CHAPTER ONE

An introductory overview to the current state of the water quality of Lake Victoria, Uganda

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Background

Lake Victoria is an international waterbody that offers the riparian communities a large number of extremely important environmental services. Over the past four decades or so, the lake has come under increasing and considerable pressure from a variety of interlinked human activities such as overfishing, species introductions, industrial pollution, eutrophication, and sedimentation. The lake provides various resources to its riparian communities.

Both renewable and non-renewable resources shall remain the foundation for social and economic development of the human kind in all the riparian countries. Effective and efficient management of the resource base is therefore essential for any nation's economic and social welfare and its environmental quality. Changes in population size, employment, settlement, consumption patterns, industrialization and resource utilization can affect the sustainability of the resources and environmental quality for better or for worse. Development implies greater economic and social changes, and these underscore the need for all countries to manage their resources well for all their citizens now and in the future.

Lake Victoria Basin is tropical in climate and should therefore have abundant biodiversity and ecologically its biodiversity should be tending towards stability. The basin also has great opportunity for sustainable environmental and socio-economic development. Prospects for future socio-economic growth and well being of its increasing population are good. However, the poorly planned socio-economic activities within the lake and in the catchments by the ever-increasing human population are already contributing to drastic ecological changes in the lake basin. It is therefore extremely important to make any planned socio-economic development sustainable.

Fortunately, a number of corrective initiatives are being implemented along side the socio-economic programmes to ensure enhancement of biodiversity, its conservation and sustainable utilization. In addition, the long-term goals of the various development initiatives within the Lake Victoria Basin are emphasizing the successful introduction and establishment of environmentally and socially sustainable economic development to the lake region through enhancing growth and eliminating poverty, while at the same time maintaining the rich biodiversity and resource base for the use of the present and future generations. They are targeting achievement of some of the objectives of the millennium development goals.

Aware of the progress in environmental conservation and technological development being made in the Baltic Sea region and in the Great Lakes region of North America, the people of Uganda (and also Kenya and Tanzania) are taking advantage of those similar initiatives in an effort to speed up the achievement of environmental and socio-economic progress in the Lake Victoria region.

In 1858, the British explorer John Speke reached Lake Victoria southern shore and proclaimed that he had discovered the source of the Nile. Within 20 years from John Speke's arrival, England had taken charge of what became Uganda and Kenya (Germany got Tanzania), and by 1902 the colonial government had pushed through a railroad from Mombasa to the lake. The explorers soon denuded vast tracts of forest in Lake Victoria's watershed to plant tea, coffee, sugarcane, tobacco, and cotton. The human population exploded, and people increasingly turned to the lake not for subsistence but to satisfy a market for fish especially the tasty tilapia in the growing urban centers.

In the early 1980s, a shift in Lake Victoria's fauna became noticeable. The bottom waters of the lake appeared to be a dead zone, devoid of oxygen and fish life. On the other hand, the lake was chockfull of algae, about five to ten times more than in the early 1960s. That suggested massive eutrophication, an oxygen-depleted condition caused by high levels of nutrients that encourage the rapid growth of plankton. Nutrient inputs have increased two to three-fold since the turn of the century. Concentrations of phosphorus have risen markedly in the deeper lake waters, and nitrogen around the edges. In addition, massive blooms of algae have developed and become increasingly dominated by the potentially toxic blue-green species. Water transparency (measured by the Secchi disc) has decreased from 5 meters in the early 1930s to 1 meter or less for most of the year now. Waterborne diseases have increased in frequency. Water hyacinth, absent as late as 1989, begun to choke important waterways and landings.

Water Quality and Ecosystem Management Component

The water quality and Ecosystems Management Component of LVEMP has made considerable progress towards understanding Lake Victoria's water quality and its ecosystem as well as effects of resource utilization and exploitation on the lake and its catchment. The component has been able to collect considerable amount of data and information.

Objectives of the Water Quality and Ecosystem Management Component

General objectives

1. Elucidating the nature and dynamics of the Lake Victoria ecosystem by providing detailed information on characteristics of the waters of the lake.
2. Establishing a water quality and quantity monitoring network throughout the catchment, estimating the effects of changes in land use planning on pollution loads in the lake, and developing policies and programs to control non-point source pollution.

The Specific Objectives

- To provide detailed and usable information on the characteristics of the waters of Lake Victoria.
- To establish and operationalise integrated water quality monitoring network so as to generate information on the physical status, chemical characteristics and biological composition of the lake.
- To develop and operationalise a water quality management model to be used as a planning tool in the management of Lake Victoria and its ecosystem.
- To develop and continuously update the mass water balance of Lake Victoria.
- To contribute on the social benefits which the community can accrue as a result of accessing lake water of good quality.
- Identify the impacts of deteriorating water quality on the beneficial uses of Lake Victoria
- To develop, enforce and regularize water quality standards and monitor compliance.
- Determine historical trends and future projections
- Build human capacity
- Define the current baseline condition under LVEMP I tenure
- Recommend for future actions including the LVEMP II phase

Summary of Findings

Chapter 2 Lake Monitoring

- A number of sampling network for littoral, pelagic and urban monitoring stations established
- Trends in physical and chemical parameters monitored
- Cruises taken.

Chapter 3 Hydro-Meteorological Conditions

- Uganda’s land catchment annual rainfall contribution to Lake Victoria is approx. 312 Million m^3/s
- Mean annual rainfall over the Ugandan side is about 2020 mm and this forms 35.2% of the mean annual lake rainfall
- No significant trends in rainfall were observed over the period of study
- Evaporation was less than rainfall by a factor of 0.66
- Lake levels in relation to the Nile outflow shows that there has been a close relationship between the levels and amount of water released through the Owen Falls dam.
- General absence / limited rains on the lake in recent years contributed to falling of lake levels
- Increased outflows at the Owen Falls dam for power generation contributed to a further fall in lake levels by about 0.34 m from the year 2001 – 2004

- Full understanding of this scenario needs understanding net basin supply (NBS) and outflow data from the rest of the basin.

Chapter 4 Non-Point Pollution Loading

- TSS, OM and TN concentrations were river-dependent
- River Bukora had significantly higher concentrations compared to River Katonga ($P<0.01$)
- TP concentrations were similar in Katonga and Bukora, and increased linearly with time ($p=0.05$).
- The concentration of TSS fluctuated, the peak was in the year 2000 for Bukora and 2001 for Katonga ($p<0.05$)
- The sub-catchments loaded 2.1 t/day of TN and 0.3 t/day of TP, confirming small contribution compared to atmospheric deposition, which loaded 26.4 t/day of TN and 5.6 t/day for TP from the wet deposition

Chapter 5 Industrial and Municipal Effluents Management

- Pollution hotspots were identified
- Fishing villages contribute significantly to Lake Victoria pollution
- Factories in Kampala, Jinja and Entebbe with threat to lake pollution identified.
- It was established that about 14.17 tons of BOD, 2.91 tons of N and 1.93 tons of P / day is discharged into Lake Victoria from urban centres
- 2.96 tons of BOD, 0.37 tons of N and 0.19 tons of P / day is discharged from 124 fishing villages
- Industrial loads was estimated to be 2.51 tons of BOD, 0.34 tons N and 0.11 tons P per day.
- Use of natural and constructed wetlands showed a significant role in pollution reduction
- Pollution management strategies and sanitation improvement is proposed.

Chapter 6 Hydraulic conditions

- Data on temperature, water velocities, oxygen concentration and secchi depths were studied from 1999 to 2005
- The temperature distribution profiles on the eastern part of the lake showed similar patterns to historical observations
- Water column temperatures and stratification are very prominent in the months of February, March and April
- The western part of Lake Victoria is much influenced by winds hence more mixing and cooling patterns
- The eastern part of Lake Victoria is much more influenced by thermal stratification patterns and therefore mixing is mainly due to density currents.
- The eastern part of Lake Victoria experiences higher water temperatures throughout the year due to a lower rate of light penetration and weaker mixing.

Chapter 7 Sedimentation

- Sedimentation rates were highest at littoral compared to pelagic stations
- The composition of the settling material is highly organic and of algal origin
- Inshore sediment cores had lower annual sediment burial rates than deep offshore
- Only 10-15% of trapped carbon and nitrogen is permanently buried on an annual basis in contrast to 40% of phosphorus
- The trapped amounts of biogenic silicon is insufficient to account for recent historic rates of burial
- This is consistent with the depletion of soluble reactive Si in the lake as a consequence of P enrichment, causing eutrophication
- Sediment cores indicate that increased loading of P began prior to 1940 and continues to the present.
- The increased loading of P has depleted dissolved Si in the lake's mixed layer and oxygen in the deeper waters
- The created nitrogen demand can only be met through nitrogen fixation creating conditions where cyanobacteria now dominate.
- Restoration of ecological conditions characteristic of the first half of the last century will require reductions in P loading

Chapter 8 and 9 Eutrophication of Lake Victoria

- Lake Victoria has clearly shown signs of eutrophication since the late 1980s
- Phosphorus concentrations have risen by a factor of 2 to 3
- High nutrient concentrations support elevated algal primary production and algal biomass have risen by a factor of 2 and 6 to 8 respectively
- Average algal primary production has increased 2-fold and supports a 4 – to 5 – fold increase in yield compared to 1950s
- Estimated abundance indicated higher densities of organisms and diversity indices around littoral compared to pelagic habitats, these trends are explained by a more productive inshore that receives nutrients
- Vertical distribution of zooplankton is related to profiles of temperature and dissolved oxygen.
- In shallow littoral habitats, there was no development of thermocline and oxycline
- In contrast, the vertical distribution at deeper pelagic stations indicated concentration of organisms in mid-to-surface water layers due to development of low dissolved oxygen conditions
- The frequent encounter of these organisms is an indicator of the deteriorating water quality of the lake basin
- Adverse eutrophication effects include harmful algal blooms associated with fish kills; and reduction in lake transparency; changes in algal and invertebrates communities, loss of desirable fish species and seasonal bottom water oxygen depletion (anoxia).

Chapter 10 Pesticides, agrochemicals and heavy metals

- Use of agricultural chemicals in the catchment has increased in recent years
- Studies under LVEMP and other international investigators have revealed gross abuse and misuse of agricultural chemicals in Uganda
- Many restricted chemicals are being used by untrained persons while adulteration of some is common.
- A number of banned organochlorinated pesticides (e.g. DDT, endosulfan, dieldrin and lindane) were detected in air showing that they may still be in use
- However, these pesticides were not detected in sediments, water or fish tissue
- Studies also showed that herbicides Touch Down (48% Glyophosate trimesium) and Gasepax (2,4-D and Ametryne) used in sugarcane cultivation pose no environmental threat in runoff water, soil and fish, four months after field application
- Elevated metal concentrations (Mn, Zn and Cr) detected in some rivers were, related to industrial activities or runoff from urban areas
- High Total Hg concentrations were higher in recently deposited lake sediments than older ones, indicating increased environmental degradation
- Nevertheless, Hg concentrations in sediment, water and fish from Lake Victoria were below the WHO and international environmental guidelines
- Results call for more stringent measures to control the types of agricultural chemicals used in the catchment coupled with massive sensitisation of communities on safe handling and use of agrochemicals

Chapter 11 Water and Health

- Studies indicated that the shore waters were highly contaminated
- Riparian communities sourced their water for domestic use mainly from the lake
- Seasonal variation in coliform counts correlates positively with waterborne disease incidences that were higher in the wet season
- The most prevalent diseases in the landing sites were malaria, dysentery, diarrhea and bilharzia
- Cases of cholera, skin-related infections and influenza, where also observed
- Fishers vulnerability to water-related diseases was further aggravated by inaccessibility to both health facilities and personnel
- There was a significant difference in disease cases between those who used latrines regularly and those who did not
- Other potential health risks in the communities arose from frequent algal blooms
- Cyanobacteria (potentially toxic to humans and animals) impaired ecological and aesthetic values of the lake
- Algal blooms caused unpleasant odours and tastes in domestic water supplies, clogged filters on pumps and machinery, increased chlorine demand, requiring a more complex and expensive treatment process , and ultimately raised tariffs

- Use of Ecosan toilets constructed by LVEMP in the riparian communities was estimated to be less than 50% on average, because of user fee and socio-cultural factors.
- People disposed their wastes in nearby bushes or in polythene bags, contaminating water sources with fecal material and leading to waterborne diseases
- Findings suggest that water quality and sanitation improvements, in association with hygiene behaviour change can have significant effects on population and health by reducing a variety of waterborne and water-related diseases.

Chapter 12 Impacts of water quality change on beneficial uses of Lake Victoria

- Lake Victoria is of immense economic and environmental importance
- Currently, it supports an estimated population of about 30 million
- Its socio-economic, scientific and environmental benefits lie mainly in respect to its land and water uses, unique land and waterborne biodiversity, wetlands and fisheries products and of its immeasurable aesthetic values
- Lake basin is a source of food, energy, drinking and irrigation water, shelter, transport, and as a repository for human, agricultural, municipal and industrial
- Combined populations of the three countries with gross economic product is of US$ 4 – 6 billion annually
- Savings in the annual cost of water hyacinth control estimated to be US$ 6 – 10 million, while savings in the cost of cleaning water supply currently a minimum of US$ 3.5 million per annum
- Savings in the cost of health services due to improved quality of water and sanitation can result into diminished incidence of diseases among the riparian communities
- Massive blooms of algae have developed, water borne diseases have increased in frequency and infestation of water hyacinth is choking important waterways and landings as well as water supply intakes
- Subsquently increase in expenditure on treatment and control measures has raised poverty levels among riparian communities

Chapter 13 Capacity Building

- During the 7 years of LVEMP, 5 MSc and 1 PhD scientists were trained in various fields of water quality and quantity studies.
- Several specialized short courses were offered to a number of scientists on the component of water quality and quantity.
- A number of specialized training consultancies were procured including outreach through workshops relevant to water quality management
- Other specialized and knowledge upgrade areas addressed were:
    - Hydraulic conditions training using “wet lease equipments”
    - Procured “wet lease contract”: RDI Acoustic Doppler Current Profiler (ADCP), RBR Temperature and Temperature/ Depth loggers

- A number of specialized training consultancies were procured including outreach through workshops relevant to water quality management
- CSI Data logging system and peripherals were procured
- A short limnology course was held at Makerere University in the year 2001
- Other on job-trainings under LVEMP support included the COWI and DHI training.
- The efficiency of laboratory and field infrastructure was improved.

Chapter 14 General recommendation

This summarizes all the major recommendations raised from the various chapters.

Characteristics of the Lake Victoria Basin (LVB)

Biophysical features

Lake Victoria is the world's second largest freshwater lake and the largest in Africa with a surface area of 68,800 Km^2. It fills a shallow depression in the center of a great plateau at 1,134 m altitude located between the eastern and western rift valleys, holding 2,760 Km^3 of water at an average depth of 40 m. and reaching a maximum depth of 84 m. This volume of water, which takes about 100 years to be replaced, is only 15 percent of that of Lake Tanganyika even though the latter has less than half the surface area of Lake Victoria. Temperature range in the lake is narrow and warm with a mean annual water mass temperature of 25^o C. The shoreline is about 3,500 Km long and it is convoluted, enclosing innumerable small, shallow bays and inlets, many of which include swamps and wetlands that differ a great deal from one another and from the lake itself. The lake is a shared resource among the riparian countries with Kenya having 6%, Uganda 45% and Tanzania 49%. Figure 1 shows the map of Lake Victoria and its catchments.

Beadle (1981) who reviewed the geological transformation within the Lake Victoria Basin concluded that the lake came into existence as a result of the earth's movements during mid-Pleistocene that led to the formation of the Western Rift Valley. These movements were believed to have prompted the reversal of the once east-west drainage system following the disappearance of the Miocene Lake Karunga that was in the present Winam Gulf and the depression around Kisumu. Many of the rivers now flowing east into the present Victoria, including Kagera, Katonga, and others, once flowed west during the Miocene, Pliocene and part of the Pleistocene eras, that is` within the past 2 million years. An upthrust of the western side of the basin was believed to have reversed these rivers to give birth to the present Lake Victoria. Beadle (1981) therefore concluded that the present lake and its basin could have formed as recently as 25,000 to 35,000 years ago. In addition, recent evidence from sediment cores suggests that it may have dried up completely between 10,000 and 14,000 years ago before refilling and establishing the new out-flow through the Ripon Falls into the Victoria Nile that flows through the swampy Lake Kyoga into Lake Albert at its extreme north-end. The water from Lake Victoria then continues right up to the Mediterranean Sea via northern Uganda and through Sudan and Egypt.

The lake has an adjoining catchment of 254,000 Km^2 of which 38,899 Km^2 is in Uganda, 47,710 Km^2 is in Kenya and 115,380 Km^2 is in Tanzania and the balance is in Rwanda and Burundi. Some 85 percent of the water entering the lake does so from precipitation directly onto the lake surface, and the remainder comes from rivers that drain the surrounding catchments. Similarly, some 85 percent of the water leaving the lake does so through direct evaporation from its surface and the remaining water leaves the lake by way of the Victoria Nile. The major inflows of the lake include River Kagera that drains the Rwanda, Burundi and Kigezi highlands and flows via Tanzania and Uganda; Rivers Katonga and Mpanga that drain western Uganda; Rivers Nzoia that drain the Mt. Elgon and Cherangani hills in Kenya and Rivers Yala, Nyando, Kuja/Miriu and Migori/Mara that drain the Nandi, Kericho and Kisii highlands. 60 percent of the lake's water comes from the Kenyan drainage systems. There are wide patches of wetlands especially along the shores and extensive areas of savannah and wooded bush lands.

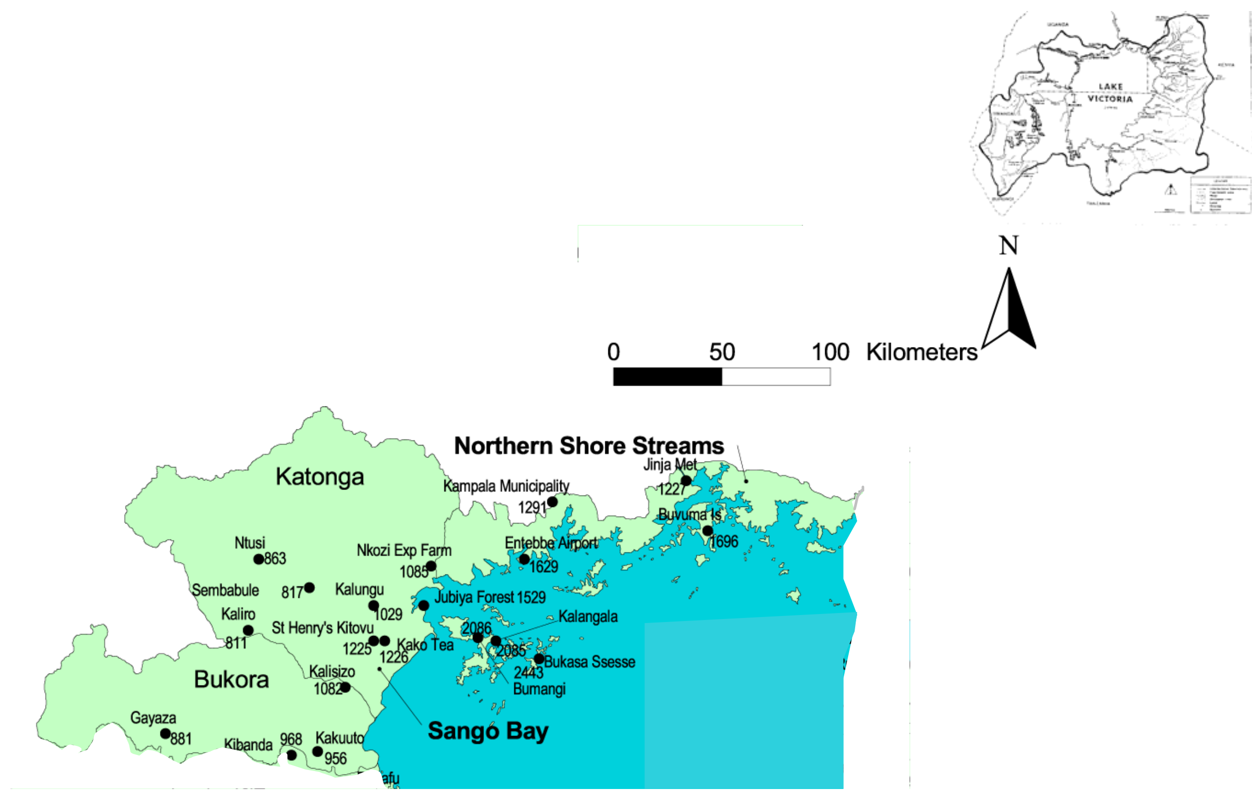

FIG. 1. Map of Lake Victoria Basin (Uganda) and its sub-catchments.

Demographic characteristics

Uganda's riparian population was about 6.2 million and the average density was 120 persons per Km^2 in 1991 (UBOS 2005). Today, the riparian districts of Uganda constitute a population of about 8,102,789 representing an increase of about 2,000,000 people over a decade (UBOS 2005) whose livelihoods directly or indirectly depend on Lake Victoria. Figure 2 presents a comparison of district census populations for the last three census exercises. From Figure 2 it can be observed that the riparian population has steadily increased in all the riparian districts of Uganda. The highest has been that in Kampala, while the lowest is that of Kalangala.

Socio-economic characteristics of Lake Victoria

The economy of the lake basin that currently supports an estimated population of about 40 million people should be viewed from the totality of socio-economic, scientific and environmental benefits that can accrue not only to the three riparian countries of Kenya, Tanzania and Uganda in particular but also to the global community in general mainly in respect of its land and water uses, unique land and waterborne biodiversity, wetlands and fisheries products and of its immeasurable aesthetic values. The lake basin is already being used as a source of food, energy, drinking and irrigation water, shelter, transport, and as a repository for human, agricultural, municipal and industrial wastes by about a third of the combined populations of the three countries whose gross economic product is in the order of US$ 4 – 6 billion annually.

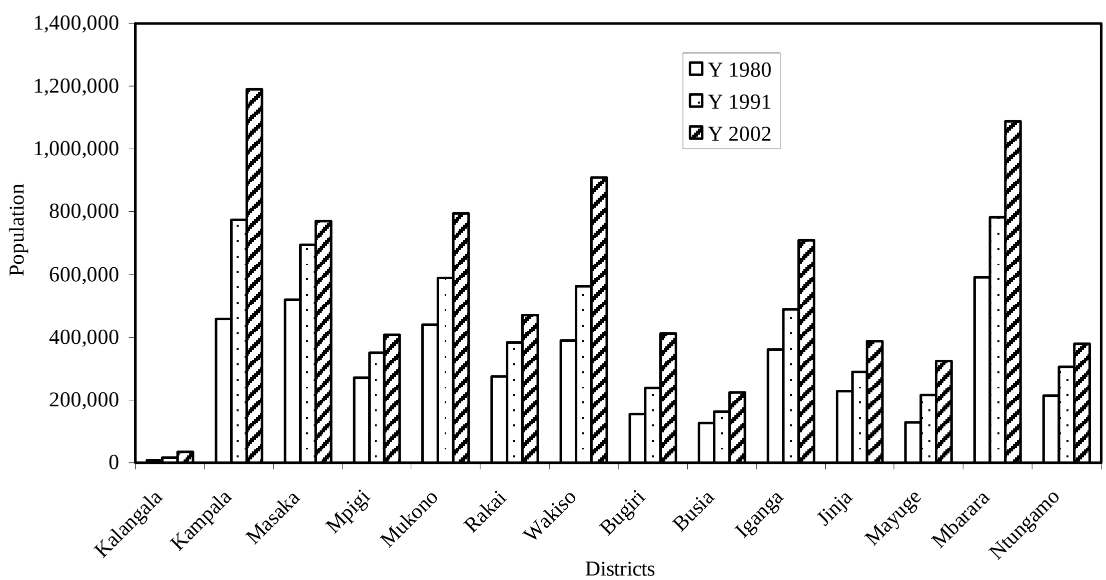

FIG. 2. Census Populations trend for the catchment districts from 1980, 1991 and 2002.

The major direct economic benefit of any well planned investment can arise from the:

- savings in the annual cost of water hyacinth control estimated to be US$ 6 – 10 million under current levels of infestation,
- savings in the cost of cleaning water supply that is currently estimated to be a minimum of US$ 3.5 million per annum,
- savings in the cost of health services due to improved quality of water and sanitary environment that can result into diminished incidence of diseases among the riparian communities and also,
- avoidance of the predicted collapse in the fisheries which is estimated to have a present value to the lake community of US$ 300 – 600 million in terms of the whole lake basin.

Benefits also arise from increased agricultural productivity resulting from improved soil and water conservation and those from the conservation of wetlands and of biodiversity as well as of aesthetic values that have not been fully estimated yet. The overall socio-economic, scientific and environmental benefits that can be derived from rational investments in billions of U.S. dollars within the Lake Victoria region can be ten times or more of the amount invested.

Prospects in the Lake Victoria Basin (LVB) lies in its richness in both renewable and non-renewable resources that are not yet being utilized optimally for socio-economic development to benefit both the riparian and the global communities. Harnessing of these natural resources is central in advancing Uganda and the region socio-economically. The environment is also conducive for investment. Economic benefits will be maximized if there is sustainability of renewable resources at reduced costs and wise use of non-renewable resources. Reduction in the incidence of diseases will lead to increased productivity, as a healthy population is the one that can be productive. Attracting investments in Uganda and the region will increase gross economic product.

Experience from other lakes

Three of East Africa rift valley lakes: Victoria, Tanganyika, and Malawi hold one quarter of the earth's total surface freshwater supply, and are home to a myriad of fish species. Apart from the diversity and endemicity of their biota, properties that distinguish the African Great Lakes from their North American counterparts include their great age, long sedimentary records, long residence times, persistent stratification, continuously warm temperatures at all depths, major ion composition, and a propensity for nitrogen limitation (Bootsma and Hecky 2003). Current management problems include over-fishing, increased input of sediment and nutrients, and in the case of Lake Victoria, loss of endemic fish species and the proliferation of the water hyacinth. As in the Laurentian Great Lakes basin, the harmonization of research programs and management strategies among the various riparian countries is a challenge. Particular issues that may be pursued most profitably in the African Great Lakes include the links between climate and biogeochemical cycles, the role of biodiversity in ecosystem functioning, and paleoclimate reconstruction over millions of years (Bootsma and Hecky 2003).

Lake Malawi is the most species-rich lake in the world, with an estimated 500 to 1,000 species of fish. Lake Tanganyika's fauna is similarly rich, with a total of 16 families and more than 200 cichlid species. Lake Victoria is also species-rich, and may have held more than 500 species, but many have either declined in number or become completely extinct over the past several decades, probably due to predation by the introduced Nile perch *(Lates niloticus*) compounded by changes in water quality (Bootsma and Hecky 2003).

Benthic invertebrate diversity in Lake Malawi appears to be comparable to that in the Laurentian Great Lakes, with diversity being greatest among the ostracods, insects, and gastropods. While Lake Tanganyika is home to fewer fish species than Lake Malawi, it boasts of a much larger number of invertebrate species, particularly gastropods and ostracods, (Okedi 1990; Sekiranda *et al*. 2004; Odong 2004).

Annual rainfall in much of East Africa is generally between 800 and 1,200 mm per year, similar to that around the Laurentian Great Lakes. Rapid evaporation leaves only a small proportion of this rain for human uses such as agriculture, industry, hydroelectric generation, and direct consumption. Terrestrial evapotranspiration also leaves little water to flow into the lakes. River discharge to the African Great Lakes is much lower than that to the Laurentian Great Lakes, even though the drainage: lake surface area ratios for the African lakes (2.8 to 6.7) are similar to or larger than those for the North American lakes (1.6 to 3.7). As a result, most of the water input to the African Great Lakes is in the form of rainfall directly on the lakes' surfaces (Bootsma and Hecky 2003). Due to high evaporation rates, the lake surface is also the path by which most water leaves the African Great Lakes.

The difference in evaporation rates between the African and North American lakes can be attributed to high year-round air temperatures over the African lakes, relatively low humidity, and the absence of ice cover. These high evaporation rates leave little water to flow out of the lakes. As a result the lake levels are very sensitive to small changes in climate. Between the 1960s and early 1980s, all three lakes were at their highest levels in the past century. The Lakes had their highest levels until the 1980s and have since then, dropped slightly for Lake Victoria, but Tanganyika and Malawi have dropped by about 4 m. Not only does evaporation represent a major water loss process in the African Great Lakes, it is also a large heat budget component, and therefore plays an important role in the annual mixing regime of these and other tropical lakes (Bootsma and Hecky 2003). Wind and air temperature appear to be the main variables controlling the seasonality of mixing and thermal structure in large tropical lakes, by means of evaporative cooling and turbulence. This generality does not necessarily apply to smaller tropical lakes, where temporal changes in thermal structure, nutrient availability, and plankton production may be controlled to a large degree by hydrologic inputs (Bootsma and Hecky 2003). Ultimately, differences that result from latitude are due to differences in the quantity and seasonal variation of solar radiation, and the diminished Coriolis effect at lower latitudes.

With regard to thermal structure and hydro-dynamics, there are three important differences between large tropical and temperate lakes. Due to small thermal gradients and the large effect of temperature on water density in the 20°C to 30°C range, thermal structure is temporally less stable in tropical lakes. As a result, small changes in heat flux or turbulence result in large, rapid changes in the depth of the surface mixed layer. Secondly, while thermal stratification is less stable than in large temperate lakes, it is more persistent, particularly at depths greater than 100 m. Lake Victoria mixes for only a brief period each year, and Lakes Malawi and Tanganyika are both meromictic with anoxic hypolimnia. Thirdly, due to the reduced Coriolis effect, wind-generated currents have a greater effect on mixing and can produce more persistent internal seiches in large tropical lakes. Lakes Malawi and Tanganyika are both oriented nearly parallel to the direction of the prevailing winds in East Africa, and internal seiches may persist throughout much of the year in these lakes. These physical movements appear to play a large role in the distribution of dissolved gases, nutrients, and plankton (Bootsma and Hecky 2003). Because of its exceptionally long flushing time, Lake Tanganyika is more saline than any of the other large lakes, as reflected in its high salinity values. Extensive areas of papyrus dominate the fringing wetlands and the noxious water hyacinth invaded the lake in 1989. However, salinity is affected by both flushing time and major ion inflow rates, and the long flushing times of the African lakes are countered by the relatively small river inflows and the low ionic content of inflowing river water.

Dilution is also provided by the relatively large amount of direct rainfall on the lakes. As a result, the salinity of Lakes Malawi and Victoria is similar to that of the temperate Great Lakes. Among the temperate Great Lakes, the role of basin geology is apparent when comparing Lake Superior with the other lakes. Despite its long flushing time, Lake Superior has a low ionic concentration, and the similarity between conductivities and flushing times in Lakes Superior and Victoria underscore the fact that, like the Superior basin, the Great African Lake basins are made up largely of solution-resistant granitic minerals. In contrast the remaining Laurentian lakes receive waters rich in calcium and bicarbonate as a consequence of the extensive limestone deposits in their basins. While calcium is the dominant cation in the Laurentian Great Lakes, sodium and potassium sulfate concentrations are low in the African Great Lakes, although they are also low in Lake Superior, again reflecting the important role of drainage basin geology.

High rates of sulfur removal may also be facilitated by the anoxic hypolimnia and organic rich sediments of the African lakes, which favor sulfate reduction and the precipitation of sulfide minerals (Muyodi *et al.* 2004). At one time sulfur limitation of algal growth was considered a possibility in Lake Victoria, but it now appears that this is unlikely (Bootsma and Hecky 2003). Another chemical distinction between large tropical and temperate lakes is the low availability of dissolved nitrogen in tropical systems. Within several of the Laurentian Great Lakes, surface nitrate concentrations have been increasing over the past century, probably due to atmospheric inputs (Bootsma and Hecky 2003). While atmospheric inputs of nitrogen to the African Great Lakes are also high, nitrogen does not accumulate in these lakes. The physical and chemical limnological characteristics associated with a tropical climate result in unique biological properties of the African Great Lakes. Warm temperatures result in high metabolic rates and rapid turnover rates of the plankton. According to classification standards that have been applied to the Laurentian Great Lakes, Lakes Malawi and Tanganyika would be considered eutrophic (Bootsma and Hecky 2003).

Previous Studies on Lake Victoria

Various authors have documented the history of scientific research on the African Great Lakes (Beadle 1981; Talling 1956; Melack 1976; Talling and Lemoalle 1998). Several expeditions were conducted to each of the lakes between 1894 and 1905, which resulted in the documentation of a large number of animal and plant species. The first studies of physical and chemical properties were those of Worthington (1930; 1931) on Lake Victoria. The work on Lake Victoria was a major step in understanding the dynamics of photosynthesis in aquatic systems, and advanced the understanding of tropical algal ecology and its relation to physical and chemical conditions. Talling's work also provided critical baseline data that has allowed for the quantification of chemical, physical, and biological changes that have occurred in Lake Victoria over the past several decades (Bootsma and Hecky 2003).

Notable research initiatives were made through the support of the IDRC of Canada to the FIRRI at Jinja in the late 1980s and 1990s. This research contributed significantly to the appreciation of the dramatic changes that were underway in the Lake Victoria environment and resources. This appreciation provided part of the basis for committing funding for regional research project including the European Union funded Lake Victoria Regional Fisheries Project (LVFRP) and LVEMP funded GEF and IDA of the World Bank.

Development Initiatives

Administrative responses by the riparian governments of Uganda (Kenya and Tanzania) to changes in the ecosystem and socio-economic problems that have been enumerated have had varied degrees of success but have also brought about some undesirable socio-economic implications. Some poorly planned macro-economic reforms generated rapid urbanization, industrialization and population increase within the lake basin amidst inadequate physical planning. Several research and scientific reports have been written about the state of the lake basin in the areas of fisheries, limnology, water quantity and quality, geo-physical and bio-chemical characteristics and socio-economics. In addition, several development projects have been and are being implemented, some of which are on-going and more are being planned. The need to integrate all these efforts at both national and regional levels for a focused and sustainable development in the basin cannot be overemphasized. More initiatives for socio-economic development within the lake basin started as early as the turn of the twentieth century.

Many of the early efforts centered on the fisheries of the lake. After completing his research on the fisheries resources of Lake Victoria, Graham (1929) recommended the establishment of fisheries management authorities in the three riparian countries that also led to the establishment of the Lake Victoria Fisheries Commission in 1932 under the East African High Commission. Later in 1947, the East African Freshwater Fisheries Research Organization (EAFFRO) that became responsible for the management for the fisheries of the lake was set up. Formation of the earlier East African Community strengthened the operations of EAFFRO. When EAC collapsed in 1976, the Sub-Committee of the Committee for the Inland Fisheries of Africa (CIFA) operating under the auspices of FAO assumed the responsibility for the management and development of the fisheries of Lake Victoria until the three countries replaced it with the Lake Victoria Fisheries Organization (LVFO). Efforts have been initiated and are still to be further under the EAC to create a more comprehensive and sustainable legal and institutional framework. The subsidiary socio-economic development programmes within the lake basin by the Nile Basin Initiative (NBI) in addition to the initiatives by the EAC under the concept that Lake Victoria region is an ECONOMIC ZONE added to the list of development interventions in the Lake Victoria Basin.

A major research effort by the United Nations Development Programme (UNDP) and United Nations Food and Agriculture Organization (FAO) took place between 1966 and 1971 and produced the first quantitative information on the fish stocks of Lake Victoria. Other initiatives by UNDP/FAO on fisheries statistics, by European Union on the supply of fishing gears, by FAO on fish quality control and assurance and by the three riparian governments on various other developmental aspects took place between 1971 and 1994. A more comprehensive development programme, the Lake Victoria Environmental Management Project (LVEMP) was initiated in 1994 as a five year project that commenced in 1997 and funded through the World Bank with the objectives of maximizing the sustainable benefits to the riparian communities from using resources within the basin to generate food, employment and income, supply safe water, sustain a disease free environment, conserve biodiversity and genetic resources for the benefit of both the riparian and global communities and promote regional cooperation. The legal and institutional building project for the Lake Victoria region and the partnership arrangement between institutions in the Baltic Sea region and the Lake Victoria region were later initiated by SIDA in 1999 under the auspices of the East African Community.

The past and on-going projects have been and are addressing a number of complex set of scientific/technical, managerial, legal and institutional issues across the three countries. They involve gathering of information, building of capacity, establishment of institutions and initiating some developmental action plans to deal with socio-economic and environmental problems as a whole. The projects have laid and are continuing to lay concrete foundations and to provide a central core around which will coalesce a larger programme of investments to clean up the lake and to establish sustainable socio-economic, scientific and environmental development within the lake basin in the face of the increasing population pressures likely to continue to be experienced.

While the various interventions so far were all for good intentions, they were largely of individual merit with respect to overall coordination. There is therefore immediate need to have a focused development programme where policy coordination for all initiatives and interventions within the lake basin can be with the EAC under the close supervision and guidance by the EAC Committee for Lake Victoria Development Programme (LVDP) while the actual implementation of the development activities on the ground remain the responsibility of the riparian states.

Popular Concerns (Threats) to Lake Victoria Basin

The major drivers for the threats stem from the ever-increasing population pressure and demand for water by the human population be it for irrigation, production of hydro-electric power, domestic, or industrial use (IUCN 2005). The multiple activities in the lake basin of the rapidly increasing riparian population have increasingly come into conflict. The population pressure is, in particular, contributing to the existence of pollution “hot spots” where there is especially heavy localized degradation of water quality in the lake from human waste, urban runoff and the effluent discharges of such industries as breweries, tanning, paper processing, fish processing, sugar factories, coffee processing factories, washing stations and abattoirs. In addition there is some inflow of residues from the use of chemical herbicides and pesticides in selected agricultural operations in the lake catchments and from specialized industries such as gold mining that are responsible for the presence of localized areas of heavy metals. Since the levels of fertilizer use in agricultural areas in the catchments are in general low, the main rural source of these nutrients is soil erosion which release nitrogen and phosphorus held in the natural soil profile. From the urban areas and lakeshore communities, the main sources of nutrients are human waste especially from untreated sewage. All of these activities are contributing to feeding the lake with nutrients and increasing eutrophication.

Compared to the works of Graham (1927) and to that of EAFFRO in 1969 on Lake Victoria where water quality measurements gave a baseline picture of, for example, chlorophyll reading ranging from 1.3 – 4.9 mgl/1 to 17 – 21 mgl/1, Hecky (1993) showed that the lake experienced a serious decline in water quality since the 1960s due to increase in phosphorus concentrations by a factor of two, a rise in algal biomasses by a factor of 8 to 10, depletion of dissolved oxygen in the deeper waters of the lake for longer periods of the year and the domination of the algal community by filamentous and colonial blue-green algae. They are also contributing to the many changes that have been taking place in and around Lake Victoria during the last 40 years.

In his hopeful predicament to changes in Lake Victoria, Hecky (1997) wrote: *"When the world's second largest lake undergoes fundamental changes which may threaten our future use of its wealth, perhaps the biggest problem we have to overcome is the feeling of helplessness."* He continued to say: "*Change is part of life. When the pace of change is slow, living beings including humans can adapt. When the pace of change becomes too rapid, then many plants and animals less adaptable than humans can be lost from the ecosystems; and the health and economy of humans can suffer. When the rates of change become exceptional and unexpected events affecting resources upon which we depend become normal, then humans finally worry about sustainability. We must not let change create panic, but we must address it and understand its causation."*

Yes, causation must be understood and change must be addressed. In the causes lie a series of specific actions by man that have led to important changes in the Lake Victoria ecosystems. The effect of increased agricultural and urban runoff in the lake's watershed and discharge of domestic and industrial waste into the lake on the ecology of the lake has been profound. Conversion of wetland areas around Lake Victoria for agricultural and/or other uses has had detrimental effect on the lake ecosystem. The water quality of the lake is deteriorating due to widespread agricultural, industrial and urbanization activity in the catchments, and this is having adverse impacts on riparian communities. The lake fauna and flora have changed drastically and this has been followed by changes in the species composition and loss of biodiversity. These changes have had far reaching socio-economic consequences on the riparian peoples of Uganda (and East Africa). Moreover, there are institutional and financial deficiencies otherwise needed to formulate remedial policies and to implement them throughout the lake basin.

Whereas the riparian communities have depended on the lake for livelihood for centuries, and whereas there has been increased fish yield from Lake Victoria, the living standard of lakeside communities has not received comparable improvement. Thus water supply and sanitation, health and disease, transportation and communication have all continued to be huge problems for the riparian communities despite ready availability of water for domestic use, lake transport and fish for food. The fishing and small holder farming communities around the lake have therefore remained bogged down by poverty and continued to be largely overlooked, under-rated and often little understood by governments, policy makers and other communities. Consequently, therefore, fishermen and small-holder lakeside families have tended to be largely illiterate and least mobilized for development.

Lack of routine monitoring / evaluation

Prior to LVEMP, there was lack of routine water quality and quantity monitoring and evaluation. There were no established criteria for regular monitoring of Lake Victoria. The staff was not equipped enough to undertake routine monitoring of the lake. Monitoring or evaluations were only organized after reported cases, for example, fish kills. Also, the institutional framework did not cater for routine monitoring.

The need for focused, planned and coordinated ecological and socio-economic research and monitoring was overwhelming. Focused research to address priority areas is therefore a very important area for management planning. The importance of socioeconomic research on Lake Victoria gained considerable momentum during the 1990s. However, more needs to be done to establish, for example, how best lakeside communities can be empowered to manage the Lake Victoria resources.

Lack of Capacity

Before the inception of LVEMP I, there was very limited capacity to manage the Lake Victoria water resources. Through training under LVEMP, many research scientists working in different water sectors have trained at graduate level. Others have undergone upgrade training to perfect their output especially in the technical field. There was also inadequate institutional capacity to undertake research in the country. Through LVEMP support, the Water Resources Management Department has been equipped with facilities to undertake research and management of water resources in the country. Inadequate participation of riparian communities in socio-economic development activities was evident. In general, there was an inadequate rational investment in education, research, economic activities and environmental conservation.

Lack of conceptual models

As management problems move from the relatively simple issue of fishery control to the more complex issues of land use and climate change, models play an important role in decision making processes. For the developing riparian countries, it is critical that management strategies have maximum positive impact with minimal expense. The hope is that these models serve as a basis for informed discussions about the present and future state of the lakes, and eventually be applied as decision-supporting tools for management.

While research activities on Lake Victoria has increased in the last decade, there remains a need for integrated, multi-disciplinary research in order to develop conceptual and numerical models that would provide insight into the functioning of a large, tropical, freshwater aquatic ecosystem.

In summary the constraints / concerns include:

1. Poor agricultural practices and deforestation associated with land degradation and soil erosion that have accelerated nutrient loading and agro-chemical input into the water systems.

2. Mismanagement and destruction of wetlands through unsustainable use that reduce their buffering capacity and destroy biodiversity.

3. Absence or inadequate provision of facilities for disposal or treatment of sewage, urban refuse and industrial waste that has led to increased pollution of the lake in the vicinity of settlements.

4. Introduction of exotic species of fish, for instance, Nile Perch and Nile Tilapia that have preyed heavily on the plankton and detritus feeding haplochromine cichlids. Nile Perch has also been considered to be the major cause of the decline of some species of fish leading to changes in the food web and the trophic structure of the lake.

5. Poorly planned increase in fishing effort that has been fueled by the use of improved technology, population growth and expanded export markets that has led to huge decline in biodiversity and other changes in the fisheries.

6. Inadequate human and institutional capacities, weak extension services and the enforcement of the available regulations in addition to the absence of adequate policies, laws and regulations.

Efforts to address the concerns

The deteriorating water quality in Lake Victoria is being addressed by studying: the nature, composition and characteristics of the pollutants; nutrients in the lake water and the organisms they sustain; characteristics of sediments; prevalence of water-borne and water related diseases, hydrologic processes and their balance. Inadequate data, information and human capacity for water quality management are also being addressed (WRMD 2003).

Conclusions and Recommendations

There is no doubt that the ecosystem of Lake Victoria has changed since the beginning of the last century. These changes, whether for better or worse, are by and large caused by man’s activities within the ecosystem. The expanding human population is contributing to increasing land degradation, agricultural / urban runoff in the lake’s watershed, discharge of domestic and industrial waste into the lake. All these have effected the ecology of the lake resulting into pollution and eutrophication. Further, conversion of wetland areas around the lake for agricultural and/or other uses has damaged their buffering capacities with detrimental effect on the lake' ecosystem. The water quality of the lake is deteriorating due to widespread poor planned agricultural, industrial and urbanization activities in the catchments and these have impacted on riparian communities adversely. The lake's fauna and flora have changed drastically and this has been followed by changes in the species composition, loss of biodiversity and changes in the fishery. All these changes have had and are having far reaching socio-economic consequences on the riparian peoples of Uganda (and East Africa in general). In addition, there are still institutional and financial deficiencies otherwise needed to formulate remedial measures for implementation.

The past and the present development initiatives have been structured to develop baseline data about the present condition of the lake's ecosystem and to assess the potential impact of human activities in the catchments. The projects also emphasized building of human and institutional capacities and assessing the effectiveness of different management measures. Some of the on-going projects have assisted Uganda (also Kenya and Tanzania) to achieve the critical mass of skilled people, equipment and facilities needed to begin effective management of the problems that have been identified. Perhaps one of the encouraging outcome of all is the visible evidence that some of the projects have helped Uganda (the riparian Governments and management agencies in the three countries) to develop methods, procedures and a history of working together to solve common problems.

The focus of the various initiatives can be summarized as having been on how to accomplish the long-term objectives for the shared vision in the lake region.

The long-term plan should therefore lay emphasis on the implementation of environmentally and socio-economically sustainable economic development to be based on both technical and participatory work done in the past and present projects. Greater emphasis will have to be placed on stakeholder monitoring of results and necessary adaptations so that positive results can be maintained and expanded. The focus shall have to be on the implementation of strategies and cost-effective methods that have been identified and tested in the past and on-going projects. It is anticipated from the present interest being shown by development partners that the long-term plan for the shared vision shall attract significant support from many bilateral and multilateral donor partners.

Development of nationally multi-sectoral and interdisciplinary strategies to control and manage enrichment of Lake Victoria ecosystems especially with nitrogen and phosphorus should be priotized. This will necessitate harmonization of policies, mandates, and legal instruments of line institutions at national (and international) level to facilitate close coordination and collaboration.

It will also necessitate undertaking joint and coordinated regional research to build a comprehensive picture about the causes, extent, dynamics and impacts of eutrophication in Lake Victoria ecosystems.

A strategy to facilitate free flow and fast exchange of information relevant to the management of shared resources to the stakeholders between institutions, nationally and regionally needs to be developed in the next phase of LVEMP.

Integrated approach to management of the lake resources involving the local communities and all other interested stakeholders is strongly recommended.

LVEMP II should focus on purpose-based water resources management, sensitization of communities around the lake in participatory approach to lake restoration. Socio-economic research is a priority area for planning and coordinated execution of sustainable utilization of lake resources.

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