss of biodiversity.

Conclusions and future outlook

The Lake Malawi fish community has been adversely impacted by increased exploitation of inshore fishes resulting in declining catches and loss of biodiversity (Turner 1994). Overfishing does not occur throughout Lake Malawi, and the deep pelagic waters of the Lake are probably under-exploited (Ribbink 2001). However, deep water demersal communities (between 50–100 m depth) are harvested by offshore trawlers in particular and have shown changes in species composition and standing stock, but nearshore, shallow demersal communities are under the greatest pressure (Ribbink 2001). At the southern end of the Lake, fishing has resulted in reduced fish size, smaller catches, and possibly reduced biodiversity. The potamodromous fishes are subjected to heavy fishing pressure when adults congregate on their spawning runs up river; simultaneously, degradation of rivers negatively affects breeding success and recruitment, so that populations of several species are in decline and many are threatened (Tweddle 1992, Ribbink 2001). As in Lake Tanganyika, the impact of ornamental fishing on population and community structure could be considerable as the rare and alien species are extracted in as high a number as possible because of the high mortality rates in shipping. Declining fish yields and CPUE, as well as disappearance of certain fishes from the catches (while the number of people involved in fishing continues to grow), suggests that present levels of exploitation are not sustainable, at least in some parts of the Lake (Ribbink 2001).

The fisheries sector is likely to become more important to the GDP of the region as more people turn from agriculture (which is now exhibiting declining productivity as a result of land degradation) to fisheries. In addition, the rapidly increasing population will fuel increased fishing effort through sheer numbers alone as the people try to sustain their livelihoods. Under immediate threat are the riverine, potamodromous and littoral zone fisheries. If the Mtwara Development Corridor is successful in its initiatives, this will open up the remote lakeshore areas of Mozambique and Tanzania, and will probably also lead to increased fishing pressure from the two countries. Currently, the deep pelagic waters of the Lake are probably under-exploited (Ribbink 2001), but as the fish stocks dwindle in the littoral and shallower areas, these deep pelagic waters will probably become the new fishing grounds that will be accessible to the large commercial trawlers. In relation to this, there is the prospect of the collapse of artisanal fisheries with dire consequences for the hundreds of thousands of people who are dependent on them for income and food. Negative spin-offs from this would be increased levels of poverty, malnutrition, and social conflicts (e.g. between artisanal and commercial fishermen as is currently the case). Declining fish stocks may accentuate the use of destructive fishing practices which would, in turn, accelerate the elimination of fish through direct (overfishing) and indirect (destruction of habitat, changes in the food chain, etc.) impacts.

Global change

Within the region, changes in the distribution of rainfall take place in response to the movement of the Inter-Tropical Convergence Zone (ITCZ) and associated belts of distribution. Climate change and variability are caused amongst others by long-term trends in the movement and characteristics of the ITCZ, shifts in the global circulation pattern, deforestation, rates of evapotranspiration, global greenhouse gas emissions and changes in the hydrological system (Government of Malawi 1998). The Lake itself exerts a considerable modifying effect on the weather and climate in its vicinity (Eccles 1984). Average rainfall around the Lake varies regionally, the general trend being less rain at the south of the Lake and more at the north end (Bootsma & Hecky 1999). Using more than two decades of data (1954–1980), Kidd (1983) calculated mean annual rainfall in the south (south of the Dwanga watershed) to be 996 mm, that in the central area to be 1 110 mm, and that in the north and northeastern area (Songwe to Ruhuhu watersheds) to be 1 542 mm. The estimated average annual rainfall directly on the Lake is estimated to be 1 414 mm (Kidd 1983). Global warming will lead to higher temperatures: the rate of warming is estimated to be between 0.2 and 0.5°C per decade for Africa (Hulme et al. 2001), and rainfall in southern Africa is projected to decline by 2050 by about 10% (IPCC 2001).

The hydrological cycle in the region is closely linked to ENSO cycles (cf. Nicholson 1996). However, as opposed to eastern Africa, El Niño in this region is associated with drought rather than excess rainfall. The correlation between El Niño and inter-annual variations in southern Africa is highly significant, but it is not a simple relationship. Not every El Niño event brings low rainfall, and in some years extremely low annual rainfall is not clearly linked to El Niño events (Clay et al. 2003). Much less well understood oceanic-atmospheric interactions in the Indian Ocean and Southern Atlantic are now recognised as important influences on rainfall patterns (Clay et al. 2003).

Agriculture accounts for between one-third to slightly over one-half of the GDP of the riparian countries (see Table 10). Most of the agricultural activities are at subsistence level, and depend directly on rainfall. The region's electricity is dependent largely on hydroelectric power production from the Shire Valley hydroelectric power plant, which in turn depends on flow from Lake Malawi. Inland fisheries and navigation are often dependent on the hydrological regime in lakes and rivers. A reliable supply of good quality water is required for human consumption, industry and irrigation (Calder et al. 1995). In the drought of 1991/1992, the Shire Valley hydrolectric system came close to power restrictions due to insufficient water flow (Clay et al. 2003). Because most rural people depend on agriculture for subsistence, unreliability of rainfall causes loss of income, and increased general vulnerability to food security (Government of Malawi 1998). The effects of sea-level change, radiation, carbon dioxide source-sink function, and temperature change, remain uninvestigated in the Lake Malawi Basin.

Environmental impacts

Changes in hydrological cycle and lake circulation

There has been an increase in the frequency of droughts in recent years (Ribbink 2001). The droughts of 1991/1992, 1994/1995 and 1997/1998 were all associated with ENSO (Clay et al. 2003), but the recent disastrous floods in Mozambique and the role which the extremely high rainfall in Malawi in 2000/2001 played in the crisis in 2002 have highlighted the risks associated with high rainfall (Clay et al. 2003). Periods of below-average or erratic rainfall were less extreme and less general in their impacts in the 1970s and 1980s than in the 1990s (Clay et al. 2003). High outflows in the Shire River were recorded in 1980 when the discharge (963 m^3/s) was over twice as high as the mean discharge (395 m^3/s), and the highest annual outflows of 825 m^3/s and 820 m^3/s occurred in 1979–1980 and 1980–1981 respectively, during an unusually wet period (Government of Malawi 1998).

Lake-level change

Lake Malawi is similar to Lake Victoria and Lake Tanganyika in that relatively small changes in rainfall and evaporation may lead to shifting between open- and closed-basin status as has happened in historical times (Beadle 1981, Owen et al. 1990, Spigel & Coulter 1996). Lake Malawi had a lowstand between 1500 and 1850 (^{210}Pb dates) (Owen et al. 1990) and in 1915 when outflow via the Shire River ceased; outflow resumed in 1935 after the lake level had risen 6 m (Beadle 1981). Lake Malawi, as the other east African lakes, also responds dramatically to El Niño events, but also to anomalous warming of the Western Equatorial Ocean, such as that which led to the high rainfall event that occurred in 1997-1998 and resulted in a water level rise in the Lake of 1.8 m (Birkett et al. 1999). Other high rainfall periods are recorded in the early 1960s and late 1970s. A modelling study of Lake Malawi shows that rainfall variation is sufficient to explain the lake-level changes on annual and seasonal resolution over the past century (1896 to 1967) irrespective of changes in land use, evaporative demand or in the hydraulic regime of the Lake (Calder et al. 1995). However, because of a 13% decrease in forest cover from 1967 to 1990 as a result of human activities, the run-off increased, and consequently the lake level was 1 m higher than it would otherwise have been during the drought of 1992 (Calder et al. 1995).

Socio-economic impacts

Impacts of increased frequency and intensity of drought are felt mostly in agriculture and in other sectors reliant on water, such as hydroelectric power generation. In southern Africa, including Lake Malawi Basin, agricultural performance is optimal with annual rainfall between 95% and 120% of long-term mean total rainfall – excesses or deficits will negatively impact on agricultural production such as the 1991/92 drought that resulted in a 60% decline in maize production (Clay et al. 2003). The economic cost of this drought in the southern African region was estimated as follows: 1 billion USD in cereal losses at import parity prices and 500 million USD in actual logistical costs of importing cereal into affected southern African countries (Clay et al. 2003). Economic costs of excess rainfall through damage to infrastructure and agriculture can also be quite extensive: in the past, floods have destroyed hotel and harbour installations, destroyed crops, and cut off communications. The degradation of catchment areas and marginal lands as a result of population pressure and inappropriate agricultural activities, has led to the reduction of base flows and increased incidences of flood disasters during heavy storms. The flood peak levels in 1976 and 1978 caused considerable difficulties to lakeshore dwellers, hotels and harbour installations (Drayton & Crossley cited in Eccles 1984). The floods of 1979 and 1980 inundated large areas of productive land, rendering many villages uninhabitable, caused the temporary closure of some hotels, threatened communications and overtopped jetties at major ports (Drayton & Crossley cited in Eccles 1984). This has resulted in temporary displacement of large populations, loss of food resources, and has been a major impediment to communications.

Conclusions and future outlook

A complex interaction between an array of climate parameters (ITCZ, shifts in the global circulation pattern, deforestation, rate of evapotranspiration, global greenhouse gas emissions and changes in the hydrological system) affect the climate of the region. The Lake itself also exerts a strong modifying influence on the regional climate. The hydrological cycle is closely linked to ENSO cycles. Drought is normally but not always associated with the ENSO, whose frequency and intensity has been observed to be increasing, probably as a result of global warming. However, the increased frequency of drought that has been observed in southern Africa, e.g., in the 1990s, cannot be conclusively linked to ENSO (and global warming), as there are other causes that are not necessarily linked to ENSO, such as oceanic-atmospheric cycles in the Indian Ocean and Southern Atlantic, that significantly affect the climate of the region (Clay et al. 2003). Changes in the rainfall patterns have had adverse economic impacts on the agricultural sector, and on infrastructure, housing and communications (Drayton & Crossley cited in Eccles 1984, Clay et al. 2003). Reductions in rainfall also threaten the production of electrical power from the Shire Valley hydroelectric power plant. Rural communities are the most vulnerable to changes in precipitation as they rely largely on subsistence agriculture for food security and income generation. Global warming will lead to higher temperatures at a rate of 0.2–0.5°C per decade in Africa (Hulme et al. 2001), while rainfall in southern Africa is projected to decline by about 10% over the next 50 years (IPCC 2001). The projected decline in rainfall relative to today does not appear to be a great threat to the region, but there may be associated increased variability and changes in the distribution of precipitation. These are issues which need further, and urgent, investigation.

As has been observed in Lake Tanganyika (O'Reilly et al. 2003, Verburg et al. 2003), warming temperatures in the region will cause greater heating in surface waters than in deep waters in the meromictic Rift Valley Lakes, and this could reduce vertical exchange of deep waters with surface waters and reduced loading from the higher nutrient concentrations in those deep waters. Vollmer et al. (2002) have documented a recent reduction in the ventilation of the deep water of Lake Malawi which has also reduced nutrient loading from the hypolimnion (Bootsma & Hecky 1999). Reduced nutrient loading could lead to lower biological production in the Lake Malawi, as in Lake Tanganyika (cf. O'Reilly et al. 2003). The possibility of a return to historically low levels is of great concern in relation to: the maintenance and planning of future hydropower development on the rivers draining into the Lake (Calder et al. 1995); disruption of electrical power supply from the Shire Valley hydroelectric powerplant, and; changes in the littoral and deltaic habitats and its effects on fisheries. Knowledge of the changes in the hydrological regime, which may result from climate change or land use change, is therefore necessary for the planning of future developments (Calder et al. 1995).

Priority concerns

The Task team prioritised the GIWA concerns as follows:

1. Unsustainable exploitation of fish and other living resources
2. Habitat and community modification
3. Pollution
4. Freshwater shortage
5. Global change

The concerns that are recommended for further analysis are: Unsustainable exploitation of fish and other living resources and Habitat and community modification.

The linkages between the GIWA concerns are illustrated in Figure 23 below. All fishes, but particularly the riverine, the potamodromous and the stenotopic lacustrine species are vulnerable to changes in water quality (pollution), freshwater shortage and habitat degradation. Pollution and unsustainable exploitation of living resources are linked primarily via the effect of sediment blanketing and turbidity on fish resources. Habitat modification and unsustainable exploitation of living resources are significantly linked as degradation of habitat would also lead to declines in fish stocks and species loss.

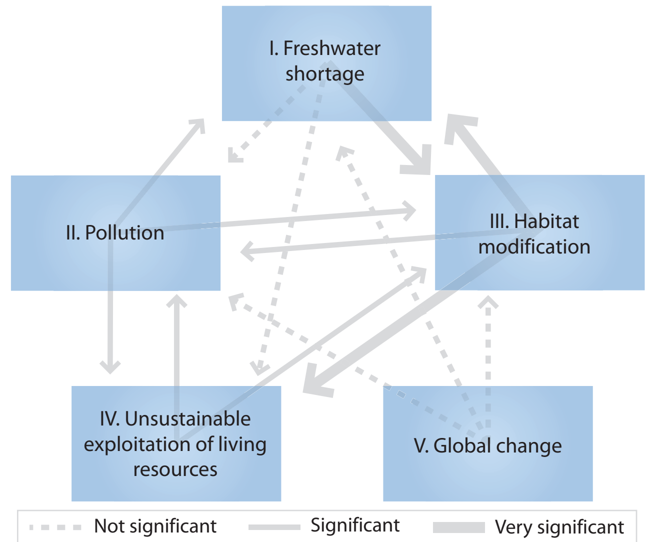

Figure 23 Linkages between GIWA concerns in Lake Malawi.

Causal chain analysis

This section aims to identify the root causes of the environmental and socio-economic impacts resulting from those issues and concerns that were prioritised during the assessment, so that appropriate policy interventions can be developed and focused where they will yield the greatest benefits for the region. In order to achieve this aim, the analysis involves a step-by-step process that identifies the most important causal links between the environmental and socio-economic impacts, their immediate causes, the human activities and economic sectors responsible and, finally, the root causes that determine the behaviour of those sectors. The GIWA Causal chain analysis also recognises that, within each region, there is often enormous variation in capacity and great social, cultural, political and environmental diversity. In order to ensure that the final outcomes of the GIWA are viable options for future remediation, the Causal chain analyses of the GIWA adopt relatively simple and practical analytical models and focus on specific sites within the region. For further details, please refer to the chapter describing the GIWA methodology.

Of the four transboundary lakes in the East African Rift Valley Lakes GIWA region that have been the subjects of this assessment, the Lake Victoria Basin (LVB) faces the most complex social, economic, political and technical barriers (Duda 2002). The environmental degradation of Lake Victoria Basin over the last three decades, due to unsustainable use of natural resources, massive algal blooms, water-borne diseases, water hyacinth infestation, oxygen depletion, introduction of alien fish species etc., has been determined as placing a present value of 270-520 million USD at risk to the lake communities if the large export fishery for Nile perch is lost (World Bank 1996). Alarm over the accelerated degradation was the key driving force in the Lake Victoria GEF project being approved in the mid-1990s as the then largest GEF international waters project at 77 million USD (Duda 2002). At about the same time, the Lake Victoria Fisheries Organisation (LVFO) was formed by Kenya, Uganda and Tanzania under the Convention of Fisheries. The Lake Victoria five-year GEF project was the first of several intended interventions over time (Duda 2002).

Given the intertwined diverse issues and complexities that have all contributed to the environmental degradation of its Basin, as well as the interventions that have been initiated in order to address and mitigate the environmental degradation, the Lake Victoria Basin stands out as the prime choice for Causal chain and Policy options analyses. Because of the similarity of environmental problems affecting the East African Great Lakes, as well as similarities in the socio-political, economic and health status of the various riparian countries, the Lake Victoria Causal chain and Policy options analyses that are presented in this report were considered to be highly applicable to the rest of the region.

Methodology

The priority concerns established from the GIWA assessment that was carried out for Lake Victoria were Unsustainable exploitation of fish and other living resources and Pollution. The major environmental issues and their relative contributions (in % terms) to environmental degradation were also identified from the assessment (Table 19 and 24). For Unsustainable exploitation of living resources, the priority issues that were identified were overexploitation, and destructive fishing practices. For Pollution, the priority issues that were identified were microbiological, eutrophication, chemical and suspended solids. Given the complex interactions, synergistic and cumulative effects of the factors contributing to pollution, it is difficult to clearly and unambiguously isolate only one or two of the issues as predominantly causing pollution in Lake Victoria. All four issues identified from the assessment are considered in the Causal chain analysis, but the role of suspended solids as a pollutant is considered to be nested within the other three issues, exacting a synergistic and cumulative effect on microbiological, eutrophication and chemical pollution.

A detailed assessment was carried out in order to determine the immediate causes, sectors/activities and root causes that related to the priority issues. The data assembled enabled the prioritising of the immediate causes according to criteria such as: 1) the transboundary nature; (2) the size of geographical area affected and whether it is widespread or localised; (3) the number of people affected including their livelihoods and health; (4) the sectors that are affected and the degree of impact; (5) community benefits derived from the environmental resources vis-à-vis costs of negative environmental impacts arising from the use of the resources; (6) the duration and degree of severity of the environmental impacts; (7) effectiveness of current structures, controls, institutions and legislation in minimising negative environmental effects; and (8) synergistic and cumulative effects. Some of the hypotheses raised are provided in Annex III. More weight was given to issues for which there was recent and quantitative data than for those which are as yet poorly studied and lack quantitative data.

Unsustainable exploitation of fish and other living resources

The important GIWA issues identified for Unsustainable exploitation of living resources were overexploitation and destructive fishing practices (Table 19).

Table 19 Unsustainable exploitation of fish in Lake Victoria: percentage contribution of issues and immediate causes of the impacts.

Issue	%	Immediate cause	%
*Overexploitation	30	Increased effort	60
		Technological change	40
Excessive by-catch and discards	20		
*Destructive fishing practices	30	Increased effort	40
		Rent-seeking behaviour	30
		Failure of monitoring and enforcement mechanisms	30
Decreased viability of stock through pollution and disease	10		
Impact on biological and genetic diversity	10		

**Issues considered relevant for Causal chain and Policy options analysis.*

Overexploitation

Immediate causes

Overexploitation is mainly due to increased effort (Figure 24). An experimental trawl Catch Per Unit Effort (CPUE) shows a continuous and significant decline since trawling research began in 1969 (Uganda): CPUE in waters less than 30 m deep averaged 797 kg/hour during the 1961–1971 surveys and declined to 115 kg/hour in the 1997–1998 surveys (Okaronon, 1999) (Figure 25). The apparent decline in fish stocks can only partially be attributed to change in species composition, and different behaviour and possibly net avoidance of the species presently targeted by the trawl (Okaronon 1999). The fishing capacity in the Uganda sector increased from about 3 200 fishing canoes in 1972 to 8 000 by 1990 and was estimated to be about 10 000 canoes in 1998 (Okaronon 1999). The number of fishermen in Lake Victoria increased from 83 816 in

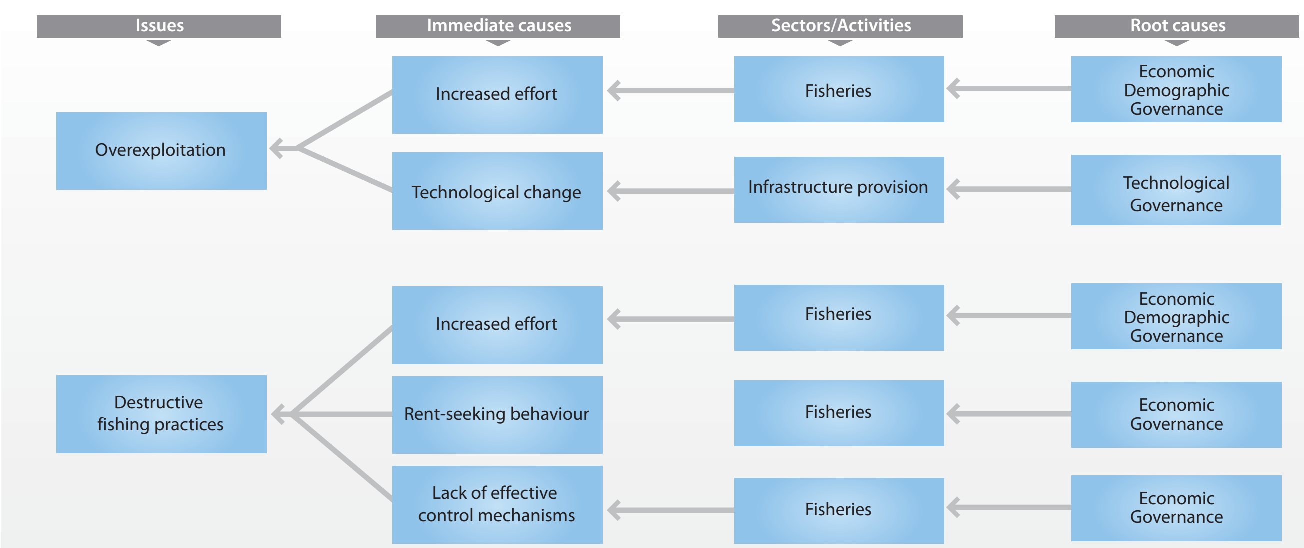

Figure 24 Causal chain diagram illustrating the causal links for Unsustainable exploitation of fish and other living resources.

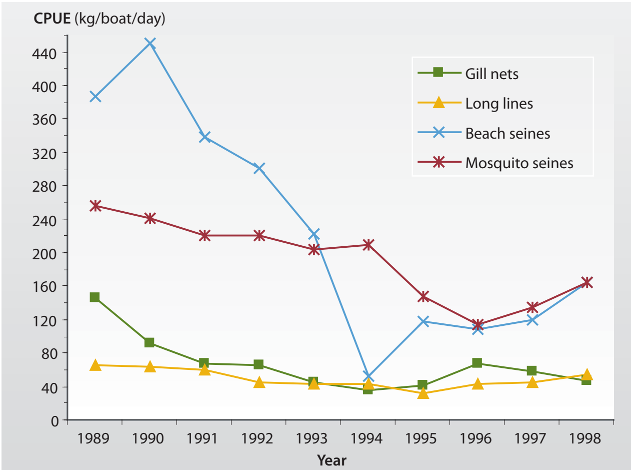

Figure 25 Trends in catch per unit effort for Nile perch in commercial fisheries of Lake Victoria.
(Source: Okaronon 1999, Othina 1999 in Bwathondi et al. 2001)

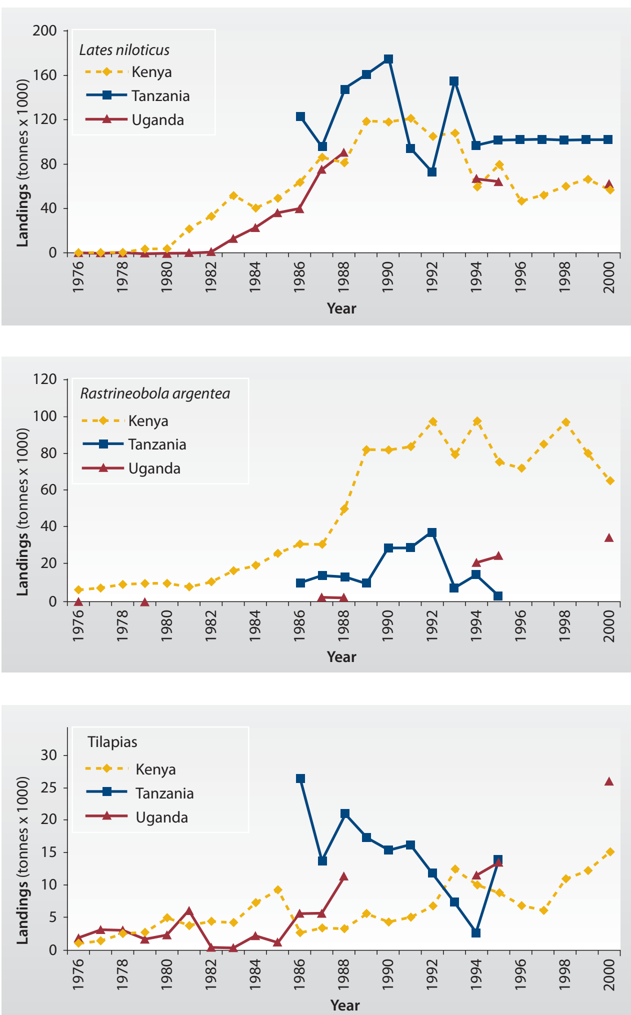

Figure 26 Trends in landings of the major commercial fish species in the riparian countries of Lake Victoria
(Source: Knaap et al. 2002)

1990/1991 to 121 941 in 2000. In Kenya the fishermen increased from 24 000 to 33 037, in Uganda the increase was from 30 000 to 32 461 while in Tanzania the fishermen increased from 29 816 to 56 443 over the same period (Hoekstra et al. 1991, Asila 2001). The increases in the number of fishermen in Uganda (~8%) appear to be minimal compared the increases in Tanzania (~90%) and Kenya (~38%).

For the 1990s, data on the fishery yield for Uganda are fragmented, and poor quality catch assessment data have prevented any evaluation of trends in Tanzania (Bwathondi et al. 2001). The increase in fishing effort and investment (Uganda) was made without clear knowledge of the magnitude and sustainability of the stocks (Okaronon 1999). Trends in fish landings in Kenyan waters of Lake Victoria (1976–1988) show that landings reached a maximum of 200 000 tonnes per year in 1989–1991 as Nile perch catches increased due to an expansion in stock size and increased fishing effort (Othina 1999). CPUE peaked at 180 kg/boat/day in 1989 and decreased thereafter with increasing effort (Othina 1999). With increased fishing pressure, predation, and competition among species, the multispecies fishery of Lake Victoria changed to only three species: Nile perch (*Lates niloticus*), the pelagic cyprinid-dagaa (*Rastrineobola argentea* Pellegrin), and the introduced tilapia (*Oreochromis niloticus* L.) (Figure 26). By 1998, total Nile perch catches were half those at the beginning of the decade despite increased effort, and catches of *Rastrineobola argentea* have also levelled off despite increased effort (Othina 1999).

Bottom trawl surveys in Kenyan waters of Lake Victoria (1997-1998) revealed that areas with relatively consistent high catches extend from west of Maboko Island up to Mbita Channel in the depth range of 5-22 m (Getabu and Nyaundi 1999). This area is outside major urban and riverine influence and is where most of the fishing effort by artisanal fishermen is currently concentrated (Getabu and Nyaundi 1999). Despite increased total fishing effort, efficiency of fishing gear and extension of fishing grounds to maintain the yield, there has been a progressive decline in CPUE and mean size of fish caught (Ligtvoet & Mkumbo 1992, Mkumbo & Cowx 1999). In all three countries, efforts in terms of boats and numbers of fishermen have more than doubled in the past 10 years (Namisi 2001, Asila 2001). The unrestricted access status of the Lake and lack of enforcement of existing legislation is linked to increasing and crippling fishing effort (Bwathondi et al. 2001).

Overexploitation is secondarily due to technological changes in the efficiency of fishing gears, motorisation of canoes and increase in total fishing effort to maintain production since the mid-1990s (Bwathondi et al. 2001). Most of the region's factories suffer from fish supply problems, attributed to low catches and competition with other fish factories

(SEDAWOG 1999) and, in order to stay operational, they drive fishermen to catch more fish by supplying nets, outboard engines, etc.

Sectors/activities

Increased effort has been driven by a much greater demand for fish by recently established fish processing factories that have a large capacity for processed products (Abila 2002). Nile perch fisheries opened up greater employment opportunities, attracting more fishers (artisanal to large-scale), more fishing gear and vessels to access the resource, and the establishment of fish filleting factories (Bwathondi et al. 2001). Industrial fish processors in Uganda are presently the main link between the artisanal fisherfolk and the overseas export markets; their entry into the market has tended to stabilise and expand the market for the artisanal fisherfolk while increasing their average earnings (Namisi 2001). Dwindling fish stocks are necessitating increased effort in order to maintain the same level of catch (Kulindwa 2001). In other words, resource rents are being reduced over time until the increase in fishing effort will no longer be beneficial.

Technological change has come about mainly due to demand for higher fish catches to supply the fish processing factories and consequently the huge export market (Table 20). A number of fish processing plants have been constructed along the shores of the Lake, 11 of which are licensed to operate in the Uganda sector of the Lake (Odongkara & Okaronon 1999), 12 in Kenya and 12 in Tanzania (Ntiba 2003). The large number of processing factories, whose capacity is about 120 000 tonnes per year (Table 21) versus the total landings for the Lake being in the region of 210 000 tonnes, is an important driver of exploitation of the fishery. Nile perch is purchased and processed mainly by the large-scale processors (Bwathondi et al. 2001).

Table 20 Export quantities for Nile perch fillets between 1988 and 1999.

Year	Kenya (tonnes)	Uganda (tonnes)	Tanzania (tonnes)
1988	ND	ND	37
1989	ND	18 347	ND
1990	4 350	1 590	ND
1991	6 364	4 751	ND
1992	11 312	7 831	9 850
1993	8 189	6 337	6 123
1994	9 439	6 564	8 454
1995	10 983	12 971	9 904
1996	16 472	16 397	15 000
1997	11 167	9 839	ND
1998	10 126	13 755	ND
1999	9 765	ND	ND

Note: ND = No Data.

(Source: Fisheries Department 1950, Gibbon 1997, Department of Fisheries Kenya, Unpublished LVFO data, from Bwathondi et al. 2001)

Of the factories currently operating in the region, the majority commenced operations after 1990, an indication of the region's relatively recent entry into the global fish market (SEDAWOG 1999). Fifteen out of 25 factories surveyed in the region have been obliged to close down at least once during 1997/1998 to carry out modifications so as to comply with EU import regulations (SEDAWOG 1999). Many of the fish processed are small-sized because demand from export markets is for small fillets, which are less fatty and portion-sized (Bwathondi et al. 2001).

The establishment of the Dutch Government-sponsored Fish Meal Plant in Mwanza (Tanzania) in the 1970s contributed substantially to the decline of the haplochromines in the Lake since the factory targeted this fish group (Bwathondi et al. 2001). The decline of fish catches over time has also necessitated the use of illegal degrading technologies in order to catch more fish (Kulindwa 2001, Abila 2002).

Root causes

The high demand for processed fish products is driven mainly by the large export market for Nile perch fillets that emerged in the early 1990s (Kulindwa & Mbelle 2002, Kulindwa 2000, Abila 2002). Increasing population within the Basin, poor governance in the fishing industry, and the unrestricted access status of the Lake are secondary drivers (Table 22). The large export fishery for the Nile perch is estimated at 270-520 million USD (Duda 2002). Fishers annual incomes (per capita) are estimated as follows: Kenya, 3 269 USD; Tanzania, 2 294 USD; and Uganda, 1 157 USD (Bwathondi et al. 2001). The gap between the richest and poorest fishers in some beaches is widening, and the gap between the benefits obtained from the fishery by vessel owners and labouring classes is also widening (Bwathondi et al., 2001). Due to high demand for Nile perch (both export and local markets), processors are providing loans to some fishers who then repatriate the outlays through catches to the companies (SEDAWOG 1999, Bwathondi et al. 2001). The scarcity of fish has increased fish prices at the landing sites (Bwathondi et al. 2001). Thus rich firms are able to displace less rich processors, some of whom have been forced to close down: this has led to serious impacts in the fisheries sector and has intensified the existing conflicts between users (Yongo 2000). By-products from the factories are numerous and include skins, off-cuts ('chips'), swim bladders and carcasses ('frames'). Swim bladders are the most valuable and are exported to the Far East (SEDAWOG 1999).

Table 21 Capacity of fish processing factories, annual landings, and maximum sustainable yield for the three riparian countries in 1999.

Country	Full capacity (tonnes)	Used capacity (%)	Annual landings (tonnes)	Maximum sustainable yield (tonnes)
Kenya	35 260	49	64 000	39 200
Tanzania	104 520	69	95 000	98 500
Uganda	74 100	45	72 632	75 500

(Source: Bwathondi et al. 2001)

Table 22 Summary of the processes and actions behind the root causes of overexploitation of fish.

Root causes	Sectors/ Activities	Immediate causes	Remarks
Economic	Fisheries	Increased effort	1. Export markets. The processing industries are geared to export markets which have a high demand for fish and fish by-products and at higher cost per kg than local markets. 2. Poverty. The rich (processing factories) provide loans to the poor (artisanal fishers) to increase the catch for fish processing factories so that they can operate at optimal capacity to service the export markets. 3. Lack of alternative economic activities for sustenance of livelihoods. Nile perch fishery opened up greater employment opportunities.
Demographic	Fisheries	Increased effort	1. In all three countries, efforts in terms of boats and numbers of fishermen have more than doubled in the past 10 years, partly as a result of demand from export markets, but also due to the very rapid population growth and consequently higher demand for fish food in the region.
Governance	Fisheries	Increased effort	1. The Lake has an unrestricted access status. 2. There are lack of rules and regulations, such as fishing quotas, to govern the fisheries sector. 3. Bans on certain types of fishing gears and trawlers have been imposed in all three countries but there is lack of enforcement by government officials. 4. Lack of taxes or other form of finance to support enforcement of regulations in fisheries sector
	Infrastructure provision	Technological change	1. Increased number of fish processing factories have been established and licensed to operate without regard to sustainability of the fisheries resource (in all three countries) 2. Operations and of fish processing factories have become more efficient to comply with EU import regulations. 3. Fish processing factories are located close to major roads and airports, while motorised canoes and trawlers reduce time taken to access fish landings and offload fish.
Technological	Infrastructure provision	Technological change	1. Technological change (more fishing gear, vessels) is driven mainly by demand for higher fish catches to supply the processing factories and consequently the huge export market. 2. Change in the efficiency of fishing gears, motorisation of canoes have contributed to the signs of decline of the Nile perch since the mid 1990s.

The marketing of Lake Victoria's fish was localised within the riparian states during the pre-Nile perch era, but as most fish filleting factories were established in the 1990s, both the regional and international trade expanded (Bwathondi et al. 2001, Kulindwa 2001, Abila 2002). The Nile perch is now sold not only to the traditional EU and Middle Eastern countries but also to Japan, Australia, North and South America (Bwathondi et al. 2001). The price ranges for fish products such as chilled fillets, frozen fillets, portions, head-on gutted fish, head-off gutted fish and kosher products is 2-4.5 USD per kilo (SEDAWOG 1999).

Destructive fishing practices

Immediate causes

Destructive fishing practices are due mainly to increased effort (Figure 24, Table 19). There has been a reduction in mesh size of nets used, and an increased proportion of immature fish in the catches (Bwathondi et al. 2001). Mesh sizes have progressively declined over the past 10 years with 24% of the nets (LVFO 2000, Kulindwa 2001) in Uganda now below the recommended mesh size of 5 inches (127 mm). More recent beach surveys suggest that this is now as high as 50% (Muhoozi cited in Bwathondi 2001). In Kenya and Tanzania, 3 and 18%, respectively, of the gillnets are below the legal mesh size limits (Bwathondi et al 2001). Trends (1987–1997) in percentage contribution by weight of the four major fishing gears to the Kenya Lake Victoria catches are as follows: mosquito seine landings increased from 25% of the total catch in 1987 to 50-60% from 1994 to 1997 (Kenya); the gillnet contribution declined from over 50% to 20%; the long-line contribution declined from 10% to 5%; while the beach seine contribution has increased from 10% to 20% despite a ban on their use (Figure 27) (Othina 1999, Kulindwa 2001, Abila 2002). Rent-seeking behaviour probably accounts for up to 20% of the contribution to destructive fishing practices. Beach seines and trawls, 10 of which were operating in Kenyan waters until recently (Njiru cited in Bwathondi et al. 2001), are banned gears in the Lake.

Reduced capacity to meet human needs can account for up to 40% of the destructive fishing practices. As traditional fishing methods are now often considered inadequate for landing a sufficient catch, fishermen

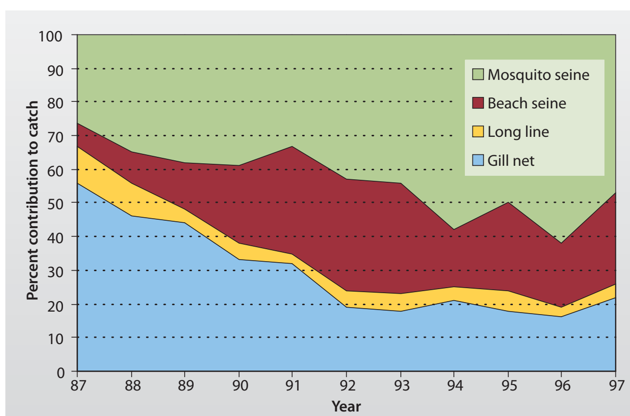

Figure 27 The percent contribution by weight of the four major fishing gears to the Kenyan Lake Victoria catches.
(Source: Othina 1999)

increasingly resort to deploying illegal fishing gear such as cast nets, fish poison and weirs to improve their catches (Ntiba 2003). Some of the gears used to fish are fallouts from other sectors such as the flower industry, where fine mesh nets that are used to protect flowers from birds are now being used. In a 1999 LVRFP study of 1 066 fishers in all three countries of the Lake, 33% of respondents linked declines in the stock to the contravention of fishing regulations, 32% felt this was due to excessive fishing effort and 11% to pollution or the presence of water hyacinth (SEDAWOG 2000). In most cases, these reasons provided for catch declines indicate a widespread acknowledgement amongst the Lake's fishing communities that effort levels are excessive, that damaging fishing techniques are in use and that regulations are generally ignored (Bwathondi et al. 2001).

Sectors/activities

Most of the region's factories suffer from fish supply problems, attributed to low catches and competition with other fish factories (SEDAWOG 1999). Due to the boom in the Nile perch export market, many more people who were never fishermen moved to cash in on the "lucrative" industry. This may have pushed traditional fishermen to resort to the use of destructive fishing methods to sustain their level of livelihood and food requirements. The use of poison, which led to a ban on fishing and the sale of fish in March 1999 (Ntiba 2003), was probably largely due to rent-seekers. The remoteness of some of the landing sites and the inadequate transportation infrastructure impose severe constraints on the post-harvest sector of the Lake Victoria fishery (Bwathondi et al. 2001). Handling facilities, ice plants, storage facilities, sanitary conditions (including boats with containers) are either lacking or inadequate at landing sites, contributing to poor fish quality (Bwathondi et al. 2001).

Root causes

The reduction of taxes on all nets has resulted in more net purchases. The increase in population has resulted in increased demand for fish (particularly tilapia) for local consumption. The unrestricted access status of the Lake and lack of enforcement of existing legislation is linked to increasing and crippling fishing effort (Bwathondi et al. 2001). There is also a lack of awareness amongst some of the fisherfolk on the mid- to long-term consequences of destructive fishing methods. The policy of free and unrestricted access to the Lake Victoria fisheries appears to be the major loophole that was exploited by the rent-seekers (Table 23). With the near disappearance of many food fish species (Mkumbo 1999) and signs of decline in Nile perch (Othina & Osewe-Odera cited in Mkumbo 1999), a number of management measures were effected, including a ban on beach seines and undersized mesh nets (<127 mm stretched mesh) in 1994, and a ban on trawlers in 1996 (Mkumbo

Table 23 Summary of the processes and actions behind the root causes of destructive fishing practices.

Root causes	Sectors/ Activities	Immediate cause	Remarks
Economic	Fisheries	Increased effort	1. Export markets. The high demand for fish and fish by-products coupled with dwindling stocks of Nile perch, tilapia and haplochromines has led to destructive fishing practices (illegal fishing gear, poison, weirs and trawling) in order to, at least, maintain the fish supply level. 2. The reduction of taxes on all nets has resulted in more net purchases. 3. Increased competition for fish supply amongst fish processing factories. 4. Poverty. The rich (processing factories) provide loans to the poor (artisanal fishers) to increase the catch for fish processing factories so that they can operate at optimal capacity to service the export markets.
	Fisheries	Rent-seeking behaviour	1. Some of the gear used to fish, i.e. fine mesh nets, are a fallout from other sectors such as the flower industry. 2. Theft (of fishing gears, vessels, etc.) and piracy are rampant on the Lake, and may become worse as the disparity in distribution of benefits from the fishery becomes more polarised. 3. Greed- individual interests take precedence over community interests.
	Fisheries	Lack of effective control mechanisms	1. As traditional fishing methods are now often considered inadequate for landing a sufficient catch, fishermen increasingly resort to deploying illegal fishing gear such as cast nets, fish poison and weirs to improve their catches. 2. Lack of resources in government to create new avenues for employment and improve livelihoods.
Demographic	Fisheries	Increased effort	1. The increase in population and increased settlements along the lake shore has resulted in increased demand for fish (particularly Tilapia) for local consumption, hence, for example, continued use of beach seining that has been banned in all three countries.
	Fisheries	Lack of effective control mechanisms	1. Entry of people from other sectors (e.g. horticultural) into the fisheries sector who do not heed the rules and regulations of the fisheries sector. 2. Political patronage.
Governance	Fisheries	Increased effort	1. The Lake has an unrestricted access status, and there is no recognition of property rights and entitlements. 2. There are lack of rules and regulations, such as fishing quotas, to govern the fisheries sector. 3. There is weak regional integration and poorly co-ordinated and disparate legal and institutional arrangements governing the fishing industry. 4. Bans on certain types of fishing gears, beach seining and trawlers have been imposed in all three countries (1994-1996) but there is lack of policing and enforcement by government officials. 5. There is a low level of civic education and awareness amongst some of the fisher-folk on the mid- to long-term consequences of destructive fishing methods.
	Fisheries	Rent-seeking behaviour	1. The policy of free and unrestricted access to the Lake Victoria fisheries appears to be the major loophole that was exploited by the rent-seekers. 2. Corruption is rampant – officials charged with monitoring and enforcement of rules and regulations in the fisheries sector are often bribed to overlook the contraventions. 3. There is a lack of institutional and legal capacity to promote compliance and enforce arrangements and policies. 4. There is inadequate integration of environmental considerations in planning and management. 5. Lack of stakeholder participation.
	Fisheries	Lack of effective control mechanisms	1. Inadequate legal and judicial framework. 2. Lack of co-ordination and co-operation between all stakeholders in the fisheries sector. 3. Inability of government and other stakeholders to control catch and cost of fish. 4. Lack of incorporation of stakeholders when drafting legislation.

1999). Failure in monitoring and enforcement of these bans is evident, for example, beach seining in Kenyan waters continues despite its ban. Overfishing and the use of damaging or illegal fishing gear is only in part a reflection of the failure of centralised management strategies on the Lake, and are symptomatic of broader social, economic and developmental dislocations (Bwathondi et al. 2001) such as poverty and lack of employment. Theft (of fishing gears, vessels, etc.) and piracy are rampant on the Lake, and may become worse as the disparity in distribution of benefits from the fishery becomes more polarised (Bwathondi et al. 2001).

Pollution

The following pollution issues: microbiological, eutrophication, chemical and suspended solids, were identified as being the most important (Table 24). It was noted that suspended solids are part and parcel of the factors that contribute to microbiological, eutrophication and chemical pollution, and that their role is more important in its synergies with the other three issues rather than on its own. Therefore, the issue suspended solids is nested within microbiological, eutrophication and chemical pollution and is excluded from direct further analysis.

Table 24 Pollution in Lake Victoria: percentage contribution of issues and immediate causes of the impacts.

Issue	%	Immediate cause	%
* Microbiological	20	Animal waste	10
		Municipal untreated effluent	40
		Run-off and stormwater	40
		Maritime transport waste	10
*Eutrophication	20	Enhanced effluent discharge	30
		Enhanced discharge of solids	10
		Run-off and stormwater	60
* Chemical	20	Enhanced effluent discharge	40
		Enhanced discharge of solids	20
		Run-off and stormwater	20
		Atmospheric deposition	20
*Suspended solids	20	Habitat modification	40
		Enhanced erosion of lake shore and river channels	30
		Increased sediment deposition	30
Solid wastes	10		
Thermal	0		
Radionuclide	0		
Spills	10		

**Issues considered relevant for Causal chain and Policy option analysis.*

Microbiological

Four immediate causes have been linked to microbiological pollution, namely: municipal untreated sewage, run-off and stormwater, animal waste, and maritime transport waste (Figure 28). Of these immediate causes, the two most important are municipal untreated sewage, and run-off and stormwater.

Immediate causes

There are a number of human pathogens (e.g. *Vibrio cholerae* and *Escherichia coli*) that can remain viable in raw wastewater and sewage. Direct discharges of municipal untreated effluent into rivers and the Lake directly contribute to microbiological pollution. These have contributed to the degradation of river and lake water quality for habitat and drinking use (Wandiga & Onyari 1987, Ntiba et al. 2001). The low standards of health in the region are caused by a general lack of awareness in good hygiene practices, direct contamination of beach waters through bathing and washing, and uncontrolled waste disposal around the shoreline (Karanja 2002). Reduction of the Biological Oxygen Demand (BOD) load of such effluent can significantly reduce the occurrence of water-borne diseases such as typhoid and cholera which are common in the Lake. Run-off and stormwater collect a lot of animal, plant and human waste from point and non-point sources and channel these to rivers and the Lake. Animal waste directly abets microbiological pollution of water by creating an environment that supports microbiological pathogens, while harbour and bilge discharges compound the microbiological pollution problem.

Sectors/activities

There are two major sectors from which the municipal untreated effluent is derived, i.e., agro-industry and urbanisation. Beer brewing, pulp and paper production, tanning, fish processing, agro-processing and abattoirs discharge raw/untreated waste to feeder rivers and lakes (e.g. Wandiga & Onyari 1987, Ntiba et al. 2001). The annual population growth is 2-4% in most parts of the Lake Basin but urban population growth is over 5-10% per year in most of the larger towns (Scheren et al. 2000). The number of people in urban population connected to sewerage systems are as shown in Table 25 (Scheren et al. 2000).

Table 25 Number of people in urban populations connected to sewerage systems in Lake Victoria Basin.

	Total population (1 000 people)	Urban population (1 000 people)		Number of towns
		Connected	Not connected	
Kenya	10 200	390	630	18
Uganda	5 600	210	870	9
Tanzania	5 200	27	340	4
Rwanda	5 900	ND	400	5
Burundi	2 800	ND	140	4
Total	29 700	627	2 380	40

Note: ND = No Data. (Source: Scheren et al. 2000)

An assessment of BOD_5 loading of Lake Victoria (corrected for purification in treatment plants, rivers and wetlands) shows that domestic pollution accounts for most of the BOD load, with the contribution of industry (mainly from breweries, sugar cane factories and soap and oil factories) being relatively low (Scheren et al. 2000). Kenya contributes a BOD load of 7 510 tonnes per year, Uganda contributes a BOD load of 4 540 tonnes per year while Tanzania contributes a BOD load of 3 920 tonnes per year (Scheren et al. 2000). 75% of the BOD load from Uganda originates from Kampala, while in Kenya, 50% of the BOD load originates from Kisumu (Scheren et al. 2000). Water hyacinth infestations have also been reported to lower the water quality in Kenya, Uganda and Tanzania (in terms of colour, pH, turbidity of water) and increase the treatment costs, particularly associated with keeping the water intake points free of water hyacinth (Mailu 2001).

There are several sectors that contribute to microbiological pollution of run-off and stormwater: these include the agriculture, urban, forestry and rural settlement sectors. Run-off and stormwater discharge are highest during the rainy seasons and consequent flooding is associated with increased incidence of water-related diseases.

There are two major sectors from which the animal waste is derived, i.e., agriculture (livestock) and wildlife. The large increase in livestock populations are exemplified in the trends for Nyanza province (Kenya), where in 1968 there were 988 571 cattle compared to 1 620 146 in 1991 (Kairu 2001). Within most of the communities, cattle are a source of wealth and status symbol so there is a tendency to keep large herds. Poor animal husbandry in cattle-keeping results in high animal waste load that can be reduced by zero-grazing methods. There are few ranches in the Basin due to the tsetse fly, and most of the herds are kept at subsistence levels following age-old traditions. Higher populations of wildlife during times of drought move towards watering points in the Basin, and there are also large hippo herds along the lake shore. Increased trade in the Lake Basin region has led to increased maritime transport, both human and in number of vessels plying the Lake, and hence larger quantities of harbour and bilge discharges.

Root causes

The treatment works in municipalities are either inadequate, using old and obsolete technology, have ageing components, or have simply ground to a halt (Table 26). They have also not been able to expand to keep pace with the increasingly larger populations. The municipal by-laws, such as those of Kisumu City, did not predict the growth and type of industries existing today, and so there is no capacity to manage the waste from these industries. Industries flout the by-laws and regulations as there is no monitoring and enforcement mechanism. Poor planning,

Table 26 Summary of the processes and actions behind the root causes of microbiological pollution.

Root causes	Sectors/ Activities	Immediate causes	Remarks
Economic	Agro-industry	Municipal untreated effluent	1. There is lack of economic incentives to encourage the industries to install clean technologies.
Technological (includes the notion of affordability)	Agro-industry	Municipal untreated effluent	1. Industries located within the municipalities have none, inadequate or dilapidated treatment facilities.
	Urbanisation	Municipal untreated effluent	1. There are inadequate and dilapidated treatment facilities in all three countries, so, for example, raw untreated sewage is pumped directly into the Lake e.g. in Kisumu. 2. There is poor sanitation infrastructure and poor waste disposal facilities in all settlements around the entire Lake.
	Urbanisation	Run-off and stormwater	1. There is poor waste management in urban settlements.
	Agro-industry	Run-off and stormwater	1. Poor animal husbandry and land management results in animal wastes being discharged in raw form into the waterways.
	Forestry	Run-off and stormwater	1. There is a lack of alternative energy sources, so deforestation takes place, and trees and bushes are cut down for woodfuel.
	Rural settlements	Run-off and stormwater	1. Poor sanitation infrastructure.
Legal	Agro-industry	Municipal untreated effluent	1. There is lack of compliance to operating standards in the industry.
	Urbanisation	Municipal untreated effluent	1. Outdated and inadequate regulations.
Governance	Agro-industry	Municipal untreated effluent	1. There is lack of monitoring and enforcement of existing legislation and regulations relating to effluent discharge from the industries.
	Urbanisation	Municipal untreated effluent	1. There is lack of enforcement of regulations. 2. Poor urban planning.
	Urbanisation	Run-off and stormwater	1. Poor urban planning. 2. Lack of monitoring and enforcement of waste disposal regulations.
	Rural Settlements	Run-off and stormwater	1. Lack of monitoring and enforcement of waste disposal regulations.
	Forestry	Run-off and stormwater	1. Lack of monitoring and enforcement of regulations governing the forestry sector.
Geographic	Agro-industry	Municipal untreated effluent	2. Industries are located close to the lake shore, discharging raw and untreated effluents in all three countries.
	Wildlife	Run-off and stormwater	1. High wildlife population close to or along the lake shore and generated waste leads to microbial contamination of the water.
Demographic	Urbanisation	Municipal untreated effluent	1. Increased rural-to-urban migration. 2. High-density of human populations.
	Agro-industry	Run-off and stormwater	1. High animal population in the Lake Victoria Basin generates a large amount of diffuse waste that finds its way into the waterways and lake.
	Wildlife	Run-off and stormwater	1. High wildlife population in the Lake Victoria Basin generates a large amount of diffuse waste that finds its way into the waterways and lake.
Environmental	Urbanisation	Run-off and stormwater	1. El Niño rains wash a lot of organic wastes into the waterways and the Lake.
	Agro-industry	Run-off and stormwater	1. El Niño rains wash a lot of organic wastes into the waterways and the Lake.

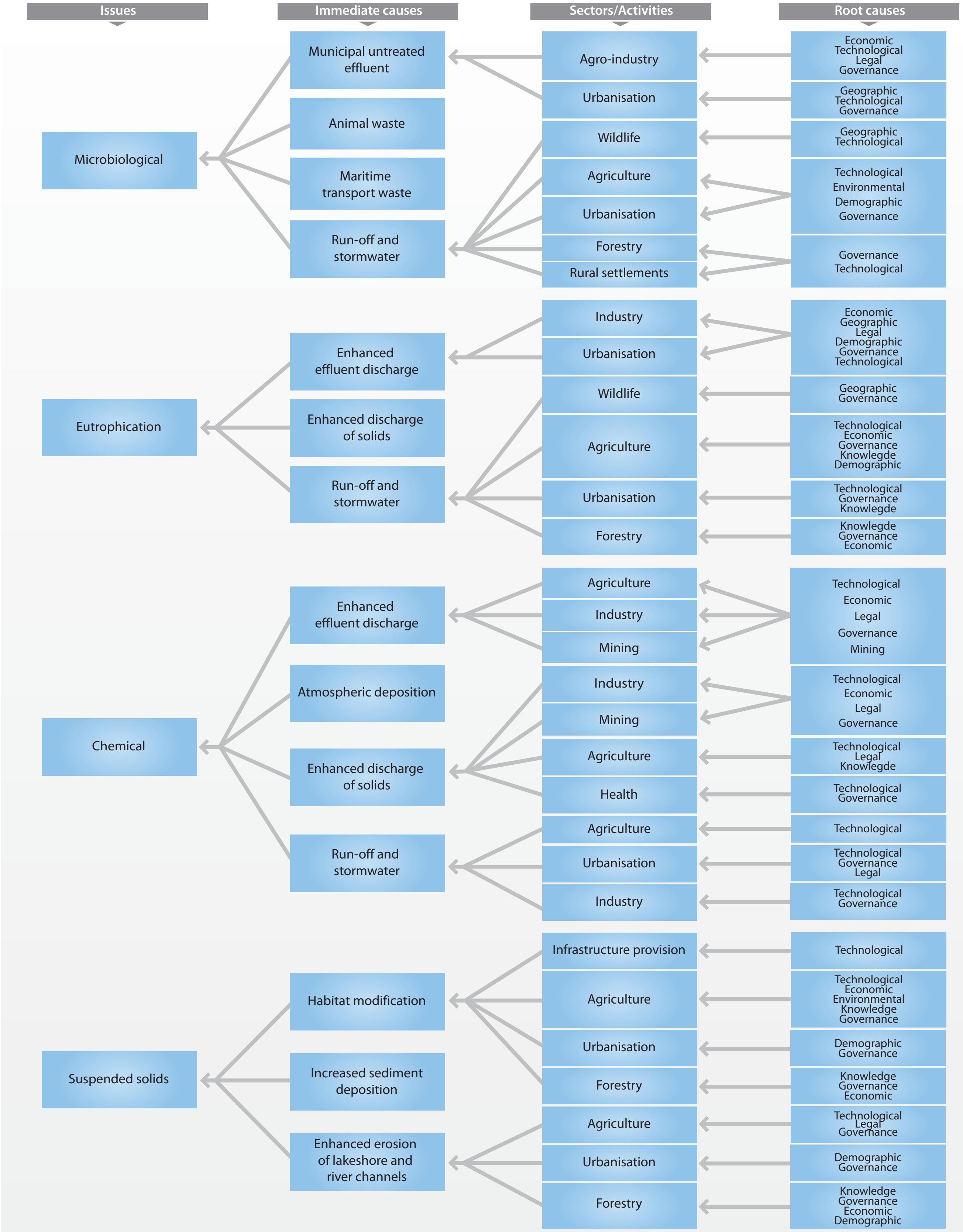

Figure 28 Causal chain diagram illustrating the causal links for Pollution

maintenance and inadequate investment in municipality wastewater treatment systems have contributed to the increased untreated effluent discharge. If the present treatment plants in Kisumu would perform optimally, the BOD loads could be brought down by 50% (Scheren et al. 2000). Water supply to both municipalities and villages is also affected by water hyacinth: in municipalities, water hyacinth interferes with the water intake points through blockage, which lowers the quantity of water pumped. In Kisumu the water supply has dropped from 20 000 m^3 to 10 000 m^3 per day (Mailu 2001). This decline in water supply invariably causes more people to look for alternative, and often untreated, water sources.

Flooding is common in the region, particularly around the lake shore, during the rainy season and its impact is exacerbated by poor practices when carrying out activities in the above sectors. Contamination of drinking water results from poor sanitation, hygiene and poor floodwater management. For example, there were 14 275 cholera admissions in Nyanza province (LVB Kenya) alone between June 1997 and March 1998, with 547 deaths reported (Karanja 2002). One of the major risk factors identified for cholera among a sample of these patients was drinking water from Lake Victoria or a stream (Karanja 2002).

The gross discharge of animal wastes into rivers and the Lake results from high livestock and wildlife populations within the Lake Victoria Basin, and poor animal husbandry and waste management. In Tanzania, however, the government is encouraging villagers to plan their land use to control livestock and game. Transport-related pollution (harbour and bilge discharges) are likely to become more important on the Lake as trade increases in the region (Cohen et al. 1996).

Eutrophication (and sedimentation)

Three immediate causes are identified for eutrophication; enhanced effluent discharge, run-off and stormwater, and enhanced discharge of solids (Figure 28). Enhanced effluent discharge, and run-off and stormwater are the most important immediate causes of eutrophication. The enhanced discharge of solids is largely a component of increased run-off and stormwater to the Lake and is therefore nested in this immediate cause.

Immediate causes

Analysis of sediment cores from the Lake show an increasing rate of sedimentation over the past 150 years (Swallow et al. 2002, Verschuren et al. 2002). There are many densely cultivated areas in the Lake Victoria Basin, especially in Kenya, Rwanda and Burundi (Scheren et al. 2000). Some rivers, such as the Sio, Nzoia, Yala, Sondu, Nyando and Kuja in the Lake Victoria Basin (Kenya) drain highly productive agricultural areas.

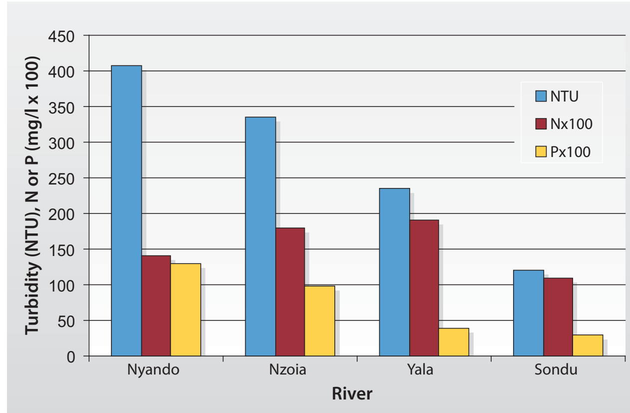

Figure 29 Comparison of turbidity, nitrogen and phosphorus levels of four Kenyan rivers, rainy season 2001.
(Source: Swallow et al. 2002)

The sediment load of the Nyando River, for example, has increased by 7.5 times during the last 16 years, with turbidity measured at 527 NTU in the rainy season 2001 (Figure 29) (Swallow et al. 2002).

Habitat modification through vegetation clearance for infrastructure provision, agriculture, urban settlements and the use of various plants for building materials, furniture making and fuel wood, etc., exposes the soil to erosion and deflation, thus contributing to increased suspended solids. Enhanced erosion of the lake shore and river channels is also directly contributing to increased suspended solids in the Lake. Soaps and detergents that are being used within the Basin are outdated or banned and are contributing to eutrophication. Analysis of nutrients (nitrogen and phosphorus) in the rainy season of 2001 in the Nyando, Sondu, Nzoia and Yala rivers indicates that continued addition of input of such high nutrient concentrations into the Winam Gulf will seriously affect aquatic systems and water quality (Figure 29) (Swallow et al. 2002). Nutrient loads to the Lake are associated mainly with atmospheric deposition and land run-off, together accounting for about 90% of the phosphorus and 94% of the nitrogen input into the Lake (Scheren et al. 2000).

Sectors/activities

The changes from small-scale to large-scale industrial production and from small to large farms have all contributed to enhanced effluent discharge. The acreage under cultivation for cash and food crops (namely tea, tobacco, rice, beans, coffee and sugar cane) in the Nyanza province, for example, has increased from about 15 400 ha in 1968 to 157 000 ha in 1991/1992 (Kairu 2001). The agricultural characteristics for the Lake Victoria Basin as a whole are as shown in Table 27.

Increased rates of urbanisation and agriculture in the region have increased the per capita demand for land (Kairu 2001), and hence more land is cleared to create the additional space required for these

Table 27 Agricultural characteristics of Lake Victoria Basin.

Country	Catchment land area (1 000 ha)		
	Cultivated	Non-cultivated	Total
Kenya	1 470	3 400	4 870
Uganda	1 400	2 100	3 500
Tanzania	1 500	5 540	7 040
Rwanda	930	1 130	2 060
Burundi	670	640	1 310
Total	5 970	12 810	18 780

(Source: Scheren et al. 2000)

sectors. There is, for example, large-scale draining of the Yala swamp (LVB Kenya) to create land for agriculture and settlement (Grabowsky & Poort 1987). Clearing of riparian vegetation has led to erosion and loss of vegetation that acted as filters (Lowe-McConnell 1994), while nutrient-rich sediments from agricultural run-off and also low-lying, deforested riparian zones and other areas surrounding the Lake contribute to eutrophication, and feed the carpets of water hyacinth (Wilson et al. 1999). During the process of the expansion and growth of agriculture, some wetlands have been drained (Kairu 2001, Gichuki 2003), leading to increased sediment deposition in the rivers and lake. The degree to which urban run-off and solid wastes contribute to suspended solids load has not been assessed (Ntiba 2003).

Root causes

There has been a lack of monitoring and enforcement of regulations (Table 28). Those industries that have tried to install recycling facilities in urban areas have not had support from the regulating authorities. The food and cash crops grown on wetlands require the application of fertilisers and pesticides (Kairu 2001). Unsustainable land use practices lead to increased soil erosion and nutrient land run-off (Scheren et al. 2000). The high atmospheric nutrient loads are attributed to forest burning and increased dust due to soil erosion (Bootsma & Hecky 1993). Sand harvesting activity is mainly performed 5-10 km away from the Lake, particularly in Winam and Ahero Divisions (LVB Kenya), but some sand harvesting is undertaken right on the shores of the Lake (Kairu 2001). This activity increases sediment mobility, and also results in physical alteration and destruction of the environment.

An important source of income is papyrus harvested for thatching houses and the making of mats, baskets, furniture (chairs), fishing floats, rafts, etc., while both shrubs and papyrus are used for wood fuel (Kairu 2001). There are farms, roads, fishing camps and housing developments close to or on the wetlands (Kairu 2001). Soil erosion in the wetlands is generally connected with cultivation, but specifically to farming methods and management (Kairu 2001).

Table 28 Summary of the processes and actions behind the root causes of eutrophication (and sedimentation).

Root causes	Sectors/ Activities	Immediate causes	Remarks
Economic	Industry Urbanisation	Enhanced effluent discharge	1. There is increasing growth in industries that generate effluents. 2. There are lack of economic incentives to encourage the industries to install clean technologies.
	Agriculture	Run-off and stormwater	1. There are lack of economic incentives to encourage proper management of farms etc.
	Forestry	Run-off and stormwater	1. Poverty is driving people to cut down vegetation cover for fuel wood, timber etc.
Technological (includes the notion of affordability)	Industry Urbanisation	Enhanced effluent discharge	1. There is a lack of clean technologies, e.g. recycling. 2. Poor sanitation. 3. Use of inappropriate or obsolete technology. 4. Inadequate treatment facilities.
	Urbanisation	Run-off and stormwater	1. There are poor or no waste disposal facilities. 2. There is poor waste management.
	Agriculture	Run-off and stormwater	1. Poor agricultural practices. 2. Use of agro-chemicals.
Legal	Industry Urbanisation	Enhanced effluent discharge	1. There is lack of compliance to regulations in the industries. 2. Poor standards that need to be updated.
Governance	Industry Urbanisation	Enhanced effluent discharge	1. There is lack of monitoring and enforcement of existing legislation and regulations relating to effluent discharge from the industries and urban settlements.
	Urbanisation	Run-off and stormwater	1. Government failure in provision of waste disposal facilities.
	Agriculture	Run-off and stormwater	1. No enforcement of regulations. 2. Lack of integrated knowledge and policy implementation (internal/external).
	Forestry	Run-off and stormwater	1. Lack of monitoring and enforcement of regulations governing the forestry sector.
Geographic	Industry Urbanisation	Enhanced effluent discharge	1. Industries are located close to the lake shore, discharging raw and untreated effluents in all three countries.
	Wildlife	Run-off and stormwater	1. High wildlife population generating unmanaged waste.
Demographic	Urbanisation	Enhanced effluent discharge	1. Increasing populations in urban areas.
	Agriculture	Run-off and stormwater	1. High livestock population in the Lake Victoria Basin generates a large amount of diffuse waste that finds its way into the waterways and lake. 2. Overstocking and over-grazing.
	Wildlife	Run-off and stormwater	1. High wildlife population in the Lake Victoria Basin generates a large amount of diffuse waste that finds its way into the waterways and lake. 2. Overstocking and over-grazing.
Knowledge	Agriculture	Run-off and stormwater	1. Lack of information, training and education, leading to over-grazing and overstocking. 2. Inadequate access to technical and scientific information. 3. Inadequate scientific understanding, e.g. replacement of traditional crops with commercial crops.
	Forestry	Run-off and stormwater	1. Lack of information, training and education e.g. on soil conservation. 2. Inadequate scientific understanding at the local level.

Chemical pollution

The identified immediate causes for chemical pollution are: enhanced effluent discharge, enhanced discharge of solids, run-off and stormwater, and atmospheric deposition (Figure 28). The latter is currently the least important but, in terms of supply of nutrients such as nitrogen and phosphorus, it may become increasingly important as land use in the Basin and outside cumulatively reduces the vegetation cover, thus increasing the atmospheric load of fine particulate matter.

Immediate causes

Enhanced chemical effluent discharges go directly into the rivers and the Lake. Agro-chemicals used in agriculture contaminate the rivers and the Lake. Leachates from mining tailings that are close to the rivers or the lake shore, industrial wastes such as barley waste and chemicals are dumped into the Lake in a non-regulated manner. There is also disposal of expired pesticides, medical waste, petrol station wastes, bunkering wastes, etc. Some companies have stockpiles of banned substances such as DDT.

Sectors/activities

Most industry is located in the larger towns bordering the Lake; Kampala and Jinja in Uganda, Mwanza and Musoma in Tanzania, and Kisumu in Kenya, with the exception of the large sugar factories in Kenya located at some distance from the Lake (Scheren et al. 2000). Small-scale mining is increasing in parts of the Tanzanian catchment, leading to contamination of the waterways by mercury. There is a lack of incorporation of clean technologies in the industrial sector. For example, Panpaper Limited in Kenya (discharging into Nzoia River) could use an extra processing step of scrubbing technology to reduce SO_2 and produce sulphuric acid (added value product). Used chlorine has been dumped into the Lake killing a lot of aquatic organisms. In Uganda for example, expired chemicals as well as drugs and partially treated domestic sewage from Kampala area is dumped into public waterways, which finally end up in Lake Victoria (Kiremire 1997).

The use of agro-chemicals is increasing in the Lake Basin where there are large-scale farms of coffee, tea, cotton, rice maize, sugar and tobacco (Ntiba et al. 2001). The food and cash crops grown on wetlands require the application of fertilisers and pesticides (Kairu 2001). Much of Ugandan industrial effluents drain through wetlands before reaching the Lake surface water (Scheren et al. 2000). The urban and peri-urban growth is rapid and largely unplanned; many buildings are erected without authorisation, run-off rates are increased due to lack of stormwater drainages to handle urban run-off, and proper waste disposal is poorly or not at all co-ordinated by municipal authorities. Most of the poorly disposed urban wastes are then washed into water courses and eventually reach the Lake.

Root causes

In Tanzania and Uganda the industrial wastewater treatment facilities are generally absent, but in Kenya a majority of factories operate a

Table 29 Summary of the processes and actions behind the root causes of chemical pollution.

Root causes	Sector/ Activities	Immediate causes	Remarks
EconomicC	Agriculture Industry Mining	Enhanced effluent discharge	1. There is increasing growth in industries that generate effluents. 2. There are lack of economic incentives to encourage the industries to install clean technologies.
	Industry Mining	Enhanced discharge of solids	1. There is increasing growth in industries that generate effluents. 1. There are lack of economic incentives to encourage the industries to install clean technologies.
Technological	Agriculture Industry Mining	Enhanced effluent discharge	1. There is a lack of clean technologies. 2. Use of inappropriate, dilapidated or obsolete technology. 3. Inadequate treatment facilities.
	Agriculture Industry Mining Health	Enhanced discharge of solids	1. There is a lack of clean technologies. 2. Use of inappropriate, dilapidated or obsolete technology. 3. Inadequate or lack of treatment facilities. 4. There are poor or no waste disposal facilities, e.g. lack of proper disposal of food processing waste and lack of scientifically acceptable waste disposal from medical institutions.
	Agriculture	Run-off and stormwater	1. Use of agro-chemicals.
	Urbanisation	Run-off and stormwater	1. Lack of stormwater drainages.
Legal	Agriculture Industry Mining	Enhanced effluent discharge	1. Lack of compliance to regulations, e.g. improper disposal of chemicals used. 2. Non-regulation of the use of chemicals e.g. pesticides and fertiliser in the agriculture industry. 3. Poor standards that need to be updated.
	Agriculture Industry Mining	Enhanced discharge of solids	1. Lack of compliance to regulations, e.g. improper disposal of chemicals used. 2. Non-regulation of the use of chemicals e.g. pesticides and fertiliser in the agriculture industry. 3. Poor standards that need to be updated.
	Urbanisation	Run-off and stormwater	1. Lack of compliance to building codes.
Governance	Agriculture Industry Mining	Enhanced effluent discharge	1. There is lack of monitoring and enforcement of existing legislation and regulations relating to effluent discharge from the industries.
	Agriculture Industry Mining Health	Enhanced discharge of solids	1. There is lack of monitoring and enforcement of existing legislation and regulations relating to discharge of solids from the industries.
	Industry Urbanisation	Run-off and stormwater	1. Poor waste management in industry and urban areas. 2. Poor urban planning. 3. Lack of monitoring and enforcement of regulations in planning, design and structures development.
Geographic	Agriculture Industry Mining Health	Enhanced effluent discharge	1. Most of these industries are located close to rivers, and empty their waste into these rivers. Some are located along the Lake shoreline and discharge the waste directly into the Lake.
	Agriculture Industry Mining Health	Enhanced discharge of solids	1. Most of these industries are located close to rivers, and empty their waste into these rivers. Some are located along the Lake shoreline and discharge the waste directly into the Lake.
	Agriculture Industry Mining Health	Run-off and stormwater	1. Most of these industries are located close to rivers, and empty their waste into these rivers. Some are located along the Lake shoreline and discharge the waste directly into the Lake.
Knowledge	Agriculture	Enhanced discharge of solids	1. Lack of information, training and education, leading to misuse of pesticides and fertilisers.

treatment plant (Scheren et al. 2000). Some recent studies have shown that fish in Lake Victoria contain varying levels of organochlorine pesticide residues (Mitema & Gitau 1990), reflecting the transport of agro-chemical residues from farms within the catchment, through rivers to the Lake. Only a minority of industries are connected to an urban sewerage system (Scheren et al. 2000). Growth in industries has taken place against a backdrop of no infrastructure development for disposal of effluents. The currently existing sewage infrastructure has not been expanded or improved for decades. However, some of the industries are being allowed to establish their operations in areas that have been designated as "non-industrial", so they lack the infrastructure to handle their waste products. There is no enforcement of existing regulations regarding chemicals use and their disposal, and the current legislations are out-dated and in need of revision (Table 29). Lack of monitoring and poor scientific knowledge has led to the use of inappropriate or obsolete technologies to the detriment of the environment. The governments of the three riparian countries have taken no deliberate actions to put in capital resources to meet economic development needs.

Summary of the analysis

Although there are a large number of root causes identified in the Causal chain analysis, the specific factors relating to the various root causes are to a large extent similar and converge into only a few issues. These include: export markets for the fisheries; improvements in fish handling capacities and technologies used in the fisheries industry; the unrestricted access status of the Lake; lack of fishing quotas; lack of compliance to and enforcement of regulations and legislation governing the industries; weak regional integration of legal, institutional and implementing mechanisms; lack of involvement of stakeholders in decision-making processes; a low level of civic education and awareness at all levels; corruption; lack of cross-sectoral harmonisation of legislation in closely related industries; poor urban planning; use of old, dilapidated and inappropriate technologies; poor maintenance of treatment plants; lack of waste treatment and disposal mechanisms; poor agricultural/land use practices; poor standards for industrial operations; lack of incentives to industry to engage clean technologies; government failure in service provision; and, in most sectors, lack of resources and will on the part of the governments to mitigate the environmental problems.

Policy options

This section aims to identify feasible policy options that target key components identified in the Causal chain analysis in order to minimise future impacts on the transboundary aquatic environment. Recommended policy options were identified through a pragmatic process that evaluated a wide range of potential policy options proposed by regional experts and key political actors according to a number of criteria that were appropriate for the institutional context, such as political and social acceptability, costs and benefits and capacity for implementation. The policy options presented in the report require additional detailed analysis that is beyond the scope of the GIWA and, as a consequence, they are not formal recommendations to governments but rather contributions to broader policy processes in the region.

Problem definition

Lake Victoria is an international water body that offers the riparian communities several environmental services. Over the past three decades or so, the Lake has come under increasing and considerable pressure from a variety of inter-linked human activities such as overfishing, species introductions, industrial pollution, eutrophication, and sedimentation. The waters of Lake Victoria and its shoreline are shared between three countries; Kenya (6%), Uganda (43%), and Tanzania (51%). Additionally, the catchment of the principal affluent river, the Kagera, runs through the countries of Rwanda and Burundi. The two GIWA concerns that are addressed for Lake Victoria are: Unsustainable exploitation of fish and other living resources, and Pollution. Under the first concern, the two important issues that were identified were overexploitation and destructive fishing practices. Under the concern Pollution, the important issues identified were microbiological, eutrophication, chemical and suspended solids, but the latter has been integrated into the former three issues.

In the Causal chain analysis, the root cause of Unsustainable exploitation of fish resources was identified as the existence of a market for fish, both domestic and, more importantly, export. This is not to say that the market is undesirable, but that it should be regulated. Other root causes are inadequate regulation, poverty, poor institutional and legal arrangements, low civic education and awareness, low management capacity by communities, availability of market for undersized fish, and corruption. Whereas these root causes lead to unsustainable exploitation practices for subsistence fishing, in most cases profit is the main factor driving the process. This prompts people to even indulge in rent-seeking behaviour for short-term gain regardless of future outcome. As a result of these mainly illegal practices, individuals and governments end up losing out on income and revenue, respectively. The EU export ban is a relevant case in point where fish contamination as a result of using poison for fishing resulted in a boycott of fish from Lake Victoria by the EU in 1999. The environmental degradation of the Lake Victoria Basin over the last three decades (due to high population, massive algal blooms, water-borne diseases, water hyacinth infestation, oxygen depletion, introduction of alien fish species etc.) has been determined as placing a present value of 270–520 million USD at risk to the lake communities, if the large export fishery for Nile perch was lost (World Bank 1996). The collapse of the Nile perch fishery may become a reality sooner rather than later in the event that things are left in a "business as usual" scenario. However, many of these concerns are being addressed through a 30 million EUR grant, from the European Union to the East African Community States, being implemented by the Secretariat of the Lake Victoria Fisheries Organization.

Sources and causes of pollution in Lake Victoria have also been discussed in the Causal chain analysis. Four types of pollution issues have been identified: microbiological, eutrophication, chemical and suspended solids. All these emanate from the catchment areas in both urban and rural settings. The role of the Kagera River as a main contributor of suspended solids, nutrients and water hyacinth is an extremely important consideration when evaluating policy options for sustainable management of the Lake. Untreated industrial and municipal effluent together with agricultural run-off are the main contributors of microbiological and chemical pollution and are a source of nutrients contributing to eutrophication, while suspended solids are derived from erosion of degraded catchments, riverbanks and lake-edge environments due to poor agricultural practices and high grazing intensities. All these contaminants make the Lake water unfit for recreation (swimming), consumption and other uses unless a huge processing cost is incurred. Pollution destroys habitat for freshwater life forms while at the same time making them unavailable for nutritional purposes. For the majority of people living by the lake shore and subsisting by fishing, this implies that malnutrition and health problems will entrench themselves and exacerbate the deepening poverty among their ranks.

When developing the Policy options for Lake Victoria, a multitude of options were discussed and evaluated. Tables 30 and 31 present the various Policy options that were considered for mitigating the identified problems in the Lake Basin.

Political and organisational frameworks

The feasibility of policy options in Lake Victoria is looked upon in conjunction with the establishment of the regional integration of the East African Community (EAC 2001). The East African Community offers a good prospect for the success of the policies, which have been proposed here, in that it provides a conducive environment for Kenya, Uganda and Tanzania to work together towards common goals. It thus provides a good framework for policy harmonisation and closer co-operation in overseeing closer and effective implementation of activities collectively agreed upon. Article 112 in the East African Community Treaty (EAC 2001) lists areas of agreement in the management of the environment as follows:

- The development of a common environmental management policy;

Table 30 Policy options analysis matrix: overexploitation and destructive fishing issues.

Issue	Root cause	Policy options	Effectiveness	Efficiency	Equity	Political feasibility	Implementation capacity
Overexploitation	Availability/access to markets for fish.	Quota for fisheries (in order to restrict effort).	**High** Existence of BMUs.	**Moderate** Community participation.	**High** All stakeholders to benefit intergenerational.	**Moderate** Existence of political will in EAC.	**Moderate** Existing capacity could be boosted with new programmes.
		Quota for processing.	**High** Few processing plants.	**High** Restriction of demand hence supply.	**Low** Structure of fish supply left intact.	**Moderate** Existence of political will in EAC.	**High** Existing national fisheries offices.
	Governance	Review of the rules and regulations and existing fisheries policies. Political will to implement rules and regulations.	**High** Some of the regulations and penalties are inadequate.	**High** Will address present and future environmental and social needs.	**High** Policies and rules geared towards safeguarding the sustainability of fisheries.	**High** Existence of political will in EAC.	**High** National fisheries departments with EAC secretariat.
		Civic education and awareness. Incorporation of environmental education in school curricula.	**High** Will enhance compliance and community co-operation.	**Moderate** Cost of training high.	**High** Enhanced awareness of rights and obligations.	**High** EAC framework facilitates.	**Moderate** NGOs and government departments exist.
Destructive fishing practices	Poor institutional and legal arrangements.	Strengthening monitoring and enforcement of restrictions.	**High** Curb illegal gear use.	**Moderate** High set-up cost for monitoring and enforcement.	**High** Involves all beneficiaries.	**Moderate** Exists under EAC initiative.	**Moderate** Cost element should be solved by involving communities under co-management.
	Corruption	Enforce rule of law.	**High** Reduced illegal activities.	**High** Safeguarding values of resources and enhancement of sustainability.	**High** Fairness in access to resources enhanced.	**Moderate** Fight against corruption is a priority by all three EAC governments.	**High** Existing police and legal authorities and the community at large in all three EAC countries.
	Low civic education and awareness and low management capacity by communities	Provide civic education and awareness, empower and involve more communities in management.	**High** Will enhance compliance and community co-operation.	**Moderate** Cost of training high.	**High** Enhanced awareness of rights and obligations.	**High** EAC framework facilitates.	**Moderate** NGOs and government departments exist.
	Availability of markets for undersized fish.	Impose slot size restrictions on the fish processing factories.	**Moderate** Maybe jeopardised by unscrupulous civil servants.	**Moderate**	**High** Everyone wins in the long run.	**High** Sustainability of fishery at stake.	**Moderate** Cost of monitoring high.
	Poverty	Provision of credit to artisan fishers.	**High** Most people in need of credit do not access it presently.	**Moderate** Improved methods of fishing.	**High** Enable poor to exploit economic opportunities.	**High** Included in national development policies	**Moderate** NGOs, relevant government departments programs.

- The development of special environmental management strategies;
- Taking measures to control transboundary air, land and water pollution arising from developmental activities;
- Integrating environmental management and conservation measures in all development activities.

The Treaty further spells out the Partner States' intention in the management of natural resources: conserve natural resources; co-operate in the management of natural resources for the conservation of the eco-systems and the arrest of environmental degradation; and adopt common regulations for the protection of shared aquatic and terrestrial resources (in Article 114).

Due to the recognition of the inevitability of negative impact on the environment and natural resources depletion arising from development activities, the Treaty further highlights areas of co-operation in its chapter 19, Article 111, as to:

(a) Foster cooperation in the joint and efficient management and sustainable utilisation of natural resources;
(b) Co-operate and co-ordinate policies and actions for the protection and conservation of the natural resources and environment against all forms of degradation arising from developmental activities;
(c) Adopt common policies for control of transboundary movement of toxic and hazardous waste including nuclear materials and any other undesirable materials;
(d) Provide timely and relevant information on natural and human activities that may or are likely to have significant transboundary environmental impact, and consultation at an early stage;
(e) Develop and promote capacity building programmes for a sustainable management of natural resources.

The above actions, which have been agreed by the community member states, aim to:

(a) Process, protect and enhance quality of the environment;
(b) Contribute towards sustainability of the environment;
(c) Ensure sustainable utilisation of natural resources such as lakes, wetlands, forests and other aquatic and terrestrial ecosystems;
(d) Jointly develop and adopt water resources conservation and management policies that ensure sustainability and preservation of ecosystems.

In Article 112, the Partner States further agree to, "integrate environmental management and conservation measures in all developmental activities such as trade, transport, agriculture, industrial development, mining and tourism in the community". This agreement is crucial to the integrity of the natural environment of member states and is bound to facilitate a greater co-ordination and success in conserving the natural environment while benefiting from it.

A lot of work has been done on sustainable development in the Lake Victoria Basin, which has been designated as a regional economic growth zone to be exploited jointly to maximise economic and social benefits while ensuring effective environmental management and protection (EAC 2001:40). Amongst these areas of cooperation are:

(a) The implementation of the Fisheries Management Plan for Lake Victoria through the Lake Victoria Fisheries Organisation (LVFO) by a grant to the East African Community States from the European Union;
(b) Establishment of the Lake Victoria Fisheries Organisation Secretariat, an information clearing-house for fisheries related information on Lake Victoria;
(c) Review of a study report on the Economic Potential and Constraints for Sustainable Development of Lake Victoria Basin as an Economic Growth Zone;
(d) Extension of Lake Victoria Environmental Management Programme (LVEMP) for Tanzania and Uganda, while Kenya has applied for a 2-year extension from the World Bank.

Reports on progress and achievements of LVEMP, since its inception, show that work on various issues pertaining to the environment and natural resources is continuing. Some of the ongoing work includes:

i. Treatment of plastic materials with special emphasis on polyethylene materials. A study is to be conducted;
ii. Development of a shared EAC Water Vision, Common Water Policy and Comprehensive Development Strategy;
iii. Implementation of the Lake Victoria Development Programme through the establishment of a Sectoral Council. The Committee on the Lake Victoria Development Programme also recommended that ways should be explored to ensure that the next phases of the LVEMP are funded on a grant basis, since most of the programmes are of a biodiversity nature with global benefits;
iv. Apart from emphasising the enforcement of slot size prohibiting processing of fish less than 50 cm or greater than 85 cm for Nile perch harvesting, the Lake Victoria Fisheries Organisation (LVFO) has been urged to initiate the patenting of the Victoria Perch by the EAC, Council of Ministers of the LVFO;
v. Other measures of practical nature which have been discussed include establishing a proper monitoring, control and surveillance (MCS) mechanism, issuing of seizure forms for confiscated items and official receipts for any fines, the use of courts of law for culprits and the sharing of this information with Partner states, etc., and a strong condemnation of fish smuggling.

The above are only some of the developments taking place in the EAC co-operation on environment and natural resources management. There has been good progress in the implementation of the decisions taken by the Council although there are funding problems. During the year 2002, the Lake Victoria Development Programme (LVDP) put emphasis on activities, which lead to strengthening and consolidating its role in promoting, coordinating and harmonising the various programmes and projects in the Lake Victoria Basin. The LVDP has already established and operationalised National Focal Points in the Partner States' Ministries responsible for Lake Victoria development. These Ministries include the Ministry of Environment and Natural Resources in Kenya, the Ministry of Water Livestock Development in Tanzania and the Ministry of Foreign Affairs in Uganda. Other achievements include studies conducted to form a basis for objective decisions on environmental and natural resources management in the implementation of the Treaty. The implication for East Africa is that the feasibility of policy options suggested here has a high probability of success owing to the solid foundation of the co-operation, which manifests the existence of political will among the member countries.

Options

Overexploitation of fish

Policy options that can address overexploitation of fish are (see also Table 30):

- Quota for fishing
- Quota for processing
- Review of the rules and regulations and existing policies
- Civic education and awareness

Option 1: Quota for fishing

This policy option has a high probability of success in the medium-term (5 years). There should be involvement of stakeholders (fishers in co-management) and a change of attitude from a government-driven to a community-driven process including ownership. The process should be initiated in areas where there is a felt need. This will ensure self-regulation and sustainability. A conducive environment should be created for the success of the instruments required (revision of by-laws, scientific basis for decision-making, education and training; financial and technological assistance, etc.). This should control the number of entrants and ensure that efforts are at a sustainable level with minimum cost. The wise use of resources and democratisation of political processes for sustainable development should be politically feasible and provide equitable dividends to stakeholders. There is, however, the risk that some people will fight against it if they are not well informed of its benefit, namely, the sustainability of the fishery. Some business people, however, may not be interested in sustainability, but would want to reap the highest profit allowed by the market. As long as their market exists, they may continue to provide effective demand to fishers by buying what is available in the market. This implies that quota for fishing should be combined with other policy options such as quota for processing to make the market conditions binding. The sustainability of fishery means that the presently threatened livelihood of the majority of the riparian people would be assured. The implementation cost for this policy option is large considering aspects such as monitoring and enforcement. However, it need not be an obstacle if communities are involved in a participatory manner. The communities, properly empowered through co-management, will absorb most of these costs.

Option 2: Quota for processing

This policy option should follow the same lines as the quotas for fisheries. However, this measure will not provide for equity since the basis for redistribution of benefits lies in the fishing and selling of fish. It does not guarantee fair distribution of access to fish. However, it holds the highest possibility of controlling the amount of fish landed by restricting the main market. Resistance is expected from both sellers and buyers of fish, but with the dwindling stock of fish and reduced supply, in terms of both quantity and quality, it is expected that proper awareness will avoid this obstacle. Recently (April/May 2003), fishers in Musoma, Tanzania, were on strike for several days withholding fish supplies to the processing plants in the area of Musoma demanding better prices and the establishment of a new buying and selling arrangement. The fishers wanted to sell directly to the processing plants instead of dealing with middlemen or agents. They succeeded in getting processing plant owners to consider their demands. Such development indicates the possibility of achieving a consensus between fishers and processors in controlling catch quantity and quality in terms of size.

Option 3: Review of the rules and regulations and existing policies

In order for co-management to succeed, a favourable environment should be provided. This includes the recognition of property rights and entitlements. This option is highly effective since the existing situation provides a loophole for offenders to escape justice through different rules and policies or uncoordinated implementation. The existing rules on buying and selling fish allow buyers to accept or even demand fish below the recommended size. Revision of these policies, regulations and rules alone does not mean success. They also require enforcement. Benefits from the review of policies and regulations are enormous across all stakeholder groups. Curbing overexploitation will greatly facilitate the sustainability of fisheries. In this case everybody wins. The review of policies, rules and regulations is already being worked out under EAC. This, however, should be carried out in conjunction with effective enforcement. The policy option will have a high probability of success if well implemented in a participatory manner, with stakeholders in the fishing communities along the lake shores, as has already begun under co-management through the Beach Management Units (BMUs).

Option 4: Civic education and awareness

It is important to increase public participation in order to enhance effective decision-making and compliance by self-regulation. There is, however, a risk of failure in some localised areas due to lack of political will at grassroots level in communities where political leaders benefit from passivity and ignorance among the constituents. Such political leaders will obstruct and hinder the move to make villagers aware of their rights and obligations. This is a localised risk and should not constitute a major obstacle to the success public participation in decision-making, as such passive communities are very few and widely scattered. There is political will at regional level, as demonstrated by the EAC treaty document and the implementation of the intended objectives so far. This option will help to remove corrupt, irresponsible and authoritarian leadership and to bring in transparent, democratic and accountable leaders. This means more popular participation of communities in environmental, economic and development issues that affect their livelihoods. It would also be more inclusive in terms of sharing accruing costs and benefits. Environmental education should also be incorporated in school curricula as an effective long-term policy.

Destructive fishing practices

The policy options that can address destructive fishing practices are listed below (see also Table 30).

- Strengthening monitoring and enforcement of restrictions; enforcing the rule of law;
- Provision of civic education and awareness; empowering and involving more communities in management;
- Imposing size restrictions on fish processing factories;
- Provision of credit to artisanal fishers.

Option 5: Strengthening monitoring and enforcement of restrictions and the rule of law

Monitoring and enforcement of regulations and restrictions encourages compliance. As has been noted, good policies and regulations exist though some may be outdated. However, without enforcement, compliance among the target group (fishers) is reduced due to the desire to maximise benefit at minimum cost, threatening the sustainability of fishery. The civil service reforms in Tanzania have aimed to reduce the number of civil servants so as to increase labour productivity and efficiency. The outcome of this exercise has been to cut down the number of field staff to below the necessary requirement for efficient operation, thus encouraging rampant law-breaking. This includes non-compliance with restrictions of fishnet mesh size and the use of illegal gear such as beach seines. The effectiveness of this policy is high, especially considering the political will and intention towards strengthening the management of Lake Victoria through the EAC initiative. The move towards co-management should be supported as it involves communities in effective management at a lower cost, thus making it possible to achieve the monitoring and enforcement goal.

Option 6: Provide civic education and awareness; empowering and involving more communities in management

The lack of awareness of the fishery status and trends, and of the impact of their actions, may be a contributing factor to the irresponsible behaviour of the people. The lack of knowledge of their rights and obligations in bringing about a conducive environment for a sustainable fishery may also undermine an effective participation in the management of natural resources, fisheries in particular. Empowering the community in both these and other forms of awareness would go a long way towards effective management and consequently sustainable utilisation of fisheries resources. As with overexploitation, implementing this policy option has a risk of failure. However, with proper and careful planning and implementation, bearing in mind that there are leadership elements who might want to reject the idea, success can be achieved.

Option 7: Imposing size restrictions on fish processing factories

Fish processing factories are the major buyers of Nile perch, in other words they provide the market for the majority of fishers and buyers. It has been alleged that the processing factories prefer smaller size fish to meet the demand of European buyers. The argument put forward is that small size fish (1 kg) contain less fat than larger fish. Scientists argue that at 1 kg, the Nile perch is still growing and has not reached the reproductive stage. Therefore, discouraging the sale of small size fish will facilitate reproduction and replenish stocks. This policy option is achievable when processing plant owners realise that the availability of fish is becoming a problem. In Tanzania, a meeting between processing plant owners and officials from the Fisheries Department achieved consensus on this issue.

Option 8: Provision of credit to artisanal fishers

Lack of capital for the purchase of recommended fishing gear hampers compliance by small-scale fishers. Having being dispossessed of their illegal gear, they cannot afford to buy new legal fishing gear. The provision of credit to fishers will facilitate compliance with restrictions and regulations by enabling them to purchase the required gear, which does not endanger sustainability. With the experience gained by numerous NGOs in credit provision to small-scale entrepreneurs, this policy option has a high probability of success. It has a double advantage of alleviating poverty among the fishing communities while at the same time facilitating sustainable utilisation of fisheries resources.

Pollution

Policy options that address the issues of pollution are listed below (see also Table 31).

- Accreditation of analytical laboratories for standards enforcement;
- Liberalisation of waste disposal activities to involve the private sector and communities;
- Revision of regulations in urban planning that have not taken into account environmental issues, and improvement of monitoring and enforcement;
- Improvement of natural resource management and farming practices through training, governance and agricultural technology;
- Stronger vetting of technology promoted by national and international agencies;
- Strengthening enforcement of regulations for mandatory effluent treatment in municipalities and industries;
- Incorporating all stakeholders in the drafting of regulations and in monitoring and enforcing agreed regulations;
- Integration of institutional framework, regulations and laws at two levels: national and regional;
- Creation of a public complaints institution with powers to investigate and recommend prosecution;
- Enforcing compliance with international conventions e.g. Ramsar, CITES, and the Biological Diversity Convention of Agenda 21;
- Strengthening the capacity of National Environmental Protection Authorities to enable a more effective enactment of legislation by providing trained manpower and sufficient funding.

Option 9: Accreditation of analytical laboratories for standards enforcement

Currently, results from analytical laboratories in the Lake Victoria Basin are not recognised internationally. In order to achieve recognition, East African laboratories must send samples to Europe or USA and other places for tests. This process is costly in both time and money. In order to facilitate water quality standards enforcement in a cost efficient way, the accreditation of water quality laboratories is essential. Implementation of this policy option will go a long way in reducing health costs and increase labour productivity. Under the EAC, programmes are already underway to address this situation, where the capacity for implementation exists within the three EAC countries.

Option 10: Liberalisation of waste disposal activities to involve the private sector and communities

Waste disposal activities have been the mandate of the government through its municipal councils. With the implementation of the Structural Adjustment Programmes where civil service reforms were undertaken, there arose a situation of inadequate capacity to carry out efficient waste disposal services. In addition, government withdrawal from commercial activities under the economic liberalisation banner, made the case for private sector participation in the economy even stronger, particularly for Tanzania. This is obviously important in order to fill the void left by public institutions, which used to render these services. The effectiveness of this policy option is in it being a business venture with the capability of generating enough income to justify its feasibility. This is already manifested by the existence of environmental and sanitation companies in urban centres of Dar es Salaam and other towns. In some places community youth groups are formed which engage in waste collection and disposal from residential areas.

Option 11: Revision of regulations in urban planning that have not taken into account environmental issues and improvement of monitoring and enforcement

Urban centres are expanding all over East Africa due to population pressure. Apart from increased population in cities and towns, changing consumption patterns driven by a modern consumerist society lead to more waste being generated today than before. In some cases town planning ignores such changes. In addition, most urban centres have a significant number of squatters in shanty structures haphazardly constructed without regard to the need for waste collection, disposal facilities, or provisions for access by disposal trucks. This is a result of outdated urban planning regulations and inadequate town planning, resulting in squatting due to a lack of surveyed plots. New approaches are being implemented to facilitate the survey of building plots in urban centres through clients' contributions towards the survey cost. Previously, budgetary inadequacy constrained the survey exercise. More plots are surveyed today under this scheme which has led to less haphazard building. Capacity to undertake the revision and corrective measures exists within relevant land offices in the EAC partner states.

Option 12: Improvement of natural resource management and farming practices through training, governance and agricultural technology

Bad farming practices result in eutrophication of the Lake, through pollution. Deforestation and loss of vegetation cover cause soil erosion

Table 31 Policy options analysis matrix: Pollution issues.

Issue	Root cause	Policy option	Effectiveness	Efficiency	Equity	Political feasibility	Implementation capacity
Microbiological Eutrophication Chemical Suspended solids	Lack of water quality standards and/or enforcement.	Accreditation of analytical laboratories for standards enforcement.	**High** Enable convenient & acceptable water quality monitoring at a cheaper cost.	**High** Reduces health costs & increase labour productivity.	**High** Better health for all and sustained fishery.	**High** Programs already underway within EAC protocol.	**High** Exists within the EAC partner countries.
Microbiological	Inadequate capacity for environmental sanitation.	Liberalisation of waste disposal activities to involve the private sector & communities particularly in large urban centres.	**High** Reduced pollution due to increased waste disposal capacity.	**High** (benefits include improved health)	**High** All win due to clean environment .	**High** Approach already practiced under economic liberalisation.	**High** Environmental sanitation companies, NGOs and community groups already work in some areas.
Chemical Microbiological	Inadequate regulations and weak enforcement of urban and rural planning and implementation.	Revise regulations in urban planning that have not taken into account environmental issues and improve monitoring and enforcement.	**High** Most urban centres do not have proper infrastructure for waste disposal.	**Moderate** (improvement of urban environment at a cost of relocating some people)	**High** Improved sanitation and reduced of medical bills.	**High** Exists under EAC.	**High** Exists with relevant lands offices in EAC partner countries.
Eutrophication	Bad farming practices.	Improve natural resource management, farming practice through training governance and technologies in agriculture.	**High** A large area is used for unsustainable farming practices of cotton and coffee.	**Moderate** Reduced pollution but cost of implementation.	**High** Protection of lake environment for all.	**High** Political will exists exhibited by the existence of LVEMP/ LVFO.	**Moderate** Exists within the LVEMP/LVFO and relevant departments in the partner states.
Chemical Suspended solids	Inappropriate technologies used in farming.	Stronger vetting of technologies that are being promoted by the national and international agencies.	**High** Will reduce pollution to some extent by stopping the used of prohibited chemicals.	**High** Reduced pollution but high cost may delay implementation.	**High** Protection of lake environment for all.	**Moderate** Existence of business lobby that may delay implementation.	**High** Existence of relevant national institutions e.g. Tanzania Bureau of Standards.
Chemical	Weak monitoring and enforcement of regulations for effluent treatment.	Strengthen enforcement of regulations requiring effluent treatment in municipalities and industries.	**High** Most industrial establishments possible to be monitored.	**Moderate** Financial constraints.	**High** Cleaner & safer environment for all.	**High** Existence of LVEMP/LVFO and other like programs is a testimony.	**Moderate** Exists within the LVEMP/LVFO and relevant departments in the partner states.
Microbiological Eutrophication Chemical Suspended solids	Implementation failure of policies and regulations.	Incorporate all stakeholders in drafting of regulations and in monitoring and enforcing agreed upon regulations.	**High** Ownership	**Moderate** Cost element.	**High** Sustainability is assured.	**High** Exercise of participatory processes.	**High** General acceptance of regulations.
Microbiological Eutrophication Chemical Suspended solids	Uncoordinated institutional level frameworks.	Integration of institutional framework at two levels: national and regional.	**High** Taking place under EAC.	**Moderate** Budgetary constraints, implementation rigidities.	**High** Region-wide acceptance.	**High** EAC	**High** Region-wide agreed regulations.
Microbiological Eutrophication Chemical Suspended solids	Conflicting and unsupportive rules and regulations at national and regional levels.	Integration of regulations and laws at two levels: national and regional.	**High** Taking place under EAC.	**Moderate** Budgetary constraints, implementation rigidities.	**High** Common basis for regulations.	**High** EAC	**High** Commonly accepted regulations,e.g. EAC.
Microbiological Eutrophication Chemical Suspended solids	Inadequate capacity & lack of legitimacy of national implementing institutions in conflict resolution.	Legal and economic empowerment of institutions e.g. LVFO.	**High** Reduction of transboundary conflicts.	**High** Harmonious co-existence of EAC partner states inhabitants.	**High** Popular participation in conflict resolution.	**Moderate** Dependent on successful establishment of EAC institutional framework.	**Moderate** Budgetary constraints.
Microbiological Eutrophication Chemical Suspended solids	Low compliance of international conventions.	Enforce compliance to international conventions e.g. Ramsar, CITES, & Biological Diversity Convention of Agenda 21*.	**Moderate** Difficult to implement at local level.	**Moderate** Budgetary constraints, implementation rigidities.	**High** Resource conservation for the benefit of all.	**Moderate** Vested interests by individuals and group lobbies.	**Moderate** Budgetary constraints, implementation rigidities.
Microbiological Eutrophication Chemical Suspended solids	Weak capacity of national environment protection agencies.	Strengthening of capacity of National Environmental Protection Authorities in order to be more effective.	**High** Process on-going for Tanzania, Kenya and Uganda.	**High** Protection of environment.	**High** Enhancement of sustainable livelihoods.	**High** Feasibility manifested by the existence of the National environmental protection authorities.	**High** Existence of Environmental protection agencies and laws in Kenya, Uganda and Tanzania.

**It should be noted that compliance to regional treaties/conventions such as the EAC and LVFO Convention, and international conventions such as POPs and BASEL conventions can go a long way in helping to tie up legislation, regulations and laws that would operate at regional levels.*

(including in wetlands). In addition, lack of buffering results in the flow of pollutants into the Lake. Furthermore, poor waste management, lack of stormwater drainage, and destruction of wetlands exacerbate the situation. Training farmers around the Lake to practice clean production and avoid bad farming practices, which result in pollution of the Lake, is essential. Currently, run-off from cotton and coffee farms carries with it solid organic waste. This is mainly due to lack of education and awareness. The establishment of a proper waste management infrastructure, and educating farmers as to the importance of wetlands, together with strengthening monitoring and enforcement, will improve the environmental status of the Lake. The implementation capacity of this policy option exists within partner states and the political and technical feasibility is manifested by LVEMP.

Option 13: Stronger vetting of technology promoted by national and international agencies

Some chemical pollution is due to the use of prohibited chemicals such as DDT. Stronger vetting of such chemicals will reduce the risk of adverse effect on human health and the environment. The political feasibility of this policy option is moderate owing to the fact that a business lobby will fight to maximise their benefits, regardless of the cost imposed on people and the environment. However, communities could be a good counter lobby to pressure their governments to take the right decisions through constituent representation in parliament.

Option 14: Strengthening enforcement of regulations for mandatory effluent treatment in municipalities and industries

While rules and regulations exist in all three countries on waste disposal, their enforcement is seriously lacking. Under Tanzanian industrial law, all processing plants must have waste treatment facilities. However, few industries have "working" treatment plants or ponds. Wastewater and solid waste is left to spread to streams and residential areas where they affect the health of inhabitants living in the vicinity and who use contaminated water from streams and rivers. In other places in Tanzania, outside the Lake Basin, the disposal of industrial and municipal effluent leads to huge economic losses through the destruction of tourist attractions such as coral reefs. With the enactment of environmental policies and frame-work legislation in all three partner states, and the establishment of environmental protection agencies, this policy option has a high probability of succeeding. The existence of LVEMP adds another dimension of seriousness and commitment in the three partner states towards proper management of the Lake.

Option 15: Incorporating all stakeholders in the drafting of regulations and in monitoring and enforcing agreed regulations

Participatory approaches have been found to be effective in the implementation of policies and decisions which require the input of the community and where the communities in turn stand to benefit from the process. This is because involvement of the beneficiaries instils a sense of responsibility and participation. They share the cost of implementation and the benefit accrues to them, thus becoming effective partners ensuring proper and successful implementation. This policy option has a high probability of success. However, traditional practices of bureaucrats and politicians may pose an initial obstacle to this new way of doing things. This approach has its setbacks in terms of speed of the process and implementation costs. However, high success rates have been experienced across the region in several project implementations.

Option 16: Integration of institutional framework, regulations and laws at two levels: national and regional

In order to have a consistent and smooth policy implementation for the management of the Lake, a harmonisation of policies, regulations and legislation is vital. Any loopholes would make the effort ineffective. This work is underway within the auspices of EAC for fisheries, the environment and natural resources management. However, this may take time and requires extensive negotiation. At the end of the day, it will facilitate smooth implementation of collective objectives.

Option 17: Creation of a public complaints institution with powers to investigate and recommend prosecution

Given that conflicts occur between people from the partner states, the current practice is that national rules, regulations and institutions are used to solve such transboundary problems. In order to avoid complaints from outside parties in conflict, the establishment of an impartial institution is recommended to take care of all disputes related to fisheries; the number of such disputes has lately increased between Kenya and Uganda, and between Kenya and Tanzania. A more harmonious co-existence among inhabitants of the three states sharing the same resources will be created through the reduction of transboundary conflicts. The political feasibility and success of this policy option will depend on the success of the establishment of an EAC institutional framework and budgetary aspects.

Option 18: Enforcing compliance with international conventions e.g. Ramsar, CITES, and the Biological Diversity Convention of Agenda 21

All the partner states have ratified international conventions including the ones mentioned above. However, not all the ratified conventions are implemented as desired. Non-implementation of such conventions is as good as non-ratification. This has resulted in exacerbated environmental degradation and biodiversity decline with disastrous effects. Conventions such as Agenda 21 set the ground for sustainable national, and ultimately global development. Disregarding or not honouring such conventions means that the future of the Lake Victoria Basin is bleak. Due to the vested business interest in natural resources exploitation, a huge lobby exists which may provide a significant obstacle. However, with proper awareness, mobilisation and commitment, popular participation seems to be one way of facilitating the achievement through putting pressure on relevant authorities.

Option 19: Strengthening the capacity of National Environmental Protection Authorities in order to be more effective

To date, the National Environmental Management Council (NEMC) of Tanzania has been a "toothless dog" in that it has not had legal backing to enable it to execute the mandate of an effective environmental protection agency, as we know it. Hopefully, this situation will soon be relegated to history books. With the work on Institutional and Legal Framework for Environmental Management in Tanzania nearing completion and with the formulation of the environmental framework law, NEMC will have executive powers to monitor and enforce rules and regulations pertaining to environmental management and protection. As for Uganda's and Kenya's National Environment Management Authority (NEMA), the situation is also much improved.

Recommended policy options

In summary, the Policy options analysis resulted in the following recommended options to combat the identified priority concerns in the Lake Victoria Basin:

- Overexploitation
  - Fish processing quota.
- Destructive fishing practices
  - Provide civic education and awareness; empowering and involving more communities in management.
- Microbiological pollution
  - Liberalisation of waste disposal activities to involve the private sector and communities.
- Eutrophication
  - Improvement of natural resource management and farming practices through training, governance and agricultural technology.
- Chemical pollution
  - Strengthening enforcement of regulations for mandatory effluent treatment in municipalities and industries.
- Suspended solids
  - Improving natural resource management, soil conservation, farming practices through training, governance and agricultural technology, improved road construction design to minimise erosion.
- Cross-cutting
  - Integration of institutional framework at two levels: national and regional;
  - Integration of regulations and laws at two levels: national and regional;
  - Enforcing compliance with international conventions e.g. Ramsar, CITES, and the Biological Diversity Convention of Agenda 21;
  - Strengthening the capacity of National Environmental Protection Authorities in order to be more effective;
  - Provide economic incentives for the use of clean technology;
  - Promote self-regulation in fisheries and pollution management.

Conclusions and recommendations

In several cases, more than one policy option should be adopted in order to achieve the desired impact. This is true for quotas for fishing and processing. Also the successful implementation of these policy options will never be achieved without involving, in a participatory manner, the communities living on the lake shores who depend on fishing as a source of subsistence livelihood and income generation. Capacity building in terms of civic education and leadership and management skills will enhance this empowerment.

Knowledge gaps exist when it comes to quantitative estimates of benefit and cost in both physical and monetary terms of the Lake Victoria water and fisheries resources. The EAC has identified natural resource valuation and accounting as highly important aspects in planning and development. The economic, social and environmental values of natural resources must be understood in order to allow efficient and equitable allocation for present and future generations. Studies on the impact of pollution and decline of fish are required to establish the extent and the gravity of the situation. In-depth studies should be carried out to establish the processes involved and to analyse the impact on various groups of people. This will help to address the impact and establish who to include in the remediation process.

Immediate further studies are required on:

- Water quality assessment;
- Socio-cultural issues (holistic, rather than only focusing on the fisheries sector, encompassing health, agriculture, education, etc. within the entire Lake Basin);
- Resource inventory, mapping and use (including mapping of critical resources);
- Assessment and harmonisation of the legal and institutional status of National Acts, regional and international treaties and conventions;
- Study of the biology of the Nile perch, suspected to have up to three different sub-populations.

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Annexes

Annex I
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Annex II
Detailed scoring tables: Lake Turkana

I: Freshwater shortage

Environmental issues	Score	Weight %	Environmental concern	Weight averaged score
1. Modification of stream flow	2	80	Freshwater shortage	1.8
2. Pollution of existing supplies	1	20		
3. Changes in the water table	0	0		

Criteria for Economic impacts	Raw score	Score	Weight %
Size of economic or public sectors affected	Very small – Very large 0 1 2 3	1	30
Degree of impact (cost, output changes etc.)	Minimum – Severe 0 1 2 3	2	60
Frequency/Duration	Occasion/Short – Continuous 0 1 2 3	3	10
Weight average score for Economic impacts		**1.8**	
Criteria for Health impacts	**Raw score**	**Score**	**Weight %**
Number of people affected	Very small – Very large 0 1 2 3	2	40
Degree of severity	Minimum – Severe 0 1 2 3	1	50
Frequency/Duration	Occasion/Short – Continuous 0 1 2 3	3	10
Weight average score for Health impacts		**1.6**	
Criteria for Other social and community impacts	**Raw score**	**Score**	**Weight %**
Number and/or size of community affected	Very small – Very large 0 1 2 3	2	35
Degree of severity	Minimum – Severe 0 1 2 3	2	45
Frequency/Duration	Occasion/Short – Continuous 0 1 2 3	1	20
Weight average score for Other social and community impacts		**1.8**	

II: Pollution

Environmental issues	Score	Weight %	Environmental concern	Weight averaged score
4. Microbiological	0	0	Pollution	1.6
5. Eutrophication	1	40		
6. Chemical	0	0		
7. Suspended solids	2	60		
8. Solid wastes	0	0		
9. Thermal	0	0		
10. Radionuclide	0	0		
11. Spills	0	0		

Criteria for Economic impacts	Raw score	Score	Weight %
Size of economic or public sectors affected	Very small – Very large 0 1 2 3	1	30
Degree of impact (cost, output changes etc.)	Minimum – Severe 0 1 2 3	1	50
Frequency/Duration	Occasion/Short – Continuous 0 1 2 3	1	20
Weight average score for Economic impacts		**1.0**	
Criteria for Health impacts	**Raw score**	**Score**	**Weight %**
Number of people affected	Very small – Very large 0 1 2 3	1	40
Degree of severity	Minimum – Severe 0 1 2 3	1	50
Frequency/Duration	Occasion/Short – Continuous 0 1 2 3	1	10
Weight average score for Health impacts		**1.0**	
Criteria for Other social and community impacts	**Raw score**	**Score**	**Weight %**
Number and/or size of community affected	Very small – Very large 0 1 2 3	1	30
Degree of severity	Minimum – Severe 0 1 2 3	1	50
Frequency/Duration	Occasion/Short – Continuous 0 1 2 3	1	20
Weight average score for Other social and community impacts		**1.0**	

III: Habitat and community modification

Environmental issues	Score	Weight %	Environmental concern	Weight averaged score
12. Loss of ecosystems	1	50	Habitat and community modification	1.5
13.Modification of ecosystems or ecotones, including community structure and/or species composition	2	50		

Criteria for Economic impacts	Raw score	Score	Weight %
Size of economic or public sectors affected	Very small 0 1 2 3 Very large	2	40
Degree of impact (cost, output changes etc.)	Minimum 0 1 2 3 Severe	3	50
Frequency/Duration	Occasion/Short 0 1 2 3 Continuous	3	10
Weight average score for Economic impacts		**2.6**	
Criteria for Health impacts	**Raw score**	**Score**	**Weight %**
Number of people affected	Very small 0 1 2 3 Very large	3	55
Degree of severity	Minimum 0 1 2 3 Severe	1	35
Frequency/Duration	Occasion/Short 0 1 2 3 Continuous	3	10
Weight average score for Health impacts		**2.3**	
Criteria for Other social and community impacts	**Raw score**	**Score**	**Weight %**
Number and/or size of community affected	Very small 0 1 2 3 Very large	3	40
Degree of severity	Minimum 0 1 2 3 Severe	2	50
Frequency/Duration	Occasion/Short 0 1 2 3 Continuous	3	10
Weight average score for Other social and community impacts		**2.5**	

IV: Unsustainable exploitation of fish

Environmental issues	Score	Weight %	Environmental concern	Weight averaged score
14. Overexploitation	1	20	Unsustainable exploitation of fish	0.7
15. Excessive by-catch and discards	1	30		
16. Destructive fishing practices	0	20		
17. Decreased viability of stock through pollution and disease	0	10		
18. Impact on biological and genetic diversity	1	20		

Criteria for Economic impacts	Raw score	Score	Weight %
Size of economic or public sectors affected	Very small 0 1 2 3 Very large	0	60
Degree of impact (cost, output changes etc.)	Minimum 0 1 2 3 Severe	0	10
Frequency/Duration	Occasion/Short 0 1 2 3 Continuous	0	30
Weight average score for Economic impacts		**0**	
Criteria for Health impacts	**Raw score**	**Score**	**Weight %**
Number of people affected	Very small 0 1 2 3 Very large	0	55
Degree of severity	Minimum 0 1 2 3 Severe	0	30
Frequency/Duration	Occasion/Short 0 1 2 3 Continuous	0	15
Weight average score for Health impacts		**0**	
Criteria for Other social and community impacts	**Raw score**	**Score**	**Weight %**
Number and/or size of community affected	Very small 0 1 2 3 Very large	0	40
Degree of severity	Minimum 0 1 2 3 Severe	0	50
Frequency/Duration	Occasion/Short 0 1 2 3 Continuous	0	10
Weight average score for Other social and community impacts		**0**	

V: Global change

Environmental issues	Score	Weight %	Environmental concern	Weight averaged score
19. Changes in the hydrological cycle	2	45	Global change	1.4
20. Sea level change	1	45		
21. Increased UV-B radiation as a result of ozone depletion	0	0		
22. Changes in ocean CO_2 source/sink function	0	10		

Criteria for Economic impacts	Raw score	Score	Weight %
Size of economic or public sectors affected	Very small – Very large 0 1 2 3	1	30
Degree of impact (cost, output changes etc.)	Minimum – Severe 0 1 2 3	3	50
Frequency/Duration	Occasion/Short – Continuous 0 1 2 3	1	20
Weight average score for Economic impacts		**2.0**	
Criteria for Health impacts	**Raw score**	**Score**	**Weight %**
Number of people affected	Very small – Very large 0 1 2 3	2	40
Degree of severity	Minimum – Severe 0 1 2 3	3	50
Frequency/Duration	Occasion/Short – Continuous 0 1 2 3	1	10
Weight average score for Health impacts		**2.4**	
Criteria for Other social and community impacts	**Raw score**	**Score**	**Weight %**
Number and/or size of community affected	Very small – Very large 0 1 2 3	3	50
Degree of severity	Minimum – Severe 0 1 2 3	3	45
Frequency/Duration	Occasion/Short – Continuous 0 1 2 3	2	5
Weight average score for Other social and community impacts		**3.0**	

Comparative environmental and socio-economic impacts of each GIWA concern

Concern	Types of impacts								Overall score
	Environmental score		Economic score		Human health score		Social and community score		
	Present (a)	Future (b)	Present (c)	Future (d)	Present (e)	Future (f)	Present (g)	Future (h)	
Freshwater shortage	1.8	3	1.8	3	1.6	2	1.8	2	**2.1**
Pollution	1.6	3	1.0	2	2.0	2	2.0	2	**2.0**
Habitat and community modification	1.5	3	2.6	3	2.3	3	2.5	3	**2.6**
Unsustainable exploitation of fish and other living resources	0.7	2	0	1	0	1	0	1	**0.7**
Global change	1.4	2	2.0	2	2.4	2	3.0	3	**2.2**

If the results in this table were not giving a clear prioritisation, the scores were weighted by assigning different relative importance to present/future and environmental/socio-economic impacts in the following way:

Weight averaged environmental and socio-economic impacts of each GIWA concern

Present (%) (i)	Future (%) (j)	Total (%)
50	50	100

Environmental (k)	Economic (l)	Health (m)	Other social and community impacts (n)	Total (%)
40	20	20	20	100

Concern	Types of impacts					Rank
	Time weight averaged Environmental score (o)	Time weight averaged Economic score (p)	Time weight averaged Human health score (q)	Time weight averaged Social and community score (r)	Time weight averaged overall score	
	(a)x(i)+(b)x(j)	(c)x(i)+(d)x(j)	(e)x(i)+(f)x(j)	(g)x(i)+(h)x(j)	(o)x(k)+(p)x(l)+(q)x(m)+(r)x(n)	
Freshwater shortage	2.4	2.4	1.8	1.9	**2.2**	**2**
Pollution	2.3	1.5	2.0	2.0	**2.0**	**3**
Habitat and community modification	2.3	2.8	2.7	2.8	**2.6**	**1**
Unsustainable exploitation of fish and other living resources	1.4	0.5	0.5	0.5	**0.9**	**5**
Global change	1.7	2.0	2.2	3.0	**2.1**	**4**

Annex II
Detailed scoring tables: Lake Victoria

I: Freshwater shortage

Environmental issues	Score	Weight %	Environmental concern	Weight averaged score
1. Modification of stream flow	1	30	Freshwater shortage	1.7
2. Pollution of existing supplies	2	40		
3. Changes in the water table	2	30		

Criteria for Economic impacts	Raw score	Score	Weight %
Size of economic or public sectors affected	Very small Very large 0 1 2 3	0	35
Degree of impact (cost, output changes etc.)	Minimum Severe 0 1 2 3	0	55
Frequency/Duration	Occasion/Short Continuous 0 1 2 3	1	10
Weight average score for Economic impacts		**0.1**	
Criteria for Health impacts	**Raw score**	**Score**	**Weight %**
Number of people affected	Very small Very large 0 1 2 3	0	40
Degree of severity	Minimum Severe 0 1 2 3	1	50
Frequency/Duration	Occasion/Short Continuous 0 1 2 3	1	10
Weight average score for Health impacts		**0.6**	
Criteria for Other social and community impacts	**Raw score**	**Score**	**Weight %**
Number and/or size of community affected	Very small Very large 0 1 2 3	35	35
Degree of severity	Minimum Severe 0 1 2 3	45	45
Frequency/Duration	Occasion/Short Continuous 0 1 2 3	20	20
Weight average score for Other social and community impacts		**1.0**	

II: Pollution

Environmental issues	Score	Weight %	Environmental concern	Weight averaged score
4. Microbiological	3	20	Pollution	2.6
5. Eutrophication	3	25		
6. Chemical	2	20		
7. Suspended solids	3	25		
8. Solid wastes	1	5		
9. Thermal	0	0		
10. Radionuclide	0	0		
11. Spills	0	5		

Criteria for Economic impacts	Raw score	Score	Weight %
Size of economic or public sectors affected	Very small Very large 0 1 2 3	2	30
Degree of impact (cost, output changes etc.)	Minimum Severe 0 1 2 3	2	50
Frequency/Duration	Occasion/Short Continuous 0 1 2 3	2	20
Weight average score for Economic impacts		**2.0**	
Criteria for Health impacts	**Raw score**	**Score**	**Weight %**
Number of people affected	Very small Very large 0 1 2 3	2	40
Degree of severity	Minimum Severe 0 1 2 3	2	50
Frequency/Duration	Occasion/Short Continuous 0 1 2 3	2	10
Weight average score for Health impacts		**2.0**	
Criteria for Other social and community impacts	**Raw score**	**Score**	**Weight %**
Number and/or size of community affected	Very small Very large 0 1 2 3	3	30
Degree of severity	Minimum Severe 0 1 2 3	1	50
Frequency/Duration	Occasion/Short Continuous 0 1 2 3	3	20
Weight average score for Other social and community impacts		**2.0**	

III: Habitat and community modification

Environmental issues	Score	Weight %	Environmental concern	Weight averaged score
12. Loss of ecosystems	2	50	Habitat and community modification	2.5
13.Modification of ecosystems or ecotones, including community structure and/or species composition	3	50		

Criteria for Economic impacts	Raw score	Score	Weight %
Size of economic or public sectors affected	Very small – Very large 0 1 2 3	1	40
Degree of impact (cost, output changes etc.)	Minimum – Severe 0 1 2 3	1	50
Frequency/Duration	Occasion/Short – Continuous 0 1 2 3	2	10
Weight average score for Economic impacts		**1.1**	
Criteria for Health impacts	**Raw score**	**Score**	**Weight %**
Number of people affected	Very small – Very large 0 1 2 3	1	55
Degree of severity	Minimum – Severe 0 1 2 3	1	35
Frequency/Duration	Occasion/Short – Continuous 0 1 2 3	3	10
Weight average score for Health impacts		**1.2**	
Criteria for Other social and community impacts	**Raw score**	**Score**	**Weight %**
Number and/or size of community affected	Very small – Very large 0 1 2 3	1	40
Degree of severity	Minimum – Severe 0 1 2 3	1	50
Frequency/Duration	Occasion/Short – Continuous 0 1 2 3	1	10
Weight average score for Other social and community impacts		**1.0**	

IV: Unsustainable exploitation of fish

Environmental issues	Score	Weight %	Environmental concern	Weight averaged score
14. Overexploitation	3	30	Unsustainable exploitation of fish	2.6
15. Excessive by-catch and discards	2	20		
16. Destructive fishing practices	3	30		
17. Decreased viability of stock through pollution and disease	2	10		
18. Impact on biological and genetic diversity	2	10		

Criteria for Economic impacts	Raw score	Score	Weight %
Size of economic or public sectors affected	Very small – Very large 0 1 2 3	2	60
Degree of impact (cost, output changes etc.)	Minimum – Severe 0 1 2 3	3	10
Frequency/Duration	Occasion/Short – Continuous 0 1 2 3	3	30
Weight average score for Economic impacts		**2.4**	
Criteria for Health impacts	**Raw score**	**Score**	**Weight %**
Number of people affected	Very small – Very large 0 1 2 3	2	55
Degree of severity	Minimum – Severe 0 1 2 3	2	30
Frequency/Duration	Occasion/Short – Continuous 0 1 2 3	3	15
Weight average score for Health impacts		**2.2**	
Criteria for Other social and community impacts	**Raw score**	**Score**	**Weight %**
Number and/or size of community affected	Very small – Very large 0 1 2 3	2	40
Degree of severity	Minimum – Severe 0 1 2 3	2	50
Frequency/Duration	Occasion/Short – Continuous 0 1 2 3	3	10
Weight average score for Other social and community impacts		**2.1**	

V: Global change

Environmental issues	Score	Weight %	Environmental concern	Weight averaged score
19. Changes in the hydrological cycle	1	50	Global change	0.7
20. Sea level change	1	20		
21. Increased UV-B radiation as a result of ozone depletion	0	20		
22. Changes in ocean CO_2 source/sink function	0	10		

Criteria for Economic impacts	Raw score	Score	Weight %
Size of economic or public sectors affected	Very small – Very large 0 1 2 3	1	30
Degree of impact (cost, output changes etc.)	Minimum – Severe 0 1 2 3	2	50
Frequency/Duration	Occasion/Short – Continuous 0 1 2 3	0	20
Weight average score for Economic impacts		**1.3**	
Criteria for Health impacts	**Raw score**	**Score**	**Weight %**
Number of people affected	Very small – Very large 0 1 2 3	1	40
Degree of severity	Minimum – Severe 0 1 2 3	2	50
Frequency/Duration	Occasion/Short – Continuous 0 1 2 3	0	10
Weight average score for Health impacts		**1.4**	
Criteria for Other social and community impacts	**Raw score**	**Score**	**Weight %**
Number and/or size of community affected	Very small – Very large 0 1 2 3	1	50
Degree of severity	Minimum – Severe 0 1 2 3	1	45
Frequency/Duration	Occasion/Short – Continuous 0 1 2 3	1	5
Weight average score for Other social and community impacts		**1.0**	

Comparative environmental and socio-economic impacts of each GIWA concern

Concern	Types of impacts: Environmental score		Economic score		Human health score		Social and community score		Overall score
	Present (a)	Future (b)	Present (c)	Future (d)	Present (e)	Future (f)	Present (g)	Future (h)	
Freshwater shortage	1.7	3	0.1	1	0.6	0	1.0	1	**1.1**
Pollution	2.6	3	2.0	2	2.0	1	2.0	1	**2.0**
Habitat and community modification	2.5	3	1.1	0	1.2	0	1.0	1	**1.2**
Unsustainable exploitation of fish and other living resources	2.6	2	2.4	1	2.2	1	2.1	1	**1.8**
Global change	0.7	2	1.3	2	1.4	1	1.0	1	**1.3**

If the results in this table were not giving a clear prioritisation, the scores were weighted by assigning different relative importance to present/future and environmental/socio-economic impacts in the following way:

Weight averaged environmental and socio-economic impacts of each GIWA concern

Present (%) (i)	Future (%) (j)	Total (%)
50	50	100

Environmental (k)	Economic (l)	Health (m)	Other social and community impacts (n)	Total (%)
40	20	20	20	100

Concern	Types of impacts: Time weight averaged Environmental score (o)	Time weight averaged Economic score (p)	Time weight averaged Human health score (q)	Time weight averaged Social and community score (r)	Time weight averaged overall score	Rank
	(a)x(i)+(b)x(j)	(c)x(i)+(d)x(j)	(e)x(i)+(f)x(j)	(g)x(i)+(h)x(j)	(o)x(k)+(p)x(l)+(q)x(m)+(r)x(n)	
Freshwater shortage	2.4	0.6	0.3	0.5	**1.3**	**5**
Pollution	2.8	2.0	1.5	1.5	**2.1**	**1**
Habitat and community modification	2.8	0.6	0.6	1.0	**1.5**	**3**
Unsustainable exploitation of fish and other living resources	2.3	1.7	1.6	2.1	**1.9**	**2**
Global change	1.4	1.7	1.2	1.0	**1.3**	**4**

Annex II
Detailed scoring tables: Lake Tanganyika

I: Freshwater shortage

Environmental issues	Score	Weight %	Environmental concern	Weight averaged score
1. Modification of stream flow	1	50	Freshwater shortage	1.0
2. Pollution of existing supplies	1	50		
3. Changes in the water table	0	0		

Criteria for Economic impacts	Raw score	Score	Weight %
Size of economic or public sectors affected	Very small 0 1 2 3 Very large	0	30
Degree of impact (cost, output changes etc.)	Minimum 0 1 2 3 Severe	0	60
Frequency/Duration	Occasion/Short 0 1 2 3 Continuous	2	10
Weight average score for Economic impacts		**0.2**	
Criteria for Health impacts	**Raw score**	**Score**	**Weight %**
Number of people affected	Very small 0 1 2 3 Very large	0	40
Degree of severity	Minimum 0 1 2 3 Severe	0	50
Frequency/Duration	Occasion/Short 0 1 2 3 Continuous	2	10
Weight average score for Health impacts		**0.2**	
Criteria for Other social and community impacts	**Raw score**	**Score**	**Weight %**
Number and/or size of community affected	Very small 0 1 2 3 Very large	0	35
Degree of severity	Minimum 0 1 2 3 Severe	0	45
Frequency/Duration	Occasion/Short 0 1 2 3 Continuous	2	20
Weight average score for Other social and community impacts		**0.2**	

II: Pollution

Environmental issues	Score	Weight %	Environmental concern	Weight averaged score
4. Microbiological	1	10	Pollution	2.4
5. Eutrophication	1	20		
6. Chemical	2	20		
7. Suspended solids	3	40		
8. Solid wastes	0	5		
9. Thermal	0	0		
10. Radionuclide	0	0		
11. Spills	1	5		

Criteria for Economic impacts	Raw score	Score	Weight %
Size of economic or public sectors affected	Very small 0 1 2 3 Very large	1	30
Degree of impact (cost, output changes etc.)	Minimum 0 1 2 3 Severe	1	50
Frequency/Duration	Occasion/Short 0 1 2 3 Continuous	3	20
Weight average score for Economic impacts		**1.4**	
Criteria for Health impacts	**Raw score**	**Score**	**Weight %**
Number of people affected	Very small 0 1 2 3 Very large	1	40
Degree of severity	Minimum 0 1 2 3 Severe	1	50
Frequency/Duration	Occasion/Short 0 1 2 3 Continuous	1	10
Weight average score for Health impacts		**1.0**	
Criteria for Other social and community impacts	**Raw score**	**Score**	**Weight %**
Number and/or size of community affected	Very small 0 1 2 3 Very large	2	30
Degree of severity	Minimum 0 1 2 3 Severe	1	50
Frequency/Duration	Occasion/Short 0 1 2 3 Continuous	1	20
Weight average score for Other social and community impacts		**1.3**	

III: Habitat and community modification

Environmental issues	Score	Weight %	Environmental concern	Weight averaged score
12. Loss of ecosystems	2	50	Habitat and community modification	2.0
13.Modification of ecosystems or ecotones, including community structure and/or species composition	2	50		

Criteria for Economic impacts	Raw score	Score	Weight %
Size of economic or public sectors affected	Very small – Very large (0 1 2 3)	2	40
Degree of impact (cost, output changes etc.)	Minimum – Severe (0 1 2 3)	3	50
Frequency/Duration	Occasion/Short – Continuous (0 1 2 3)	3	10
Weight average score for Economic impacts		**2.6**	
Criteria for Health impacts	**Raw score**	**Score**	**Weight %**
Number of people affected	Very small – Very large (0 1 2 3)	1	55
Degree of severity	Minimum – Severe (0 1 2 3)	1	35
Frequency/Duration	Occasion/Short – Continuous (0 1 2 3)	0	10
Weight average score for Health impacts		**0.9**	
Criteria for Other social and community impacts	**Raw score**	**Score**	**Weight %**
Number and/or size of community affected	Very small – Very large (0 1 2 3)	3	40
Degree of severity	Minimum – Severe (0 1 2 3)	1	50
Frequency/Duration	Occasion/Short – Continuous (0 1 2 3)	3	10
Weight average score for Other social and community impacts		**2.0**	

IV: Unsustainable exploitation of fish

Environmental issues	Score	Weight %	Environmental concern	Weight averaged score
14. Overexploitation	3	40	Unsustainable exploitation of fish	2.1
15. Excessive by-catch and discards	0	5		
16. Destructive fishing practices	2	40		
17. Decreased viability of stock through pollution and disease	0	5		
18. Impact on biological and genetic diversity	1	10		

Criteria for Economic impacts	Raw score	Score	Weight %
Size of economic or public sectors affected	Very small – Very large (0 1 2 3)	3	60
Degree of impact (cost, output changes etc.)	Minimum – Severe (0 1 2 3)	2	10
Frequency/Duration	Occasion/Short – Continuous (0 1 2 3)	3	30
Weight average score for Economic impacts		**2.9**	
Criteria for Health impacts	**Raw score**	**Score**	**Weight %**
Number of people affected	Very small – Very large (0 1 2 3)	1	55
Degree of severity	Minimum – Severe (0 1 2 3)	1	30
Frequency/Duration	Occasion/Short – Continuous (0 1 2 3)	3	15
Weight average score for Health impacts		**1.3**	
Criteria for Other social and community impacts	**Raw score**	**Score**	**Weight %**
Number and/or size of community affected	Very small – Very large (0 1 2 3)	3	40
Degree of severity	Minimum – Severe (0 1 2 3)	2	50
Frequency/Duration	Occasion/Short – Continuous (0 1 2 3)	3	10
Weight average score for Other social and community impacts		**2.5**	

V: Global change

Environmental issues	Score	Weight %	Environmental concern	Weight averaged score
19. Changes in the hydrological cycle	1	45	Global change	1
20. Sea level change	1	45		
21. Increase UV-B radiation as a result of ozone depletion	0	0		
22. Changes in ocean CO_2 source/sink function	0	10		

Criteria for Economic impacts	Raw score	Score	Weight %
Size of economic or public sectors affected	Very small – Very large 0 1 2 3	1	30
Degree of impact (cost, output changes etc.)	Minimum – Severe 0 1 2 3	2	50
Frequency/Duration	Occasion/Short – Continuous 0 1 2 3	0	20
Weight average score for Economic impacts		**1.3**	
Criteria for Health impacts	**Raw score**	**Score**	**Weight %**
Number of people affected	Very small – Very large 0 1 2 3	1	40
Degree of severity	Minimum – Severe 0 1 2 3	1	50
Frequency/Duration	Occasion/Short – Continuous 0 1 2 3	1	10
Weight average score for Health impacts		**1.0**	
Criteria for Other social and community impacts	**Raw score**	**Score**	**Weight %**
Number and/or size of community affected	Very small – Very large 0 1 2 3	1	50
Degree of severity	Minimum – Severe 0 1 2 3	1	45
Frequency/Duration	Occasion/Short – Continuous 0 1 2 3	1	5
Weight average score for Other social and community impacts		**1.0**	

Comparative environmental and socio-economic impacts of each GIWA concern

Concern	Types of impacts								Overall score
	Environmental score		Economic score		Human health score		Social and community score		
	Present (a)	Future (b)	Present (c)	Future (d)	Present (e)	Future (f)	Present (g)	Future (h)	
Freshwater shortage	1.0	2	0.2	1	0.2	1	0.2	1	**0.8**
Pollution	2.4	3	1.4	2	1.0	2	1.3	3	**2.0**
Habitat and community modification	2.0	3	2.6	3	0.9	2	2.0	3	**2.3**
Unsustainable exploitation of fish and other living resources	2.1	3	2.9	3	1.3	2	2.5	3	**2.5**
Global change	0.9	2	1.3	2	1.0	2	1.0	2	**1.5**

If the results in this table were not giving a clear prioritisation, the scores were weighted by assigning different relative importance to present/future and environmental/socio-economic impacts in the following way:

Weight averaged environmental and socio-economic impacts of each GIWA concern

Present (%) (i)	Future (%) (j)	Total (%)
50	50	100

Environmental (k)	Economic (l)	Health (m)	Other social and community impacts (n)	Total (%)
40	20	20	20	100

Concern	Types of impacts					Rank
	Time weight averaged Environmental score (o)	Time weight averaged Economic score (p)	Time weight averaged Human health score (q)	Time weight averaged Social and community score (r)	Time weight averaged overall score	
	(a)x(i)+(b)x(j)	(c)x(i)+(d)x(j)	(e)x(i)+(f)x(j)	(g)x(i)+(h)x(j)	(o)x(k)+(p)x(l)+(q)x(m)+(r)x(n)	
Freshwater shortage	1.5	0.6	0.6	0.6	**1.0**	**5**
Pollution	2.7	1.7	1.5	2.2	**2.2**	**3**
Habitat and community modification	2.5	2.8	1.5	2.5	**2.4**	**1**
Unsustainable exploitation of fish and other living resources	2.6	3.0	1.7	2.8	**2.5**	**2**
Global change	1.5	1.7	1.5	1.5	**1.5**	**4**

Annex II
Detailed scoring tables: Lake Malawi

I: Freshwater shortage

Environmental issues	Score	Weight %	Environmental concern	Weight averaged score
1. Modification of stream flow	2	80	Freshwater shortage	2.0
2. Pollution of existing supplies	2	20		
3. Changes in the water table	0	0		

Criteria for Economic impacts	Raw score	Score	Weight %
Size of economic or public sectors affected	Very small – Very large (0 1 2 3)	1	30
Degree of impact (cost, output changes etc.)	Minimum – Severe (0 1 2 3)	1	60
Frequency/Duration	Occasion/Short – Continuous (0 1 2 3)	2	10
Weight average score for Economic impacts		**1.1**	
Criteria for Health impacts	**Raw score**	**Score**	**Weight %**
Number of people affected	Very small – Very large (0 1 2 3)	2	40
Degree of severity	Minimum – Severe (0 1 2 3)	2	50
Frequency/Duration	Occasion/Short – Continuous (0 1 2 3)	2	10
Weight average score for Health impacts		**2.0**	
Criteria for Other social and community impacts	**Raw score**	**Score**	**Weight %**
Number and/or size of community affected	Very small – Very large (0 1 2 3)	1	35
Degree of severity	Minimum – Severe (0 1 2 3)	0	45
Frequency/Duration	Occasion/Short – Continuous (0 1 2 3)	2	20
Weight average score for Other social and community impacts		**0.8**	

II: Pollution

Environmental issues	Score	Weight %	Environmental concern	Weight averaged score
4. Microbiological	2	20	Pollution	2
5. Eutrophication	2	20		
6. Chemical	1	20		
7. Suspended solids	3	30		
8. Solid wastes	0	5		
9. Thermal	0	0		
10. Radionuclide	0	0		
11. Spills	1	5		

Criteria for Economic impacts	Raw score	Score	Weight %
Size of economic or public sectors affected	Very small – Very large (0 1 2 3)	1	30
Degree of impact (cost, output changes etc.)	Minimum – Severe (0 1 2 3)	1	50
Frequency/Duration	Occasion/Short – Continuous (0 1 2 3)	2	20
Weight average score for Economic impacts		**1.2**	
Criteria for Health impacts	**Raw score**	**Score**	**Weight %**
Number of people affected	Very small – Very large (0 1 2 3)	1	40
Degree of severity	Minimum – Severe (0 1 2 3)	0	50
Frequency/Duration	Occasion/Short – Continuous (0 1 2 3)	2	10
Weight average score for Health impacts		**0.6**	
Criteria for Other social and community impacts	**Raw score**	**Score**	**Weight %**
Number and/or size of community affected	Very small – Very large (0 1 2 3)	2	30
Degree of severity	Minimum – Severe (0 1 2 3)	2	50
Frequency/Duration	Occasion/Short – Continuous (0 1 2 3)	2	20
Weight average score for Other social and community impacts		**2.0**	

III: Habitat and community modification

Environmental issues	Score	Weight %	Environmental concern	Weight averaged score
12. Loss of ecosystems	2	50	Habitat and community modification	2.0
13.Modification of ecosystems or ecotones, including community structure and/or species composition	2	50		

Criteria for Economic impacts	Raw score	Score	Weight %
Size of economic or public sectors affected	Very small – Very large 0 1 2 3	1	40
Degree of impact (cost, output changes etc.)	Minimum – Severe 0 1 2 3	2	50
Frequency/Duration	Occasion/Short – Continuous 0 1 2 3	3	10
Weight average score for Economic impacts		**1.7**	
Criteria for Health impacts	**Raw score**	**Score**	**Weight %**
Number of people affected	Very small – Very large 0 1 2 3	3	55
Degree of severity	Minimum – Severe 0 1 2 3	1	35
Frequency/Duration	Occasion/Short – Continuous 0 1 2 3	3	10
Weight average score for Health impacts		**2.3**	
Criteria for Other social and community impacts	**Raw score**	**Score**	**Weight %**
Number and/or size of community affected	Very small – Very large 0 1 2 3	3	40
Degree of severity	Minimum – Severe 0 1 2 3	2	50
Frequency/Duration	Occasion/Short – Continuous 0 1 2 3	3	10
Weight average score for Other social and community impacts		**2.5**	

IV: Unsustainable exploitation of fish

Environmental issues	Score	Weight %	Environmental concern	Weight averaged score
14. Overexploitation	3	60	Unsustainable exploitation of fish	2.6
15. Excessive by-catch and discards	0	0		
16. Destructive fishing practices	2	40		
17. Decreased viability of stock through pollution and disease	0	0		
18. Impact on biological and genetic diversity	1	0		

Criteria for Economic impacts	Raw score	Score	Weight %
Size of economic or public sectors affected	Very small – Very large 0 1 2 3	1	60
Degree of impact (cost, output changes etc.)	Minimum – Severe 0 1 2 3	2	10
Frequency/Duration	Occasion/Short – Continuous 0 1 2 3	3	30
Weight average score for Economic impacts		**1.7**	
Criteria for Health impacts	**Raw score**	**Score**	**Weight %**
Number of people affected	Very small – Very large 0 1 2 3	2	55
Degree of severity	Minimum – Severe 0 1 2 3	1	30
Frequency/Duration	Occasion/Short – Continuous 0 1 2 3	1	15
Weight average score for Health impacts		**1.6**	
Criteria for Other social and community impacts	**Raw score**	**Score**	**Weight %**
Number and/or size of community affected	Very small – Very large 0 1 2 3	3	40
Degree of severity	Minimum – Severe 0 1 2 3	1	50
Frequency/Duration	Occasion/Short – Continuous 0 1 2 3	3	10
Weight average score for Other social and community impacts		**2.0**	

V: Global change

Environmental issues	Score	Weight %	Environmental concern	Weight averaged score
19. Changes in the hydrological cycle	1	50	Global Change	1.0
20. Sea level change	1	50		
21. Increased UV-B radiation as a result of ozone depletion	0	0		
22. Changes in ocean CO_2 source/sink function	0	0		

Criteria for Economic impacts	Raw score	Score	Weight %
Size of economic or public sectors affected	Very small — Very large 0 1 2 3	3	30
Degree of impact (cost, output changes etc.)	Minimum — Severe 0 1 2 3	2	50
Frequency/Duration	Occasion/Short — Continuous 0 1 2 3	0	20
Weight average score for Economic impacts		**1.9**	
Criteria for Health impacts	**Raw score**	**Score**	**Weight %**
Number of people affected	Very small — Very large 0 1 2 3	2	40
Degree of severity	Minimum — Severe 0 1 2 3	1	50
Frequency/Duration	Occasion/Short — Continuous 0 1 2 3	0	10
Weight average score for Health impacts		**1.3**	
Criteria for Other social and community impacts	**Raw score**	**Score**	**Weight %**
Number and/or size of community affected	Very small — Very large 0 1 2 3	1	50
Degree of severity	Minimum — Severe 0 1 2 3	2	45
Frequency/Duration	Occasion/Short — Continuous 0 1 2 3	0	5
Weight average score for Other social and community impacts		**1.4**	

Comparative environmental and socio-economic impacts of each GIWA concern

Concern	Types of impacts								Overall score
	Environmental score		Economic score		Human health score		Social and community score		
	Present (a)	Future (b)	Present (c)	Future (d)	Present (e)	Future (f)	Present (g)	Future (h)	
Freshwater shortage	2.0	2	1.1	2	2.0	2	0.8	2	**1.7**
Pollution	2.0	3	1.2	2	0.6	2	2.0	2	**1.9**
Habitat and community modification	2.0	3	1.7	2	2.3	3	2.5	3	**2.4**
Unsustainable exploitation of fish and other living resources	2.6	3	1.7	3	1.6	3	2.0	2	**2.4**
Global change	1.0	2	1.9	1	1.3	1	1.4	1	**1.3**

If the results in this table were not giving a clear prioritisation, the scores were weighted by assigning different relative importance to present/future and environmental/socio-economic impacts in the following way:

Weight averaged environmental and socio-economic impacts of each GIWA concern

Present (%) (i)	Future (%) (j)	Total (%)
50	50	100

Environmental (k)	Economic (l)	Health (m)	Other social and community impacts (n))	Total (%)
40	20	20	20	100

Concern	Types of impacts					Rank
	Time weight averaged Environmental score (o)	Time weight averaged Economic score (p)	Time weight averaged Human health score (q)	Time weight averaged Social and community score (r)	Time weight averaged overall score	
	(a)x(i)+(b)x(j)	(c)x(i)+(d)x(j)	(e)x(i)+(f)x(j)	(g)x(i)+(h)x(j)	(o)x(k)+(p)x(l)+(q)x(m)+(r)x(n)	
Freshwater shortage	.20	1.6	2.0	1.4	**1.8**	**4**
Pollution	2.5	1.6	1.3	2.0	**2.0**	**3**
Habitat and community modification	2.5	1.9	2.7	2.8	**2.5**	**2**
Unsustainable exploitation of fish and other living resources	2.8	2.4	2.3	2.0	**2.5**	**1**
Global change	1.5	1.5	1.2	1.2	**1.4**	**5**

Annex III
Causal chain analysis – Outline of the process

Unsustainable exploitation of fish and other living resources: Issue 1 – Overfishing			
Questions asked	**Hypotheses**	**Assumptions**	**Evidence**
Why is there increased effort?	There are increasing numbers of fishermen. There are increased number of nets per fisherman.	Poverty is driving more people to the fishing industry. Agriculture has failed, so more people are turning to fishing. More people are involved in fishing as a result of increased urban settlements along the Lakeshore. Fishing methods requiring more nets are used as a result of declining fish catch per net.	Fishermen are normally hired or employed and will change fishing grounds depending on the catches (Katunzi 1996). People with few options for employment were drawn to a lucrative industry (Cohen et al. 1996). The heaviest populations (both urban and rural) are concentrated within a short distance of the Lake (Bootsma & Hecky 1993). “Multiple hanging” of nets emerged in late 1994 (Gibbon 1997, Kulindwa 2001).
	Increasing efforts by fishermen (e.g. increased gear and greed).	Increased fishing is not driven by greed. Increased fishing is not driven by increased access to gear.	
	The government is deliberately trying to increase the number of fishermen.	The government is encouraging fishing among local populations for economic returns and food security.	
	Price of fish has been increasing.	The price of fish per unit effort has increased over the last few years.	
	There is increased demand for fisheries export (regionally and internationally).	The demand for fish is not offset by increasing fish landings from other inland lakes.	
	There is more demand for inland fish than marine fish.	For socio-cultural reasons the regional population insist on inland fish.	
	There is no alternative cheap source of protein.	Animal and plant protein costs more than fish protein. There is increasing lack of land for subsistence farming due to increasing population.	Fish is the least expensive form of animal protein available. Fish comprises over 50% of the animal protein consumed in the intralacustrine region of eastern Africa (Hecky & Bugenyi 1992).
	There are reduced taxes and subsidies in the fishing industry.	More people are able to purchase fishing gear etc. at reduced cost.	
	There are credits/support available to fishermen.	More people are turning to fisheries as a result.	
	Current fishing efforts are still way below the maximum sustainable yield.	The maximum sustainable yield is known.	The resource base (MSY) still needs to be identified (Katunzi 1996). Lack of information on the size of the Nile perch stock has strongly limited the planning and development of the fishery (Katunzi 1996). The average size of fish caught in the gill-net fishery has decreased over the years (Katunzi 1996).
How is technological change contributing to overfishing?	Reduced taxes and subsidies on nets have enabled more fishermen to purchase nets, leading to higher catch per unit effort. Beach seining as a large scale technique of fishing for the market provides opportunities for employment but also destroys the habitat, enhances indiscriminate harvesting of fish (juvenile and adults) etc.	Proper net sizes are used to catch the target fish. Proper net size not used. The number of fishermen has not increased significantly.	Gill-nets and beach seines are still in use (Katunzi 1996). The use of hooks is encouraged since the required investment is low and the gear is highly selective, but still only few fishermen use them (Katunzi 1996). Beach seines are still in use though they are officially banned. (Mbuga et al. 1998, Kulindwa 2001).
	Processing industries have increased in number.	There is a higher demand for fish as the capacity for processing fish has increased.	There has been rapid expansion of the fish processing factories on the Tanzania side of the Lake (Katunzi 1996).
	Processing industries are geared to export markets.	Demand for fish in the world market is high and increasing. There is more demand for fish as a result.	The transformation of the Victoria from a locally based fishery to a commercial fishery has been the result of the strong demand from the global markets (Abila & Jansen 1997).
	Trawling has increased to meet demand for fish.	No fish quotas are in place.	Use of trawlers expanded greatly during the 1970s with the original targets being abundant benthic haplochromine cichlids (Cohen et al. 1996). With the collapse of the indigenous fauna in Lake Victoria (Barel et al. 1991), a new open-lake trawl fishery developed for the Nile perch with heavy foreign subsidy (Cohen et al. 1996).
	Improvements have been made in fish storage and transport.	Capacity for storage and transport has increased.	
	There is lack of fish storage facilities at fish landing sites.	Fresh fish tends to spoil if not taken immediately to processing factories or markets.	Fishermen are exploited by middlemen who buy at throw-away prices, forcing the fishermen to intensify their fishing. *Rastrineobola argentia* (80%) is sold dry after sun-drying on the beaches (Katunzi 1996).
	There is improper use of technology (e.g. nets) leading to overfishing.	Fine mesh sizes are used.	Nets are produced for various industries, e.g. horticultural industry where fine mesh nets are used to guard against birds. These are now being used in the fishing industry.
	There are no refrigeration facilities and infrastructure for fish transport at the coast.	There is more reliance on inland fisheries on a regional scale.	

Unsustainable exploitation of fish and other living resources: Issue 2 – Destructive fishing practices			
Questions asked	**Hypotheses**	**Assumptions**	**Evidence**
Why is there increased effort?	Recommended fishing gear is not used – smaller size nets are used to capture target fish.	There is a decline in catch per unit effort.	A progressive decrease in mesh size of gill nets (Nile perch) has been noted (Ligtvoet & Mkumbo, 1992), increasing the likelihood of overexploitation (Katunzi 1996). Evidence shows that the availability of all type of fish and particularly Nile Perch is declining (Kulindwa 2001). Beach seining catches a lot of juvenile fish and destroys breeding sites and eggs (Katunzi 1996).
	Higher demand for fish leads to a scramble for limited resources by increasing numbers of fishermen.	There exists high demand of Nile Perch in the regional and world market.	Export of Nile Perch increased over time from 1996 (Kulindwa & Mbelle 2002, Kulindwa, 2001, Abila, 2002).
	There are credits/support available to fishermen.	More people are turning to fisheries as a result.	
	Lack of adequate enforcement.		Gill-nets have had a devastating effect impact around river mouths during spawning migrations of potadromous fishes (Ogutu-Ohwayo 1990).
	Failure of agricultural production due to adverse weather conditions and inadequate markets for cotton, coffee etc.	Lack of alternative livelihoods.	The change of occupation coincided with the decline of cotton and coffee price declines (Kulindwa 2001) and decline in food production due to bad weather conditions (Abila 2002).
Why is rent-seeking behaviour prominent?	There are windfall profits for those dealing with the export market.	Profit maximisation is a major motivating force. More commercial fishermen are setting up in the region. Lack of regulation, enforcement and monitoring capacity. Dwindling fish stocks are leading to use of unconventional fishing methods to meet market demand.	Number of fish processing industries and trawlers has increased. With the collapse of the indigenous fauna in Lake Victoria (Barel et al. 1991), a new open-lake trawl fishery developed for the Nile perch with heavy foreign subsidy (Cohen et al 1996). Pesticides have been used to kill fish (leading to EU ban on fish from LVB). Illegal fishing practices such as the use of beach seine, poison or smuggling continue despite the efforts made by the government (Kulindwa 2001, Mbuga et al. 1998)
	There is lack of fishing quotas, or fishing quotas are not enforced.	Over fishing is occurring in main fishing grounds due to free access.	Fish exports increasing due to increased world market demand (Abila 2002) despite efforts to limit exports by limiting the number of cargo planes per week (Kulindwa 2001).
	There are no clear-cut property rights or entitlements.	There are scuffles in fishing grounds among fishermen competing for fishing territory.	In some areas, the large number of new fishing operations, particularly large-scale operations, has undermined traditional paths of authority which governed fishing rights (Yongo 1991). Fishing camps by processing plants create havoc between the company fishermen and small-scale fishermen (Kulindwa 2001)
	There are no legal or institutional arrangements between governments and resource users.		The existing fisheries regulation regarding mesh sizes needs revision because they are outdated and are no longer binding (Katunzi 1996).
	Political patronage and corruption protects commercial fishermen when they flout regulations.	Regulations exist but are not being enforced.	Although trawling in bays, gulfs, and inlets at depths of 20m or less is prohibited, most of the trawling and beach seining operations are made in these places without permission (Katunzi 1996). Those assigned duties of enforcing regulations at the village level have been accused of accepting bribes (Bwathondi et al. 2001).
How does failure of monitoring and enforcement mechanisms contribute to destructive fishing practices?	Issuing of licences for fishing is not enforced. Inadequate monitoring and enforcement capacity results in destructive fishing practices.	Excess fishing licences results into excessive fishing effort. Use of small sized fishnets, beach seines, multiple hanging and poison exists.	Licences used for tax collection and fund raising (Owino 1999). Illegal fishing practices continue despite efforts by government to curb them (URT/JICA 2002, Kulindwa 2001, Abila 2002).
	Corruption is rampant.		
	There is no regional integration of institutions, laws and enforcement.		The proposal to ban beach seining in the Lake has met with partial success in Uganda and Kenya, but is yet to be implemented in Tanzania (Katunzi 1996).
	Lack of resources in government to police the Lake.		

Pollution: Issue 1 – Microbiological			
Questions asked	**Hypotheses**	**Assumptions**	**Evidence**
Why is there increased animal waste?	There are larger populations of livestock and wildlife in the catchment.	Increase in animal waste is directly proportional to increases in livestock and wildlife populations. Efforts to manage livestock waste are minimal and insignificant.	The dense rural human population of LVD (>100/km^2) (Cohen et al., 1996), is matched by an equally high cattle population (Bootsma & Hecky 1993).
Why is there enhanced municipal effluent discharge that contributes to microbiological pollution?	The number and size of urban settlements and agro-industries are growing.	Increase in municipal effluent discharge is directly proportional to increases in human population and industry.	Human population density in LVB is >100km^2 and rapidly growing (Cohen et al. 1996).
	Untreated municipal effluents are largely discharged directly into the Lake.	There is no provision made to manage the existing and increasing effluents. Current effluent treatment technologies are outdated or non-functioning.	The highest population concentrations (both urban and rural) are within a short distance of the Lake (Bootsma & Hecky 1993). Except for Mwanza Tanneries, all the industries in Mwanza discharged their raw effluent into the Lake (Kishimba & Amkenda 1995).
	Rules and regulations for managing effluent from industry are not adhered to.	There is no enforcement of rules and regulations.	

How do runoff and stormwater contribute to microbiological pollution?	Land clearance for agriculture and settlements has led to increased run-off and stormwater.	There has not been a significant change in rainfall patterns and amount. There is increased erosion due to lack of soil conservation measures.	The highest population concentrations (both urban and rural) are within a short distance of the Lake (Bootsma & Hecky 1993). Rapid population growth has resulted in rapid conversion of forest and savannah woodland habitats to agricultural and range land (Cohen et al. 1996). Terracing is practiced by only about 25% of farmers in western Kenya today and this is probably a maximum for the region (Cohen et al. 1996).
	Poor urban planning has enhanced runoff and stormwater.	There has not been a significant change in rainfall patterns and amount.	The highest population concentrations (both urban and rural) are within a short distance of the Lake (Bootsma & Hecky 1993).
How does maritime waste contribute to microbiological pollution?	There are no regulations on over-board dumping of wastes.	There are a large number of craft that in total make a significant contribution to microbiological pollution in the Lake.	

Pollution: Issue 2 – Eutrophication			
Questions asked	**Hypotheses**	**Assumptions**	**Evidence**
Why is there enhanced effluent discharge?	The number and size of urban settlements and agro-industries are growing.	There is no provision made to manage the existing and increasing effluents. Current effluent treatment technologies are outdated or non- functioning.	The highest population concentrations (both urban and rural) are within a short distance of the Lake (Bootsma & Hecky 1993).
Why is there enhanced discharge of solids?	Land clearance for agriculture and settlements, poor waste disposal mechanisms or practices, and lack of soil conservation measures have led to increased discharge of solids.	There has not been a significant change in rainfall patterns and amount.	Rapid population growth has resulted in rapid conversion of forest and savannah woodland habitats to agricultural and range land (Cohen et al. 1996).
How do runoff and stormwater contribute to eutrophication?	Land clearance for agriculture and settlements has led to increased load of nutrient elements in run-off and stormwater.	There has not been a significant change in rainfall patterns and amount. There is increased erosion due to lack of soil conservation measures.	Rapid population growth has resulted in rapid conversion of forest and savannah woodland habitats to agricultural and range land (Cohen et al. 1996). The highest population concentrations (both urban and rural) are within a short distance of the Lake (Bootsma & Hecky 1993). The most densely populated (human and livestock) Lake margins are also areas where eutrophication problems are most serious (Cohen et al. 1996). Terracing is practiced by only about 25% of farmers in western Kenya today and this is probably a maximum for the region (Cohen et al. 1996).
	Poor urban planning has enhanced amounts of nutrient elements in runoff and stormwater.	There has not been a significant change in rainfall patterns and amount.	
	Widespread biomass burning has contributed to the total nutrient flux to the Lake.	Atmospheric dry and wet deposition is significant to the nutrient budget of the Lake.	The use of fuel wood among rural populations has accelerated deforestation and has enhanced nutrient load to the Lake (via particles carried by wind (Hecky & Bugenyi 1992, Bootsma & Hecky 1993, Cohen et al. 1996).

Pollution: Issue 3 – Chemical			
Questions asked	**Hypotheses**	**Assumptions**	**Evidence**
What has caused enhanced effluent discharge to the rivers and Lake?	Increase in industrial processing, mining, and use of agro-chemicals.	Inadequate or non-existent treatment of effluents prior to discharge in the rivers and Lake.	Manufacturing industries in Mwanza discharge their raw effluent direct into streams, rivers and into the Lake (Kishimba & Mkenda 1995). Kisumu effluent treatment facilities dysfunctional (actual observation) and effluent discharge from industrial areas flow into the Lake through black river (actual observation).
	Lack of monitoring and enforcement of regulations, hence non-compliance by industry.	Sufficient regulations exists which if adhered to would greatly minimise the chemical load in industrial and agro-chemical effluents.	
	Use of inadequate or outdated technologies.	Incentives exist for incorporation of clean technologies in industrial processes.	
Why is there enhanced discharge of solids?	Lack of regulations governing dumping of chemical waste	Solids are dumped close or into rivers and the Lake. Sufficient regulations exist and if adhered to would greatly minimise the chemical load in industrial and agro-chemical effluents.	Mining dumps.
How do runoff and stormwater contribute to chemical pollution?	Excessive use of agro-chemicals in agriculture.	There has not been a significant change in rainfall patterns and amount. There is increased erosion due to lack of soil conservation measures.	Terracing is practiced by only about 25% of farmers in western Kenya today and this is probably a maximum for the region (Cohen et al. 1996).
	Poor waste management leads to enhanced chemical load in stormwater drains.	There has not been a significant change in rainfall patterns and amount.	

Annex IV
List of important water-related programmes and assessments in the region

Programme	Aims / Objectives
East African Community Secretariat : Lake Victoria Development Programme (LVDP)	Puts emphasis on activities which lead to strengthening and consolidation of its role in promoting, coordinating and harmonising the various programmes and projects in the Lake Victoria Basin. The LVDP has already established and operationalised National Focal Points in the Partner States' Ministries, responsible for Lake Victoria development.
Lake Victoria Regional Authorities Cooperation (LVRLAC)	Socio-economic concerns.
Kenya Agricultural Research Institute (KARI)	Introduction of weevils from Australia, South Africa and Uganda to control water hyacinth.
Lake Victoria Environmental Management Programme (LVEMP)	Programme to monitor water quality, control water hyacinth, and manage fisheries, wetlands and land use
East African Communities Organisation for Management of Lake Victoria (ECOVIC)	Clean productive Lake with a healthy and productive community.
Urban Management Programme of the World Bank, in partnership with the Municipal Development Programme (MDP) of East and Southern Africa, and the Swedish International Development Agency (Sida)	Mobilising city/municipal governments along Lake Victoria to develop a programme on environmental management/improvement for poverty reduction in the lake region.
Lake Victoria Fisheries Organisation (LVFO)	Protect and restore the Lake: foster cooperation among the three East African countries on Lake issues, coordinate and harmonise national measures for the sustainable utilisation of the living resources of the Lake, develop and adopt conservation and management measures.
Lake Victoria Fisheries Research Project (LVFRP)	Status of fish stocks in the Lake, and socio-economics of the fisheries sector.
Lake Victoria Water Research Project (LVWRP)	Addressing issues of Lake water balances.
Kenya Marine Fisheries Research Institute (KMFRI)	
Tanzania Fisheries Research Institute (TAFIRI)	
Fisheries Research Institute of Uganda (FIRI)	
Kenya Medical Research Institute (KEMRI)	
Lake Basin Development Authority (LBDA)	
The Nile Perch Fishery Project, IUCN	
The Vulnerability Assessment of Lake Victoria basin to Environmental Change, UNEP-DEWA	
National Environment Action Plans (NEAP) for Kenya, Uganda and Tanzania	Regional cooperation to address problems such as water pollution, biodiversity loss, land degradation, deforestation, damage to wetlands.

Annex V
List of conventions and specific laws that affect water use in the region

East African Community Treaty

LVFO Convention

RAMSAR Convention

CITES Convention

Biological Diversity Convention of Agenda 21

Persistent Organic Pollutants (POPs) Convention

BASEL Convention

National Environmental Coordination Acts

National Fisheries Acts

National Water Acts

Nile Basin Treaty

SADC Protocols on Fisheries, Shared Watercourse Systems, Mining, Wildlife Conservation, and Law Enforcement

Annex VI
Addendum: A Journalists Diary for a Lake Victoria Tour

Lake Victoria Basin: So Rich Yet So Poor

By Parsellelo Kantai

The East African, Magazine, Monday, January 14, 2002

The Lake Victoria Basin is, potentially, the richest region in East Africa. So why are its people so poor, its environment in such deep crisis? Special Correspondent PARSELELO KANTAI toured the region, looking for answers.

Of the 320 odd fish species native to Lake Victoria 40 years ago, only eight remain. Their disappearance from the lake has been described as "the greatest mass extinction of modem times.

Its problems begin in bulging middle-age. At its source near Londiani, the River Nyando bubbles with the clarity and rebelliousness of youth. But age quickly thickens and corrupts it; travel darkens it. The Nyando's winding course down the Rift Valley and into Lake Victoria is a grim study in waste mismanagement. Municipalities, farms - large and small, industries and markets - all empty their waste into the river, so that by the time it nears the lake, the Nyando shows none of the purity of its youth. It has, in fact, become the filthiest of all the rivers flowing into Lake Victoria. Old and drunk - a sampling of its
waters some time ago revealed they were actually alcoholic - the Nyando is a danger to itself and to all those that use it or dwell within it. At Ahero Bridge, some 20 kilometres from the lakeshore, it is impossible to see more than an inch or two into the murk.

The River Nyando is also an important spawning ground for some of the lake's native fish species. At the start of the mating season they swim upriver, their course determined by a remarkable sensitivity to the quality of water. Today, many of them are either endangered or extinct, unable or unwilling to breed in the Nyando's foul waters. *Synodontis victorianus*, Okoko in Dholuo: rare. *Barbus* spp., Adel: rare. The Eel, *Mastecebelus* spp.: extinct. Of the 320 odd fish species native to Lake Victoria 40 years ago, only eight remain. Their disappearance from the lake has been described as "the greatest mass extinction of modem times."

Many blame the introduction of the Nile Perch, that voracious carnivore, for the disappearance of the native fish species. "That's garbage," says Okoth Mireri, a chemist by training and an environmentalist by profession, working with Osienala (Dholuo for 'Friends of Lake Victoria'). "What destroyed those species? Our poor environmental practices, our agricultural practices that have resulted in chemicals entering the lake through the rivers; our land use patterns that have brought a lot of silt into the lake. The fish have disappeared because the water quality in the Winam Gulf and around the shoreline has changed. We have destroyed the sub-ecosystems of the shoreline where most of the fish, like Tilapia, would breed in the littoral zone. The riverine fish species are threatened because their breeding grounds are polluted."

The Nyando is one of 10 rivers that drain into Lake Victoria from the Kenya side. Another 10 feed the lake, four from Uganda and six from Tanzania. The Nyando is a dirty mirror image of them all. They may not be as polluted, but they all suffer, in varying degrees, from the same disease: untreated sewage from municipalities and rural towns, toxic effluent from industries and, above all else, sediment - the biggest contributor of pollution in the lake basin.

"The sheer magnitude of soil and land degradation is phenomenal," says Markus Walsh, an ecologist researching land degradation in the lake basin. "This sort of destruction is, I think, unparalleled in Africa."

The state of the Nvando illustrates a widelvheld view: of the three East African countries that share this resource, Kenya's impact on the lake's ecological health is by tar the most severe, "All the East African countries contribute to the pollution of the lake basin in general and Lake Victoria in particular," says Tom Anyonge of SIDA, the Swedish development agency which funds much of the research into the environmental problems of the lake basin. "75 per cent of the lake's recharge comes from Kenya. Kenya is also the biggest polluter of the lake, and it is doing the least about it."

A 1998 SIDA-funded report. The Lake Victoria Basin Hot Spots Study, paints a terrifying picture of pollution from all sides of the lake basin: broke and broken-down municipalities - Kisumu's sewer treatment works, for instance, stopped functioning 10 years ago; largely unregulated, agro-industries dump untreated or partially treated effluent into rivers or directly into the lake; fertilisers, herbicides and pesticides all find their way into river systems and the lake.

On the banks of" the Nyando, at the junction of the new Kisii road and the main Nakuru -Kisumu road, Ahero town is alive with activity. The market centre, located close to the river and flush against the road, is crammed with hotels, lodgings and hundreds of hawkers selling anything from those noisy alarm clocks on offer along Nairobi's Uhuru Highway to vegetables, dried fish, fried and smoked fish, nyama choma and mitumba of all kinds. Music in three languages fills the market place, competing with shouted offers for clothes, shoes, trinkets and toys, and motor vehicle spare parts. Itinerant photographers hover. Two-man welding operations squeeze between the kiosks and hotels. quick-servicing the vehicles that ply the various Nyanza routes. Matatus enter the market, hooting like there's a medical emergency. Touts holler. Everybody's doing roaring, raucous business. The age of trinkets and second-hand clothes has arrived. Liberalisation and rural poverty are a heady mix.

Behind the market and across the road, on the banks of the river, are scenes of people living the sort of semi-rural existence that is repeated a thousand times throughout East Africa. Scores of mabati shanties interspersed with jua kali workshops; tiny shambas line the banks. The entire weight of Ahero's waste rolls down into River Nyando, transported by rainwash or dumped directly into the river.

In towns like these, whose existence is incidental to the larger aims of cross-country trade, the need to connect towns and cities located hundreds of kilometres apart by tarmac, the presence of a river is frequently disastrous. For all of its chequered upstream history of human activity and rural waste, the Nyando is also Ahero's only source of drinking water.

"This water is used directly for domestic consumption. That is the sad part of it. There is no sewage trealment at Ahero, no sewer works." explains Okoth Mireri, who is also our guide during our Nyanza tour. "The toilets of Ahero are the banks of the river. Everybody shits into the river."

For all of its problems, however, the Lake Victoria Basin also contains immense natural wealth. "The lake is this region's IMF and World Bank," says Okoth Mireri. "But only if we manage it correctly."

The lake sustains the largest freshwater fisheries in the world. In the 1990s, and, paradoxically, thanks to the introduction of the Nile Perch and the Nile Tilapia, total fish catches in Lake Victoria accounted for 25 per cent of all the fish caught in Africa's inland fisheries. In 1999 at the height of the EU fish ban and water hyacinth infestation, Kenyan fishermen still managed to catch and sell fish worth about Ksh 8 billion($100 million).

Water hyacinth

The lake's resource wealth is further increased by the fact that its soils are among the most fertile in East Africa. The varied and rich cultures of its peoples, its breathtaking scenery and abundant wildlife as well as the sheer vastness of the lake make it, potentially, a prime tourism destination. Factor in the region's capacity for industry, its potential for hydro-electricity, the gold and other mineral deposits in such places as Geita in Tanzania and Macalder in Kenya, and you are looking at, again potentially, the richest region in East Africa.

And yet the people of the lake basin are among the poorest in the world. On the Uganda side. 55 per cent of the population is classified as absolutely poor. In Kenya and Tanzania, official statistics suggest poverty levels of 42 per cent and 52 per cent respectively. Malnutrition is rife. Child mortality high, protein deficiency, in this richest of protein-rich zones, acute. Add to this the economic, social and environmental cost of HIV/Aids, whose incidence in the lake basin is, once again, among the highest in the world, and a grim picture begins to appear tragic.

Why?

There are clues, but no easy answers. The dreams for the lake basin's development were as grand as the area's size and potential; fisheries, sugar production, irrigation schemes for rice and cotton. In Kenya, however, where much of the early development look place, many of the dreams' monuments are either unfinished or rusting from disuse, giant jokes wilt painfully farcical punch-lines. A molasses plant that never look off; the new offices of the Lake Basin Development Authority, which cost a reported Ksh900 million ($11.25 million) but never got past the foundation stage; limping sugar factories, an empty cotton mill, disused fish-ponds; a rice-plantation scheme now filled with maize; an abandoned irrigation scheme at Yala Swamp. The road between Homa Bay and Mbita Point is officially tarmacked, the contractor paid, but it remains a dirt road, bone-shaking when it's dry, nearly impassable when it rains.

Waste in the lake basin is a two-lane highway: flowing down into the lake is the waste and pollution generated upstream. In the opposite direction, leaving the basin, flows the region's wealth. Few other places display such a lack of re-investment in the midst of such riches.

Take Mbita Point, for instance. Facing the open lake, with its back to the Winam Gulf, its waters are rich fishing grounds. So rich. in fact, that the brokers and agents of various, mostly foreign-owned fish processing companies, riding in fleets of two-Ion Isuzu trucks, make up to three round-trips a day from Mbita to Homa Ray, a 40 km, 90-minute trip over the barest excuse for a road.

On each departure, their trucks are laden with the lake's harvest, belching smoke and the fumes of dead fish. *Lates niloticus*, Nile Perch. At the beach landing sites on an especially desperate day, the fishermen will sell a kilo of Nile Perch for Ksh20 (25 US cents). On a good day, it may go for Ksh9O, just over $l. A mature Nile Perch weighs between 30 and 180 kg, the heaviest ever recorded. The brokers, who sell to the processors, claim to make a paltry five shillings on every kilo; "These are bad times. After fuel and maintenance, there's nothing left." said Ali, a broker we met at a fish banda in Mbita, supervising the weighing and lugging of a 52 kg Nile Perch into his van.

The Nile Perch has been a blessing and a curse. To paraphrase the findings of a study by International Union for Conservation of Nalure (IUCN), "Rich Fisheries, Poor Fisherfolk," over the past two decades its presence has dramatically increased the total fish harvest from Lake Victoria. It has commercialised fishing and created employment; it has also left itinerant fishermen at the mercy of wealthy industrial fish exporters, and is rapidly pushing local fish traders out of existence. Along the Mbita Causeway, fish mamas sell the dried skeletons of small, immature Nile Perch, or dried Tilapia from distant Lake Turkana. Of the huge tonnage caught from the waters off Mbila Point, this is what remains for local consumption. Small fry. The big fish have been loaded onto the trucks, headed for Nairobi, Mombasa, the export market.

"One problem we have here is the middleman. There is a lot of money going out but the fishermen remain poor." explains Malachi Magero, the finance manager of the Suba District Co-operative Union. "At times they will bid down to less than Ksh20 per kilo. They sell the fish at throwaway prices because they can't store it," Once processed into fillet, a kilo will go for Ksh475 (S5.9) in Nairobi's supermarkets, and at least twice that on the international market.

There is little evidence of re-investment in Mbita - or any of the fishing towns and villages on the Kenya side of the lake. In 1992, Kenyan fishermen caught 219,000 tonnes offish. At an average ofKsh50 ($0.6)per kilo, this translates to nearly Ksh11 billion ($137.5 million). Where did it all go?

Whatever money left behind in Mbita is quickly frittered away, drained down the urinals of the many bars and hotels, testimony to the fisherman's firm belief that there is always more where that came from. Drink today, for tomorrow we fish. It's a trend that extends across the lake basin, beyond borders.

"A fisherman is a hard person to tame," says Magero. "He doesn't understand the idea of saving. We tried to implement a credit system, whereby we buy their fish and pay them after three days, or they could be paid in Homa Bay through a bank. They rejected that. They want to be paid directly and immediately."

The money left over has, presumably, helped construct the many semi-permanent structures, the mabati shops, the kiosks, hotelis and bars that populate this one-street township, but there is little if any evidence of long-term prosperity here.

The region's challenges remain enormous. Waste and poverty make awful bedfellows, and in the lake basin, they have spawned a demon child - a debilitating culture of dependency.

"If you ask fishermen on the Kenya side of the lake, 'Who owns the fish?', they will tell you that it belongs to the government," says Mireri. Such attitudes indicate the extent to which many feel that they have lost out or lack a stake in managing their own resources. It doesn't help either, that with the many disasters that have stalked the region in the recent past, have also come armies of aid agencies and NGOs, doing little more than taking the place of Mama na Baba, the government.

The region needs a lot more than fresh injections of funding. "Ultimately, the lake basin's problems can only be solved by the people of the lake themselves," says Tom Anyonge. Uganda seems to have taken this sentiment to heart in its campaign to protect and boost the wetland ecologies that fringe the lake and serve as a crucial natural filter.

Launched in 1989, the key to the Uganda National Wetlands Programme's success has been community involvement, and specifically women, because, as one observer put it, "the government recognises that they are the guardians of water and fire in the community. They know best how to manage those resources."

The programme also offers a five-week course in wetland management, trains communities in making a range of products from sustainably-harvested wetland plants such as papyrus, rattan cane and hyacinth, and is in the process of quantifying the economic contribution of the wetlands' natural services.

Pollution must also be aggressively tackled at its source. Before Okoth Mireri and Osienala began preaching the virtues of waste treatment to the managers at Muhoroni Sugar Factory and its molasses-producing counterpart, Agrochemicals and Foods Ltd, the two were among the worst industrial polluters in the lake basin. Effluent released from Agrochemicals had a BOD (biological oxygen demand, a measure of its pollutants) of 95 000 milligrammes per litre. The World Health Organisation recommended level is 100.

The giant mollasses plant in Kisumu has never taken off.

Like many other factories, they had taken advantage of weak environmental laws and opted to pay ridiculously small fines rather than improving their treatment plants. Osienala was faced with the choice of either exposing them, eventually getting them closed down and leaving thousands of people unemployed, or working with them to steadily reduce their pollution-levels. They chose the latter.

Working with the District Development Committee, they managed to get the government to offer them some tax breaks. Eventually, and at a huge cost to both companies - Ksh300 million for Agrochemicals and Kshl20 million for Muhoroni ($3.75 million/$1.5 million) - the two installed new treatment works and are
gradually reducing the toxicity of their effluents.

All of these opportunities, bright spots flickering on the horizon, are fragile, easily extinguished. And they won't amount to much overall if the fundamental problem of the lake basin is not addressed: resource ownership. It is not for lack of laws - whether old or new - that fishermen poison fish, that industries flush their untreated waste down rivers, that municipal councils endanger the lives of their citizens by emptying raw sewage directly into the lake. These acts of irresponsibility are nurtured in an environment where entire communities have been disenfranchised and the extraction and exportation of wealth have become the dominant trends. Until these basic issues are addressed, the region's economic potential will be something we'll be talking about forever.

This article was first published in 'Ecoforum' magazine.

The Global International Waters Assessment

This report presents the results of the Global International Waters Assessment (GIWA) of the transboundary waters of the East African Rift Valley Lakes. This and the subsequent chapter offer a background that describes the impetus behind the establishment of GIWA, its objectives and how the GIWA was implemented.

The need for a global international waters assessment

Globally, people are becoming increasingly aware of the degradation of the world's water bodies. Disasters from floods and droughts, frequently reported in the media, are considered to be linked with ongoing global climate change (IPCC 2001), accidents involving large ships pollute public beaches and threaten marine life and almost every commercial fish stock is exploited beyond sustainable limits - it is estimated that the global stocks of large predatory fish have declined to less that 10% of pre-industrial fishing levels (Myers & Worm 2003). Further, more than 1 billion people worldwide lack access to safe drinking water and 2 billion people lack proper sanitation which causes approximately 4 billion cases of diarrhoea each year and results in the death of 2.2 million people, mostly children younger than five (WHO-UNICEF 2002). Moreover, freshwater and marine habitats are destroyed by infrastructure developments, dams, roads, ports and human settlements (Brinson & Malvárez 2002, Kennish 2002). As a consequence, there is growing public concern regarding the declining quality and quantity of the world's aquatic resources because of human activities, which has resulted in mounting pressure on governments and decision makers to institute new and innovative policies to manage those resources in a sustainable way ensuring their availability for future generations.

Adequately managing the world's aquatic resources for the benefit of all is, for a variety of reasons, a very complex task. The liquid state of the most of the world's water means that, without the construction of reservoirs, dams and canals it is free to flow wherever the laws of nature dictate. Water is, therefore, a vector transporting not only a wide variety of valuable resources but also problems from one area to another. The effluents emanating from environmentally destructive activities in upstream drainage areas are propagated downstream and can affect other areas considerable distances away. In the case of transboundary river basins, such as the Nile, Amazon and Niger, the impacts are transported across national borders and can be observed in the numerous countries situated within their catchments. In the case of large oceanic currents, the impacts can even be propagated between continents (AMAP 1998). Therefore, the inextricable linkages within and between both freshwater and marine environments dictates that management of aquatic resources ought to be implemented through a drainage basin approach.

In addition, there is growing appreciation of the incongruence between the transboundary nature of many aquatic resources and the traditional introspective nationally focused approaches to managing those resources. Water, unlike laws and management plans, does not respect national borders and, as a consequence, if future management of water and aquatic resources is to be successful, then a shift in focus towards international cooperation and intergovernmental agreements is required (UN 1972). Furthermore, the complexity of managing the world's water resources is exacerbated by the dependence of a great variety of domestic and industrial activities on those resources. As a consequence, cross-sectoral multidisciplinary approaches that integrate environmental, socio-economic and development aspects into management must be adopted. Unfortunately however, the scientific information or capacity within each discipline is often not available or is inadequately translated for use by managers, decision makers and policy developers. These inadequacies constitute a serious impediment to the implementation of urgently needed innovative policies.

Continual assessment of the prevailing and future threats to aquatic ecosystems and their implications for human populations is essential if governments and decision makers are going to be able to make strategic policy and management decisions that promote the sustainable use of those resources and respond to the growing concerns of the general public. Although many assessments of aquatic resources are being conducted by local, national, regional and international bodies, past assessments have often concentrated on specific themes, such as biodiversity or persistent toxic substances, or have focused only on marine or freshwaters. A globally coherent, drainage basin based assessment that embraces the inextricable links between transboundary freshwater and marine systems, and between environmental and societal issues, has never been conducted previously.

The Global Environment Facility (GEF)

The Global Environment Facility forges international co-operation and finances actions to address six critical threats to the global environment: biodiversity loss, climate change, degradation of international waters, ozone depletion, land degradation, and persistent organic pollutants (POPs).

The overall strategic thrust of GEF-funded international waters activities is to meet the incremental costs of: (a) assisting groups of countries to better understand the environmental concerns of their international waters and work collaboratively to address them; (b) building the capacity of existing institutions to utilise a more comprehensive approach for addressing transboundary water-related environmental concerns; and (c) implementing measures that address the priority transboundary environmental concerns. The goal is to assist countries to utilise the full range of technical, economic, financial, regulatory, and institutional measures needed to operationalise sustainable development strategies for international waters.

United Nations Environment Programme (UNEP)

United Nations Environment Programme, established in 1972, is the voice for the environment within the United Nations system. The mission of UNEP is to provide leadership and encourage partnership in caring for the environment by inspiring, informing, and enabling nations and peoples to improve their quality of life without compromising that of future generations.

UNEP work encompasses:

- Assessing global, regional and national environmental conditions and trends;
- Developing international and national environmental instruments;
- Strengthening institutions for the wise management of the environment;
- Facilitating the transfer of knowledge and technology for sustainable development;
- Encouraging new partnerships and mind-sets within civil society and the private sector.

University of Kalmar

University of Kalmar hosts the GIWA Co-ordination Office and provides scientific advice and administrative and technical assistance to GIWA. University of Kalmar is situated on the coast of the Baltic Sea. The city has a long tradition of higher education; teachers and marine officers have been educated in Kalmar since the middle of the 19th century. Today, natural science is a priority area which gives Kalmar a unique educational and research profile compared with other smaller universities in Sweden. Of particular relevance for GIWA is the established research in aquatic and environmental science. Issues linked to the concept of sustainable development are implemented by the research programme Natural Resources Management and Agenda 21 Research School.

Since its establishment GIWA has grown to become an integral part of University activities. The GIWA Co-ordination office and GIWA Core team are located at the Kalmarsund Laboratory, the university centre for water-related research. Senior scientists appointed by the University are actively involved in the GIWA peer-review and steering groups. As a result of the cooperation the University can offer courses and seminars related to GIWA objectives and international water issues.

International call for action

The need for a holistic assessment of transboundary waters in order to respond to growing public concerns and provide advice to governments and decision makers regarding the management of aquatic resources was recognised by several international bodies focusing on the global environment. In particular, the Global Environment Facility (GEF) observed that the International Waters (IW) component of the GEF suffered from the lack of a global assessment which made it difficult to prioritise international water projects, particularly considering the inadequate understanding of the nature and root causes of environmental problems. In 1996, at its fourth meeting in Nairobi, the GEF Scientific and Technical Advisory Panel (STAP), noted that: *"Lack of an International Waters Assessment comparable with that of the IPCC, the Global Biodiversity Assessment, and the Stratospheric Ozone Assessment, was a unique and serious impediment to the implementation of the International Waters Component of the GEF"*.

The urgent need for an assessment of the causes of environmental degradation was also highlighted at the UN Special Session on the Environment (UNGASS) in 1997, where commitments were made regarding the work of the UN Commission on Sustainable Development (UNCSD) on freshwater in 1998 and seas in 1999. Also in 1997, two international Declarations, the Potomac Declaration: Towards enhanced ocean security into the third millennium, and the Stockholm Statement on interaction of land activities, freshwater and enclosed seas, specifically emphasised the need for an investigation of the root causes of degradation of the transboundary aquatic environment and options for addressing them. These processes led to the development of the Global International Waters Assessment (GIWA) that would be implemented by the United Nations Environment Programme (UNEP) in conjunction with the University of Kalmar, Sweden, on behalf of the GEF. The GIWA was inaugurated in Kalmar in October 1999 by the Executive Director of UNEP, Dr. Klaus Töpfer, and the late Swedish Minister of the Environment, Kjell Larsson. On this occasion Dr. Töpfer stated: *"GIWA is the framework of UNEP´s global water assessment strategy and will enable us to record and report on critical water resources for the planet for consideration of sustainable development management practices as part of our responsibilities under Agenda 21 agreements of the Rio conference*".

The importance of the GIWA has been further underpinned by the UN Millennium Development Goals adopted by the UN General Assembly in 2000 and the Declaration from the World Summit on Sustainable

Development in 2002. The development goals aimed to halve the proportion of people without access to safe drinking water and basic sanitation by the year 2015 (United Nations Millennium Declaration 2000). The WSSD also calls for integrated management of land, water and living resources (WSSD 2002) and, by 2010, the Reykjavik Declaration on Responsible Fisheries in the Marine Ecosystem should be implemented by all countries that are party to the declaration (FAO 2001).

The conceptual framework and objectives

Considering the general decline in the condition of the world's aquatic resources and the internationally recognised need for a globally coherent assessment of transboundary waters, the primary objectives of the GIWA are:

- To provide a prioritising mechanism that allows the GEF to focus their resources so that they are used in the most cost effective manner to achieve significant environmental benefits, at national, regional and global levels; and
- To highlight areas in which governments can develop and implement strategic policies to reduce environmental degradation and improve the management of aquatic resources.

In order to meet these objectives and address some of the current inadequacies in international aquatic resources management, the GIWA has incorporated four essential elements into its design:

- A broad transboundary approach that generates a truly regional perspective through the incorporation of expertise and existing information from all nations in the region and the assessment of all factors that influence the aquatic resources of the region;
- A drainage basin approach integrating freshwater and marine systems;
- A multidisciplinary approach integrating environmental and socio-economic information and expertise; and
- A coherent assessment that enables global comparison of the results.

The GIWA builds on previous assessments implemented within the GEF International Waters portfolio but has developed and adopted a broader definition of transboundary waters to include factors that influence the quality and quantity of global aquatic resources. For example, due to globalisation and international trade, the market for penaeid shrimps has widened and the prices soared. This, in turn, has encouraged entrepreneurs in South East Asia to expand aquaculture resulting in the large-scale deforestation of mangroves for ponds (Primavera 1997). Within the GIWA, these "non-hydrological" factors constitute as large a transboundary influence as more traditionally recognised problems, such as the construction of dams that regulate the flow of water into a neighbouring country, and are considered equally important. In addition, the GIWA recognises the importance of hydrological units that would not normally be considered transboundary but exert a significant influence on transboundary waters, such as the Yangtze River in China which discharges into the East China Sea (Daoji & Daler 2004) and the Volga River in Russia which is largely responsible for the condition of the Caspian Sea (Barannik et al. 2004). Furthermore, the GIWA is a truly regional assessment that has incorporated data from a wide range of sources and included expert knowledge and information from a wide range of sectors and from each country in the region. Therefore, the transboundary concept adopted by the GIWA extends to include impacts caused by globalisation, international trade, demographic changes and technological advances and recognises the need for international cooperation to address them.

International waters and transboundary issues

The term "international waters", as used for the purposes of the GEF Operational Strategy, includes the oceans, large marine ecosystems, enclosed or semi-enclosed seas and estuaries, as well as rivers, lakes, groundwater systems, and wetlands with transboundary drainage basins or common borders. The water-related ecosystems associated with these waters are considered integral parts of the systems.

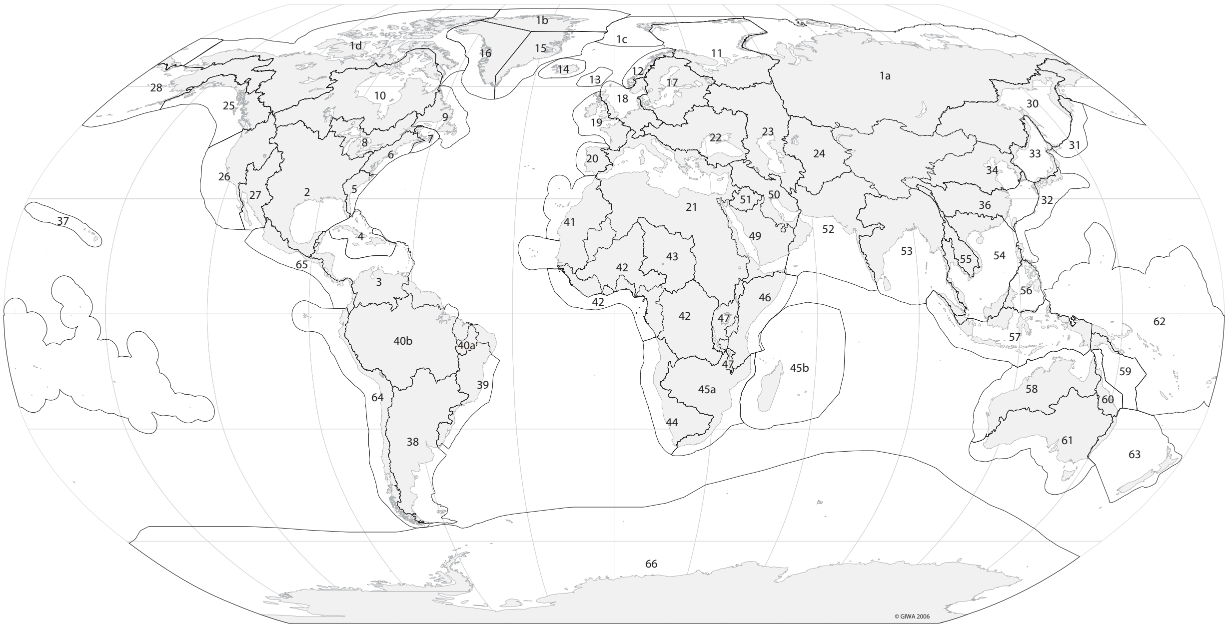
The term "transboundary issues" is used to describe the threats to the aquatic environment linked to globalisation, international trade, demographic changes and technological advancement, threats that are additional to those created through transboundary movement of water. Single country policies and actions are inadequate in order to cope with these challenges and this makes them transboundary in nature.

The international waters area includes numerous international conventions, treaties, and agreements. The architecture of marine agreements is especially complex, and a large number of bilateral and multilateral agreements exist for transboundary freshwater basins. Related conventions and agreements in other areas increase the complexity. These initiatives provide a new opportunity for cooperating nations to link many different programmes and instruments into regional comprehensive approaches to address international waters.

The organisational structure and implementation of the GIWA

The scale of the assessment

Initially, the scope of the GIWA was confined to transboundary waters in areas that included countries eligible to receive funds from the GEF. However, it was recognised that a truly global perspective would only be achieved if industrialised, GEF-ineligible regions of the world were also assessed. Financial resources to assess the GEF-eligible countries were obtained primarily from the GEF (68%), the Swedish International Development Cooperation Agency (Sida) (18%), and the Finnish Department for International Development Cooperation (FINNIDA)



1a Russian Arctic (4 LMEs)
1b Arctic Greenland (LME)
1c Arctic European/Atlantic
1d Arctic North American
2 Gulf of Mexico (LME)
3 Caribbean Sea (LME)
4 Caribbean Islands (LME)
5 Southeast Shelf (LME)
6 Northeast Shelf (LME)
7 Scotian Shelf (LME)
8 Gulf of St Lawrence
9 Newfoundland Shelf (LME)
10 Baffin Bay, Labrador Sea, Canadian Archipelago
11 Barents Sea (LME)
12 Norwegian Sea (LME)
13 Faroe plateau
14 Iceland Shelf (LME)
15 East Greenland Shelf (LME)
16 West Greenland Shelf (LME)
17 Baltic Sea (LME)
18 North Sea (LME)
19 Celtic-Biscay Shelf (LME)
20 Iberian Coastal Sea (LME)
21 North Africa and Nile River Basin (LME)
22 Black Sea (LME)
23 Caspian Sea
24 Aral Sea
25 Gulf of Alaska (LME)
26 California Current (LME)
27 Gulf of California (LME)
28 Bering Sea (LME)
30 Sea of Okhotsk (LME)
31 Oyashio Current (LME)
32 Kuroshio Current (LME)
33 Sea of Japan (LME)
34 Yellow Sea (LME)
36 East China Sea (LME)
37 Hawaiian Archipelago (LME)
38 Patagonian Shelf (LME)
39 Brazil Current (LME)
40a Northeast Brazil Shelf (2 LMEs)
40b Amazon
41 Canary Current (LME)
42 Guinea Current (LME)
43 Lake Chad
44 Benguela Current (LME)
45a Agulhas Current (LME)
45b Indian Ocean Islands
46 Somali Coastal Current (LME)
47 East African Rift Valley Lakes
49 Red Sea and Gulf of Aden (LME)
50 Euphrates and Tigris River Basin
51 Jordan
52 Arabian Sea (LME)
53 Bay of Bengal
54 South China Sea (2 LMEs)
55 Mekong River
56 Sulu-Celebes Sea (LME)
57 Indonesian Seas (LME)
58 North Australian Shelf (LME)
59 Coral Sea Basin
60 Great Barrier Reef (LME)
61 Great Australian Bight
62 Pacific Islands
63 Tasman Sea
64 Humboldt Current (LME)
65 Eastern Equatorial Pacific (LME)
66 Antarctic (LME)

Figure 1 The 66 transboundary regions assessed within the GIWA project.

(10%). Other contributions were made by Kalmar Municipality, the University of Kalmar and the Norwegian Government. The assessment of regions ineligible for GEF funds was conducted by various international and national organisations as in-kind contributions to the GIWA.

In order to be consistent with the transboundary nature of many of the world's aquatic resources and the focus of the GIWA, the geographical units being assessed have been designed according to the watersheds of discrete hydrographic systems rather than political borders (Figure 1). The geographic units of the assessment were determined during the preparatory phase of the project and resulted in the division of the world into 66 regions defined by the entire area of one or more catchments areas that drains into a single designated marine system. These marine systems often correspond to Large Marine Ecosystems (LMEs) (Sherman 1994, IOC 2002).

Considering the objectives of the GIWA and the elements incorporated into its design, a new methodology for the implementation of the assessment was developed during the initial phase of the project. The methodology focuses on five major environmental concerns which constitute the foundation of the GIWA assessment; Freshwater shortage, Pollution, Habitat and community modification, Overexploitation of fish and other living resources, and Global change. The GIWA methodology is outlined in the following chapter.

Large Marine Ecocsystems (LMEs)

Large Marine Ecosystems (LMEs) are regions of ocean space encompassing coastal areas from river basins and estuaries to the seaward boundaries of continental shelves and the outer margin of the major current systems. They are relatively large regions on the order of 200 000 km^2 or greater, characterised by distinct: (1) bathymetry, (2) hydrography, (3) productivity, and (4) trophically dependent populations.

The Large Marine Ecosystems strategy is a global effort for the assessment and management of international coastal waters. It developed in direct response to a declaration at the 1992 Rio Summit. As part of the strategy, the World Conservation Union (IUCN) and National Oceanic and Atmospheric Administration (NOAA) have joined in an action program to assist developing countries in planning and implementing an ecosystem-based strategy that is focused on LMEs as the principal assessment and management units for coastal ocean resources. The LME concept is also adopted by GEF that recommends the use of LMEs and their contributing freshwater basins as the geographic area for integrating changes in sectoral economic activities.

The global network

In each of the 66 regions, the assessment is conducted by a team of local experts that is headed by a Focal Point (Figure 2). The Focal Point can be an individual, institution or organisation that has been selected on the basis of their scientific reputation and experience implementing international assessment projects. The Focal Point is responsible for assembling members of the team and ensuring that it has the necessary expertise and experience in a variety of environmental and socio-economic disciplines to successfully conduct the regional assessment. The selection of team members is one of the most critical elements for the success of GIWA and, in order to ensure that the most relevant information is incorporated into the assessment, team members were selected from a wide variety of institutions such as

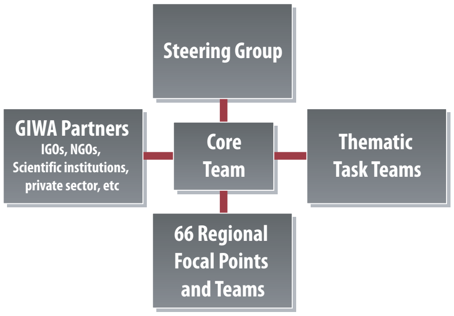


Figure 2 The organisation of the GIWA project.

universities, research institutes, government agencies, and the private sector. In addition, in order to ensure that the assessment produces a truly regional perspective, the teams should include representatives from each country that shares the region.

In total, more than 1 000 experts have contributed to the implementation of the GIWA illustrating that the GIWA is a participatory exercise that relies on regional expertise. This participatory approach is essential because it instils a sense of local ownership of the project, which ensures the credibility of the findings and moreover, it has created a global network of experts and institutions that can collaborate and exchange experiences and expertise to help mitigate the continued degradation of the world's aquatic resources.

GIWA Regional reports

The GIWA was established in response to growing concern among the general public regarding the quality of the world's aquatic resources and the recognition of governments and the international community concerning the absence of a globally coherent international waters assessment. However, because a holistic, region-by-region, assessment of the condition of the world's transboundary water resources had never been undertaken, a methodology guiding the implementation of such an assessment did not exist. Therefore, in order to implement the GIWA, a new methodology that adopted a multidisciplinary, multi-sectoral, multi-national approach was developed and is now available for the implementation of future international assessments of aquatic resources.

UNEP Water Policy and Strategy

The primary goals of the UNEP water policy and strategy are:

(a) Achieving greater global understanding of freshwater, coastal and marine environments by conducting environmental assessments in priority areas;

(b) Raising awareness of the importance and consequences of unsustainable water use;

(c) Supporting the efforts of Governments in the preparation and implementation of integrated management of freshwater systems and their related coastal and marine environments;

(d) Providing support for the preparation of integrated management plans and programmes for aquatic environmental hot spots, based on the assessment results;

(e) Promoting the application by stakeholders of precautionary, preventive and anticipatory approaches.

The GIWA is comprised of a logical sequence of four integrated components. The first stage of the GIWA is called Scaling and is a process by which the geographic area examined in the assessment is defined and all the transboundary waters within that area are identified. Once the geographic scale of the assessment has been defined, the assessment teams conduct a process known as Scoping in which the magnitude of environmental and associated socio-economic impacts of Freshwater shortage, Pollution, Habitat and community modification, Unsustainable exploitation of fish and other living resources, and Global change is assessed in order to identify and prioritise the concerns that require the most urgent intervention. The assessment of these predefined concerns incorporates the best available information and the knowledge and experience of the multidisciplinary, multi-national assessment teams formed in each region. Once the priority concerns have been identified, the root causes of these concerns are identified during the third component of the GIWA, Causal chain analysis. The root causes are determined through a sequential process that identifies, in turn, the most significant immediate causes followed by the economic sectors that are primarily responsible for the immediate causes and finally, the societal root causes. At each stage in the Causal chain analysis, the most significant contributors are identified through an analysis of the best available information which is augmented by the expertise of the assessment team. The final component of the GIWA is the development of Policy options that focus on mitigating the impacts of the root causes identified by the Causal chain analysis.

The results of the GIWA assessment in each region are reported in regional reports that are published by UNEP. These reports are designed to provide a brief physical and socio-economic description of the most important features of the region against which the results of the assessment can be cast. The remaining sections of the report present the results of each stage of the assessment in an easily digestible form. Each regional report is reviewed by at least two independent external reviewers in order to ensure the scientific validity and applicability of each report. The 66 regional assessments of the GIWA will serve UNEP as an essential complement to the UNEP Water Policy and Strategy and UNEP's activities in the hydrosphere.

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The GIWA methodology

The specific objectives of the GIWA were to conduct a holistic and globally comparable assessment of the world's transboundary aquatic resources that incorporated both environmental and socio-economic factors and recognised the inextricable links between freshwater and marine environments, in order to enable the GEF to focus their resources and to provide guidance and advice to governments and decision makers. The coalition of all these elements into a single coherent methodology that produces an assessment that achieves each of these objectives had not previously been done and posed a significant challenge.

The integration of each of these elements into the GIWA methodology was achieved through an iterative process guided by a specially convened Methods task team that was comprised of a number of international assessment and water experts. Before the final version of the methodology was adopted, preliminary versions underwent an extensive external peer review and were subjected to preliminary testing in selected regions. Advice obtained from the Methods task team and other international experts and the lessons learnt from preliminary testing were incorporated into the final version that was used to conduct each of the GIWA regional assessments.

Considering the enormous differences between regions in terms of the quality, quantity and availability of data, socio-economic setting and environmental conditions, the achievement of global comparability required an innovative approach. This was facilitated by focusing the assessment on the impacts of five pre-defined concerns namely; Freshwater shortage, Pollution, Habitat and community modification, Unsustainable exploitation of fish and other living resources and Global change, in transboundary waters. Considering the diverse range of elements encompassed by each concern, assessing the magnitude of the impacts caused by these concerns was facilitated by evaluating the impacts of 22 specific issues that were grouped within these concerns (see Table 1).

The assessment integrates environmental and socio-economic data from each country in the region to determine the severity of the impacts of each of the five concerns and their constituent issues on the entire region. The integration of this information was facilitated by implementing the assessment during two participatory workshops that typically involved 10 to 15 environmental and socio-economic experts from each country in the region. During these workshops, the regional teams performed preliminary analyses based on the collective knowledge and experience of these local experts. The results of these analyses were substantiated with the best available information to be presented in a regional report.

Table 1 Pre-defined GIWA concerns and their constituent issues addressed within the assessment.

Environmental issues	Major concerns
1. Modification of stream flow 2. Pollution of existing supplies 3. Changes in the water table	**I Freshwater shortage**
4. Microbiological 5. Eutrophication 6. Chemical 7. Suspended solids 8. Solid wastes 9. Thermal 10. Radionuclide 11. Spills	**II Pollution**
12. Loss of ecosystems 13. Modification of ecosystems or ecotones, including community structure and/or species composition	**III Habitat and community modification**
14. Overexploitation 15. Excessive by-catch and discards 16. Destructive fishing practices 17. Decreased viability of stock through pollution and disease 18. Impact on biological and genetic diversity	**IV Unsustainable exploitation of fish and other living resources**
19. Changes in hydrological cycle 20. Sea level change 21. Increased uv-b radiation as a result of ozone depletion 22. Changes in ocean CO_2 source/sink function	**V Global change**

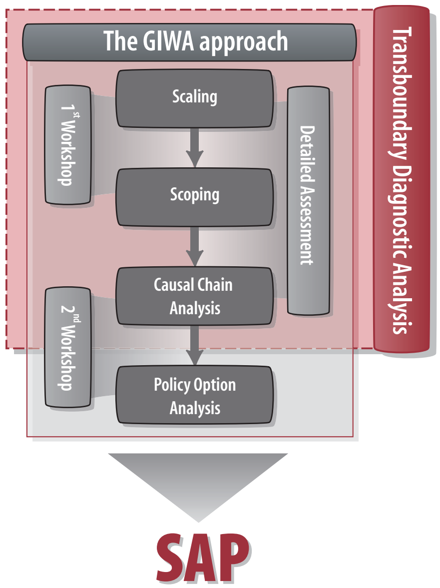

Figure 1 Illustration of the relationship between the GIWA approach and other projects implemented within the GEF International Waters (IW) portfolio.

The GIWA is a logical contiguous process that defines the geographic region to be assessed, identifies and prioritises particularly problems based on the magnitude of their impacts on the environment and human societies in the region, determines the root causes of those problems and, finally, assesses various policy options that addresses those root causes in order to reverse negative trends in the condition of the aquatic environment. These four steps, referred to as Scaling, Scoping, Causal chain analysis and Policy options analysis, are summarised below and are described in their entirety in two volumes: *GIWA Methodology Stage 1: Scaling and Scoping*; and *GIWA Methodology: Detailed Assessment, Causal Chain Analysis and Policy Options Analysis*. Generally, the components of the GIWA methodology are aligned with the framework adopted by the GEF for Transboundary Diagnostic Analyses (TDAs) and Strategic Action Programmes (SAPs) (Figure 1) and assume a broad spectrum of transboundary influences in addition to those associated with the physical movement of water across national borders.

Scaling – Defining the geographic extent of the region

Scaling is the first stage of the assessment and is the process by which the geographic scale of the assessment is defined. In order to facilitate the implementation of the GIWA, the globe was divided during the design phase of the project into 66 contiguous regions. Considering the transboundary nature of many aquatic resources and the transboundary focus of the GIWA, the boundaries of the regions did not comply with political boundaries but were instead, generally defined by a large but discrete drainage basin that also included the coastal marine waters into which the basin discharges. In many cases, the marine areas examined during the assessment coincided with the Large Marine Ecosystems (LMEs) defined by the US National Atmospheric and Oceanographic Administration (NOAA). As a consequence, scaling should be a relatively straight-forward task that involves the inspection of the boundaries that were proposed for the region during the preparatory phase of GIWA to ensure that they are appropriate and that there are no important overlaps or gaps with neighbouring regions. When the proposed boundaries were found to be inadequate, the boundaries of the region were revised according to the recommendations of experts from both within the region and from adjacent regions so as to ensure that any changes did not result in the exclusion of areas from the GIWA. Once the regional boundary was defined, regional teams identified all the transboundary elements of the aquatic environment within the region and determined if these elements could be assessed as a single coherent aquatic system or if there were two or more independent systems that should be assessed separately.

Scoping – Assessing the GIWA concerns

Scoping is an assessment of the severity of environmental and socio-economic impacts caused by each of the five pre-defined GIWA concerns and their constituent issues (Table 1). It is not designed to provide an exhaustive review of water-related problems that exist within each region, but rather it is a mechanism to identify the most urgent problems in the region and prioritise those for remedial actions. The priorities determined by Scoping are therefore one of the main outputs of the GIWA project.

Focusing the assessment on pre-defined concerns and issues ensured the comparability of the results between different regions. In addition, to ensure the long-term applicability of the options that are developed to mitigate these problems, Scoping not only assesses the current impacts of these concerns and issues but also the probable future impacts according to the "most likely scenario" which considered demographic, economic, technological and other relevant changes that will potentially influence the aquatic environment within the region by 2020.

The magnitude of the impacts caused by each issue on the environment and socio-economic indicators was assessed over the entire region using the best available information from a wide range of sources and the knowledge and experience of the each of the experts comprising the regional team. In order to enhance the comparability of the assessment between different regions and remove biases in the assessment caused by different perceptions of and ways to communicate the severity of impacts caused by particular issues, the results were distilled and reported as standardised scores according to the following four point scale:

- 0 = no known impact
- 1 = slight impact
- 2 = moderate impact
- 3 = severe impact

The attributes of each score for each issue were described by a detailed set of pre-defined criteria that were used to guide experts in reporting the results of the assessment. For example, the criterion for assigning a score of 3 to the issue Loss of ecosystems or ecotones is: "*Permanent destruction of at least one habitat is occurring such as to have reduced their surface area by >30% during the last 2-3 decades.*" The full list of criteria is presented at the end of the chapter, Table 5a-e. Although the scoring inevitably includes an arbitrary component, the use of predefined criteria facilitates comparison of impacts on a global scale and also encouraged consensus of opinion among experts.

The trade-off associated with assessing the impacts of each concern and their constituent issues at the scale of the entire region is that spatial resolution was sometimes low. Although the assessment provides a score indicating the severity of impacts of a particular issue or concern on the entire region, it does not mean that the entire region suffers the impacts of that problem. For example, eutrophication could be identified as a severe problem in a region, but this does not imply that all waters in the region suffer from severe eutrophication. It simply means that when the degree of eutrophication, the size of the area affected, the socio-economic impacts and the number of people affected is considered, the magnitude of the overall impacts meets the criteria defining a severe problem and that a regional action should be initiated in order to mitigate the impacts of the problem.

When each issue has been scored, it was weighted according to the relative contribution it made to the overall environmental impacts of the concern and a weighted average score for each of the five concerns was calculated (Table 2). Of course, if each issue was deemed to make equal contributions, then the score describing the overall impacts of the concern was simply the arithmetic mean of the scores allocated to each issue within the concern. In addition, the socio-economic impacts of each of the five major concerns were assessed for the entire region. The socio-economic impacts were grouped into three categories; Economic impacts, Health impacts and Other social and community impacts (Table 3). For each category, an evaluation of the size, degree and frequency of the impact was performed and, once completed, a weighted average score describing the overall socio-economic impacts of each concern was calculated in the same manner as the overall environmental score.

Table 2 Example of environmental impact assessment of Freshwater shortage.

Environmental issues	Score	Weight %	Environmental concerns	Weight averaged score
1. Modification of stream flow	1	20	Freshwater shortage	1.50
2. Pollution of existing supplies	2	50		
3. Changes in the water table	1	30		

Table 3 Example of Health impacts assessment linked to one of the GIWA concerns.

Criteria for Health impacts	Raw score	Score	Weight %
Number of people affected	Very small – Very large (0 1 2 3)	2	50
Degree of severity	Minimum – Severe (0 1 2 3)	2	30
Frequency/Duration	Occasion/Short – Continuous (0 1 2 3)	2	20
Weight average score for Health impacts		**2**	

After all 22 issues and associated socio-economic impacts have been scored, weighted and averaged, the magnitude of likely future changes in the environmental and socio-economic impacts of each of the five concerns on the entire region is assessed according to the most likely scenario which describes the demographic, economic, technological and other relevant changes that might influence the aquatic environment within the region by 2020.

In order to prioritise among GIWA concerns within the region and identify those that will be subjected to causal chain and policy options analysis in the subsequent stages of the GIWA, the present and future scores of the environmental and socio-economic impacts of each concern are tabulated and an overall score calculated. In the example presented in Table 4, the scoping assessment indicated that concern III, Habitat and community modification, was the priority concern in this region. The outcome of this mathematic process was reconciled against the knowledge of experts and the best available information in order to ensure the validity of the conclusion.

In some cases however, this process and the subsequent participatory discussion did not yield consensus among the regional experts regarding the ranking of priorities. As a consequence, further analysis was required. In such cases, expert teams continued by assessing the relative importance of present and potential future impacts and assign weights to each. Afterwards, the teams assign weights indicating the relative contribution made by environmental and socio-economic factors to the overall impacts of the concern. The weighted average score for each concern is then recalculated taking into account

Table 4 Example of comparative environmental and socio-economic impacts of each major concern, presently and likely in year 2020.

Concern	Environmental score		Economic score		Human health score		Social and community score		Overall score
	Present (a)	Future (b)	Present (c)	Future (d)	Present (e)	Future (f)	Present (g)	Future (h)	
Freshwater shortage	1.3	2.3	2.7	2.8	2.6	3.0	1.8	2.2	**2.3**
Pollution	1.5	2.0	2.0	2.3	1.8	2.3	2.0	2.3	**2.0**
Habitat and community modification	2.0	3.0	2.4	3.0	2.4	2.8	2.3	2.7	**2.6**
Unsustainable exploitation of fish and other living resources	1.8	2.2	2.0	2.1	2.0	2.1	2.4	2.5	**2.1**
Global change	0.8	1.0	1.5	1.7	1.5	1.5	1.0	1.0	**1.2**

the relative contributions of both present and future impacts and environmental and socio-economic factors. The outcome of these additional analyses was subjected to further discussion to identify overall priorities for the region.

Finally, the assessment recognises that each of the five GIWA concerns are not discrete but often interact. For example, pollution can destroy aquatic habitats that are essential for fish reproduction which, in turn, can cause declines in fish stocks and subsequent overexploitation. Once teams have ranked each of the concerns and determined the priorities for the region, the links between the concerns are highlighted in order to identify places where strategic interventions could be applied to yield the greatest benefits for the environment and human societies in the region.

Causal chain analysis

Causal Chain Analysis (CCA) traces the cause-effect pathways from the socio-economic and environmental impacts back to their root causes. The GIWA CCA aims to identify the most important causes of each concern prioritised during the scoping assessment in order to direct policy measures at the most appropriate target in order to prevent further degradation of the regional aquatic environment.

Root causes are not always easy to identify because they are often spatially or temporally separated from the actual problems they cause. The GIWA CCA was developed to help identify and understand the root causes of environmental and socio-economic problems in international waters and is conducted by identifying the human activities that cause the problem and then the factors that determine the ways in which these activities are undertaken. However, because there is no universal theory describing how root causes interact to create natural resource management problems and due to the great variation of local circumstances under which the methodology will be applied, the GIWA CCA is not a rigidly structured assessment but should be regarded as a framework to guide the analysis, rather than as a set of detailed instructions. Secondly, in an ideal setting, a causal chain would be produced by a multidisciplinary group of specialists that would statistically examine each successive cause and study its links to the problem and to other causes. However, this approach (even if feasible) would use far more resources and time than those available to GIWA[1]. For this reason, it has been necessary to develop a relatively simple and practical analytical model for gathering information to assemble meaningful causal chains.

Conceptual model

A causal chain is a series of statements that link the causes of a problem with its effects. Recognising the great diversity of local settings and the resulting difficulty in developing broadly applicable policy strategies, the GIWA CCA focuses on a particular system and then only on those issues that were prioritised during the scoping assessment. The starting point of a particular causal chain is one of the issues selected during the Scaling and Scoping stages and its related environmental and socio-economic impacts. The next element in the GIWA chain is the immediate cause; defined as the physical, biological or chemical variable that produces the GIWA issue. For example, for the issue of eutrophication the immediate causes may be, inter alia:

- Enhanced nutrient inputs;
- Increased recycling/mobilisation;
- Trapping of nutrients (e.g. in river impoundments);
- Run-off and stormwaters

Once the relevant immediate cause(s) for the particular system has (have) been identified, the sectors of human activity that contribute most significantly to the immediate cause have to be determined. Assuming that the most important immediate cause in our example had been increased nutrient concentrations, then it is logical that the most likely sources of those nutrients would be the agricultural, urban or industrial sectors. After identifying the sectors that are primarily

[1] This does not mean that the methodology ignores statistical or quantitative studies; as has already been pointed out, the available evidence that justifies the assumption of causal links should be provided in the assessment.

responsible for the immediate causes, the root causes acting on those sectors must be determined. For example, if agriculture was found to be primarily responsible for the increased nutrient concentrations, the root causes could potentially be:

- Economic (e.g. subsidies to fertilisers and agricultural products);
- Legal (e.g. inadequate regulation);
- Failures in governance (e.g. poor enforcement); or
- Technology or knowledge related (e.g. lack of affordable substitutes for fertilisers or lack of knowledge as to their application).

Once the most relevant root causes have been identified, an explanation, which includes available data and information, of how they are responsible for the primary environmental and socio-economic problems in the region should be provided.

Policy option analysis

Despite considerable effort of many Governments and other organisations to address transboundary water problems, the evidence indicates that there is still much to be done in this endeavour. An important characteristic of GIWA's Policy Option Analysis (POA) is that its recommendations are firmly based on a better understanding of the root causes of the problems. Freshwater scarcity, water pollution, overexploitation of living resources and habitat destruction are very complex phenomena. Policy options that are grounded on a better understanding of these phenomena will contribute to create more effective societal responses to the extremely complex water related transboundary problems. The core of POA in the assessment consists of two tasks:

Construct policy options

Policy options are simply different courses of action, which are not always mutually exclusive, to solve or mitigate environmental and socio-economic problems in the region. Although a multitude of different policy options could be constructed to address each root cause identified in the CCA, only those few policy options that have the greatest likelihood of success were analysed in the GIWA.

Select and apply the criteria on which the policy options will be evaluated

Although there are many criteria that could be used to evaluate any policy option, GIWA focuses on:

- Effectiveness (certainty of result)
- Efficiency (maximisation of net benefits)
- Equity (fairness of distributional impacts)
- Practical criteria (political acceptability, implementation feasibility).

The policy options recommended by the GIWA are only contributions to the larger policy process and, as such, the GIWA methodology developed to test the performance of various options under the different circumstances has been kept simple and broadly applicable.

Global International Waters Assessment

Table 5a: Scoring criteria for environmental impacts of Freshwater shortage

Issue	Score 0 = no known impact	Score 1 = slight impact	Score 2 = moderate impact	Score 3 = severe impact
Issue 1: Modification of stream flow "An increase or decrease in the discharge of streams and rivers as a result of human interventions on a local/ regional scale (see Issue 19 for flow alterations resulting from global change) over the last 3-4 decades."	■ No evidence of modification of stream flow.	■ There is a measurably changing trend in annual river discharge at gauging stations in a major river or tributary (basin > 40 000 km^2); or ■ There is a measurable decrease in the area of wetlands (other than as a consequence of conversion or embankment construction); or ■ There is a measurable change in the interannual mean salinity of estuaries or coastal lagoons and/or change in the mean position of estuarine salt wedge or mixing zone; or ■ Change in the occurrence of exceptional discharges (e.g. due to upstream damming.	■ Significant downward or upward trend (more than 20% of the long term mean) in annual discharges in a major river or tributary draining a basin of >250 000 km^2; or ■ Loss of >20% of flood plain or deltaic wetlands through causes other than conversion or artificial embankments; or ■ Significant loss of riparian vegetation (e.g. trees, flood plain vegetation); or ■ Significant saline intrusion into previously freshwater rivers or lagoons.	■ Annual discharge of a river altered by more than 50% of long term mean; or ■ Loss of >50% of riparian or deltaic wetlands over a period of not less than 40 years (through causes other than conversion or artificial embankment); or ■ Significant increased siltation or erosion due to changing in flow regime (other than normal fluctuations in flood plain rivers); or ■ Loss of one or more anadromous or catadromous fish species for reasons other than physical barriers to migration, pollution or overfishing.
Issue 2: Pollution of existing supplies "Pollution of surface and ground fresh waters supplies as a result of point or diffuse sources"	■ No evidence of pollution of surface and ground waters.	■ Any monitored water in the region does not meet WHO or national drinking water criteria, other than for natural reasons; or ■ There have been reports of one or more fish kills in the system due to pollution within the past five years.	■ Water supplies does not meet WHO or national drinking water standards in more than 30% of the region; or ■ There are one or more reports of fish kills due to pollution in any river draining a basin of >250 000 km^2 .	■ River draining more than 10% of the basin have suffered polysaprobic conditions, no longer support fish, or have suffered severe oxygen depletion ■ Severe pollution of other sources of freshwater (e.g. groundwater)
Issue 3: Changes in the water table "Changes in aquifers as a direct or indirect consequence of human activity"	■ No evidence that abstraction of water from aquifers exceeds natural replenishment.	■ Several wells have been deepened because of excessive aquifer draw-down; or ■ Several springs have dried up; or ■ Several wells show some salinisation.	■ Clear evidence of declining base flow in rivers in semi-arid areas; or ■ Loss of plant species in the past decade, that depend on the presence of ground water; or ■ Wells have been deepened over areas of hundreds of km^2;or ■ Salinisation over significant areas of the region.	■ Aquifers are suffering salinisation over regional scale; or ■ Perennial springs have dried up over regionally significant areas; or ■ Some aquifers have become exhausted

Table 5b: Scoring criteria for environmental impacts of Pollution

Issue	Score 0 = no known impact	Score 1 = slight impact	Score 2 = moderate impact	Score 3 = severe impact
Issue 4: Microbiological pollution "The adverse effects of microbial constituents of human sewage released to water bodies."	■ Normal incidence of bacterial related gastroenteric disorders in fisheries product consumers and no fisheries closures or advisories.	■ There is minor increase in incidence of bacterial related gastroenteric disorders in fisheries product consumers but no fisheries closures or advisories.	■ Public health authorities aware of marked increase in the incidence of bacterial related gastroenteric disorders in fisheries product consumers; or ■ There are limited area closures or advisories reducing the exploitation or marketability of fisheries products.	■ There are large closure areas or very restrictive advisories affecting the marketability of fisheries products; or ■ There exists widespread public or tourist awareness of hazards resulting in major reductions in the exploitation or marketability of fisheries products.
Issue 5: Eutrophication "Artificially enhanced primary productivity in receiving water basins related to the increased availability or supply of nutrients, including cultural eutrophication in lakes."	■ No visible effects on the abundance and distributions of natural living resource distributions in the area; and ■ No increased frequency of hypoxia[1] or fish mortality events or harmful algal blooms associated with enhanced primary production; and ■ No evidence of periodically reduced dissolved oxygen or fish and zoobenthos mortality; and ■ No evident abnormality in the frequency of algal blooms.	■ Increased abundance of epiphytic algae; or ■ A statistically significant trend in decreased water transparency associated with algal production as compared with long-term (>20 year) data sets; or ■ Measurable shallowing of the depth range of macrophytes.	■ Increased filamentous algal production resulting in algal mats; or ■ Medium frequency (up to once per year) of large-scale hypoxia and/or fish and zoobenthos mortality events and/or harmful algal blooms.	■ High frequency (>1 event per year), or intensity, or large areas of periodic hypoxic conditions, or high frequencies of fish and zoobenthos mortality events or harmful algal blooms; or ■ Significant changes in the littoral community; or ■ Presence of hydrogen sulphide in historically well oxygenated areas.

Issue 6: Chemical pollution "The adverse effects of chemical contaminants released to standing or marine water bodies as a result of human activities. Chemical contaminants are here defined as compounds that are toxic or persistent or bioaccumulating."	■ No known or historical levels of chemical contaminants except background levels of naturally occurring substances; and ■ No fisheries closures or advisories due to chemical pollution; and ■ No incidence of fisheries product tainting; and ■ No unusual fish mortality events. If there is no available data use the following criteria: ■ No use of pesticides; and ■ No sources of dioxins and furans; and ■ No regional use of PCBs; and ■ No bleached kraft pulp mills using chlorine bleaching; and ■ No use or sources of other contaminants.	■ Some chemical contaminants are detectable but below threshold limits defined for the country or region; or ■ Restricted area advisories regarding chemical contamination of fisheries products. If there is no available data use the following criteria: ■ Some use of pesticides in small areas; or ■ Presence of small sources of dioxins or furans (e.g., small incineration plants or bleached kraft/pulp mills using chlorine); or ■ Some previous and existing use of PCBs and limited amounts of PCB-containing wastes but not in amounts invoking local concerns; or ■ Presence of other contaminants.	■ Some chemical contaminants are above threshold limits defined for the country or region; or ■ Large area advisories by public health authorities concerning fisheries product contamination but without associated catch restrictions or closures; or ■ High mortalities of aquatic species near outfalls. If there is no available data use the following criteria: ■ Large-scale use of pesticides in agriculture and forestry; or ■ Presence of major sources of dioxins or furans such as large municipal or industrial incinerators or large bleached kraft pulp mills; or ■ Considerable quantities of waste PCBs in the area with inadequate regulation or has invoked some public concerns; or ■ Presence of considerable quantities of other contaminants.	■ Chemical contaminants are above threshold limits defined for the country or region; and ■ Public health and public awareness of fisheries contamination problems with associated reductions in the marketability of such products either through the imposition of limited advisories or by area closures of fisheries; or ■ Large-scale mortalities of aquatic species. If there is no available data use the following criteria: ■ Indications of health effects resulting from use of pesticides; or ■ Known emissions of dioxins or furans from incinerators or chlorine bleaching of pulp; or ■ Known contamination of the environment or foodstuffs by PCBs; or ■ Known contamination of the environment or foodstuffs by other contaminants.
Issue 7: Suspended solids "The adverse effects of modified rates of release of suspended particulate matter to water bodies resulting from human activities"	■ No visible reduction in water transparency; and ■ No evidence of turbidity plumes or increased siltation; and ■ No evidence of progressive riverbank, beach, other coastal or deltaic erosion.	■ Evidently increased or reduced turbidity in streams and/or receiving riverine and marine environments but without major changes in associated sedimentation or erosion rates, mortality or diversity of flora and fauna; or ■ Some evidence of changes in benthic or pelagic biodiversity in some areas due to sediment blanketing or increased turbidity.	■ Markedly increased or reduced turbidity in small areas of streams and/or receiving riverine and marine environments; or ■ Extensive evidence of changes in sedimentation or erosion rates; or ■ Changes in benthic or pelagic biodiversity in areas due to sediment blanketing or increased turbidity.	■ Major changes in turbidity over wide or ecologically significant areas resulting in markedly changed biodiversity or mortality in benthic species due to excessive sedimentation with or without concomitant changes in the nature of deposited sediments (i.e., grain-size composition/redox); or ■ Major change in pelagic biodiversity or mortality due to excessive turbidity.
Issue 8: Solid wastes "Adverse effects associated with the introduction of solid waste materials into water bodies or their environs."	■ No noticeable interference with trawling activities; and ■ No noticeable interference with the recreational use of beaches due to litter; and ■ No reported entanglement of aquatic organisms with debris.	■ Some evidence of marine-derived litter on beaches; or ■ Occasional recovery of solid wastes through trawling activities; but ■ Without noticeable interference with trawling and recreational activities in coastal areas.	■ Widespread litter on beaches giving rise to public concerns regarding the recreational use of beaches; or ■ High frequencies of benthic litter recovery and interference with trawling activities; or ■ Frequent reports of entanglement/ suffocation of species by litter.	■ Incidence of litter on beaches sufficient to deter the public from recreational activities; or ■ Trawling activities untenable because of benthic litter and gear entanglement; or ■ Widespread entanglement and/or suffocation of aquatic species by litter.
Issue 9: Thermal "The adverse effects of the release of aqueous effluents at temperatures exceeding ambient temperature in the receiving water body."	■ No thermal discharges or evidence of thermal effluent effects.	■ Presence of thermal discharges but without noticeable effects beyond the mixing zone and no significant interference with migration of species.	■ Presence of thermal discharges with large mixing zones having reduced productivity or altered biodiversity; or ■ Evidence of reduced migration of species due to thermal plume.	■ Presence of thermal discharges with large mixing zones with associated mortalities, substantially reduced productivity or noticeable changes in biodiversity; or ■ Marked reduction in the migration of species due to thermal plumes.
Issue 10: Radionuclide "The adverse effects of the release of radioactive contaminants and wastes into the aquatic environment from human activities."	■ No radionuclide discharges or nuclear activities in the region.	■ Minor releases or fallout of radionuclides but with well regulated or well-managed conditions complying with the Basic Safety Standards.	■ Minor releases or fallout of radionuclides under poorly regulated conditions that do not provide an adequate basis for public health assurance or the protection of aquatic organisms but without situations or levels likely to warrant large scale intervention by a national or international authority.	■ Substantial releases or fallout of radionuclides resulting in excessive exposures to humans or animals in relation to those recommended under the Basic Safety Standards; or ■ Some indication of situations or exposures warranting intervention by a national or international authority.
Issue 11: Spills "The adverse effects of accidental episodic releases of contaminants and materials to the aquatic environment as a result of human activities."	■ No evidence of present or previous spills of hazardous material; or ■ No evidence of increased aquatic or avian species mortality due to spills.	■ Some evidence of minor spills of hazardous materials in small areas with insignificant small-scale adverse effects one aquatic or avian species.	■ Evidence of widespread contamination by hazardous or aesthetically displeasing materials assumed to be from spillage (e.g. oil slicks) but with limited evidence of widespread adverse effects on resources or amenities; or ■ Some evidence of aquatic or avian species mortality through increased presence of contaminated or poisoned carcasses on beaches.	■ Widespread contamination by hazardous or aesthetically displeasing materials from frequent spills resulting in major interference with aquatic resource exploitation or coastal recreational amenities; or ■ Significant mortality of aquatic or avian species as evidenced by large numbers of contaminated carcasses on beaches.

Table 5c: Scoring criteria for environmental impacts of Habitat and community modification

Issue	Score 0 = no known impact	Score 1 = slight impact	Score 2 = moderate impact	Score 3 = severe impact
Issue 12: Loss of ecosystems or ecotones "The complete destruction of aquatic habitats. For the purpose of GIWA methodology, recent loss will be measured as a loss of pre-defined habitats over the last 2-3 decades."	■ There is no evidence of loss of ecosystems or habitats.	■ There are indications of fragmentation of at least one of the habitats.	■ Permanent destruction of at least one habitat is occurring such as to have reduced their surface area by up to 30 % during the last 2-3 decades.	■ Permanent destruction of at least one habitat is occurring such as to have reduced their surface area by >30% during the last 2-3 decades.
Issue 13: Modification of ecosystems or ecotones, including community structure and/or species composition "Modification of pre-defined habitats in terms of extinction of native species, occurrence of introduced species and changing in ecosystem function and services over the last 2-3 decades."	■ No evidence of change in species complement due to species extinction or introduction; and ■ No changing in ecosystem function and services.	■ Evidence of change in species complement due to species extinction or introduction	■ Evidence of change in species complement due to species extinction or introduction; and ■ Evidence of change in population structure or change in functional group composition or structure	■ Evidence of change in species complement due to species extinction or introduction; and ■ Evidence of change in population structure or change in functional group composition or structure; and ■ Evidence of change in ecosystem services[2].

[2] Constanza, R. et al. (1997). The value of the world ecosystem services and natural capital, Nature 387:253-260.

Table 5d: Scoring criteria for environmental impacts of Unsustainable exploitation of fish and other living resources

Issue	Score 0 = no known impact	Score 1 = slight impact	Score 2 = moderate impact	Score 3 = severe impact
Issue 14: Overexploitation "The capture of fish, shellfish or marine invertebrates at a level that exceeds the maximum sustainable yield of the stock."	■ No harvesting exists catching fish (with commercial gear for sale or subsistence).	■ Commercial harvesting exists but there is no evidence of over-exploitation.	■ One stock is exploited beyond MSY (maximum sustainable yield) or is outside safe biological limits.	■ More than one stock is exploited beyond MSY or is outside safe biological limits.
Issue 15: Excessive by-catch and discards "By-catch refers to the incidental capture of fish or other animals that are not the target of the fisheries. Discards refers to dead fish or other animals that are returned to the sea."	■ Current harvesting practices show no evidence of excessive by-catch and/or discards.	■ Up to 30% of the fisheries yield (by weight) consists of by-catch and/or discards.	■ 30-60% of the fisheries yield consists of by-catch and/or discards.	■ Over 60% of the fisheries yield is by-catch and/or discards; or ■ Noticeable incidence of capture of endangered species.
Issue 16: Destructive fishing practices "Fishing practices that are deemed to produce significant harm to marine, lacustrine or coastal habitats and communities."	■ No evidence of habitat destruction due to fisheries practices.	■ Habitat destruction resulting in changes in distribution of fish or shellfish stocks; or ■ Trawling of any one area of the seabed is occurring less than once per year.	■ Habitat destruction resulting in moderate reduction of stocks or moderate changes of the environment; or ■ Trawling of any one area of the seabed is occurring 1-10 times per year; or ■ Incidental use of explosives or poisons for fishing.	■ Habitat destruction resulting in complete collapse of a stock or far reaching changes in the environment; or ■ Trawling of any one area of the seabed is occurring more than 10 times per year; or ■ Widespread use of explosives or poisons for fishing.
Issue 17: Decreased viability of stocks through contamination and disease "Contamination or diseases of feral (wild) stocks of fish or invertebrates that are a direct or indirect consequence of human action."	■ No evidence of increased incidence of fish or shellfish diseases.	■ Increased reports of diseases without major impacts on the stock.	■ Declining populations of one or more species as a result of diseases or contamination.	■ Collapse of stocks as a result of diseases or contamination.
Issue 18: Impact on biological and genetic diversity "Changes in genetic and species diversity of aquatic environments resulting from the introduction of alien or genetically modified species as an intentional or unintentional result of human activities including aquaculture and restocking."	■ No evidence of deliberate or accidental introductions of alien species; and ■ No evidence of deliberate or accidental introductions of alien stocks; and ■ No evidence of deliberate or accidental introductions of genetically modified species.	■ Alien species introduced intentionally or accidentally without major changes in the community structure; or ■ Alien stocks introduced intentionally or accidentally without major changes in the community structure; or ■ Genetically modified species introduced intentionally or accidentally without major changes in the community structure.	■ Measurable decline in the population of native species or local stocks as a result of introductions (intentional or accidental); or ■ Some changes in the genetic composition of stocks (e.g. as a result of escapes from aquaculture replacing the wild stock).	■ Extinction of native species or local stocks as a result of introductions (intentional or accidental); or ■ Major changes (>20%) in the genetic composition of stocks (e.g. as a result of escapes from aquaculture replacing the wild stock).

Table 5e: Scoring criteria for environmental impacts of Global change

Issue	Score 0 = no known impact	Score 1 = slight impact	Score 2 = moderate impact	Score 3 = severe impact
Issue 19: Changes in hydrological cycle and ocean circulation "Changes in the local/regional water balance and changes in ocean and coastal circulation or current regime over the last 2-3 decades arising from the wider problem of global change including ENSO."	■ No evidence of changes in hydrological cycle and ocean/coastal current due to global change.	■ Change in hydrological cycles due to global change causing changes in the distribution and density of riparian terrestrial or aquatic plants without influencing overall levels of productivity; or ■ Some evidence of changes in ocean or coastal currents due to global change but without a strong effect on ecosystem diversity or productivity.	■ Significant trend in changing terrestrial or sea ice cover (by comparison with a long-term time series) without major downstream effects on river/ocean circulation or biological diversity; or ■ Extreme events such as flood and drought are increasing; or ■ Aquatic productivity has been altered as a result of global phenomena such as ENSO events.	■ Loss of an entire habitat through desiccation or submergence as a result of global change; or ■ Change in the tree or lichen lines; or ■ Major impacts on habitats or biodiversity as the result of increasing frequency of extreme events; or ■ Changing in ocean or coastal currents or upwelling regimes such that plant or animal populations are unable to recover to their historical or stable levels; or ■ Significant changes in thermohaline circulation.
Issue 20: Sea level change "Changes in the last 2-3 decades in the annual/seasonal mean sea level as a result of global change."	■ No evidence of sea level change.	■ Some evidences of sea level change without major loss of populations of organisms.	■ Changed pattern of coastal erosion due to sea level rise has became evident; or ■ Increase in coastal flooding events partly attributed to sea-level rise or changing prevailing atmospheric forcing such as atmospheric pressure or wind field (other than storm surges).	■ Major loss of coastal land areas due to sea-level change or sea-level induced erosion; or ■ Major loss of coastal or intertidal populations due to sea-level change or sea level induced erosion.
Issue 21: Increased UV-B radiation as a result of ozone depletion "Increased UV-B flux as a result polar ozone depletion over the last 2-3 decades."	■ No evidence of increasing effects of UV/B radiation on marine or freshwater organisms.	■ Some measurable effects of UV/B radiation on behavior or appearance of some aquatic species without affecting the viability of the population.	■ Aquatic community structure is measurably altered as a consequence of UV/B radiation; or ■ One or more aquatic populations are declining.	■ Measured/assessed effects of UV/B irradiation are leading to massive loss of aquatic communities or a significant change in biological diversity.
Issue 22: Changes in ocean CO_2 source/sink function "Changes in the capacity of aquatic systems, ocean as well as freshwater, to generate or absorb atmospheric CO_2 as a direct or indirect consequence of global change over the last 2-3 decades."	■ No measurable or assessed changes in CO_2 source/sink function of aquatic system.	■ Some reasonable suspicions that current global change is impacting the aquatic system sufficiently to alter its source/sink function for CO_2.	■ Some evidences that the impacts of global change have altered the source/sink function for CO_2 of aquatic systems in the region by at least 10%.	■ Evidences that the changes in source/sink function of the aquatic systems in the region are sufficient to cause measurable change in global CO_2 balance.

The Global International Waters Assessment (GIWA) is a holistic, globally comparable assessment of the world's transboundary waters that recognises the inextricable links between the freshwater and the coastal marine environments and integrates environmental and socio-economic information to determine the impacts of a broad range of influences on the world's aquatic environment.

Broad Transboundary Approach

GIWA recognises that many water bodies and resources, and the human impacts on them, are not confined to a single country.

Regional Assessment – Global Perspective

GIWA provides a global perspective of the world's transboundary waters by assessing regions that encompass major drainage basins and adjacent Large Marine Ecosystems. The GIWA Assessment incorporates information and multidisciplinary expertise from all countries sharing the transboundary water resources of each region.

Global Comparability

In each region, the assessment focuses on five major concerns comprising 22 specific water-related issues.

Integration of Information and Ecosystems

GIWA recognises the inextricable links between the freshwater and the coastal marine environments and assesses them together as an integrated unit. GIWA recognises that the integration of socio-economic and environmental information and expertise is essential in order to obtain an holistic understanding of the interactions between the environmental and societal aspects of transboundary waters.

Priorities, Root Causes and Options for the Future

GIWA identifies the priority concerns of each region, determines their societal root causes and discusses options to mitigate the future impact of those concerns.

This Report

This report presents the assessment of Lakes Turkana, Tanganyika, Victoria and Malawi – the largest of the East African Rift Valley Lakes and among the oldest lakes in the world. The lakes are renowned for their high endemism and support a vital socio-economic service as a core for transportation, water supply, fisheries, recreation and tourism. Anthropogenic impacts have significantly altered the ecosystem function of these lakes. Lake Victoria, shared by three countries and influenced by two more in the catchment area, was targeted for causal chain and policy option analysis. Root causes related to pollution and overexploitation are discussed and policy options to address the driving issues are presented.

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