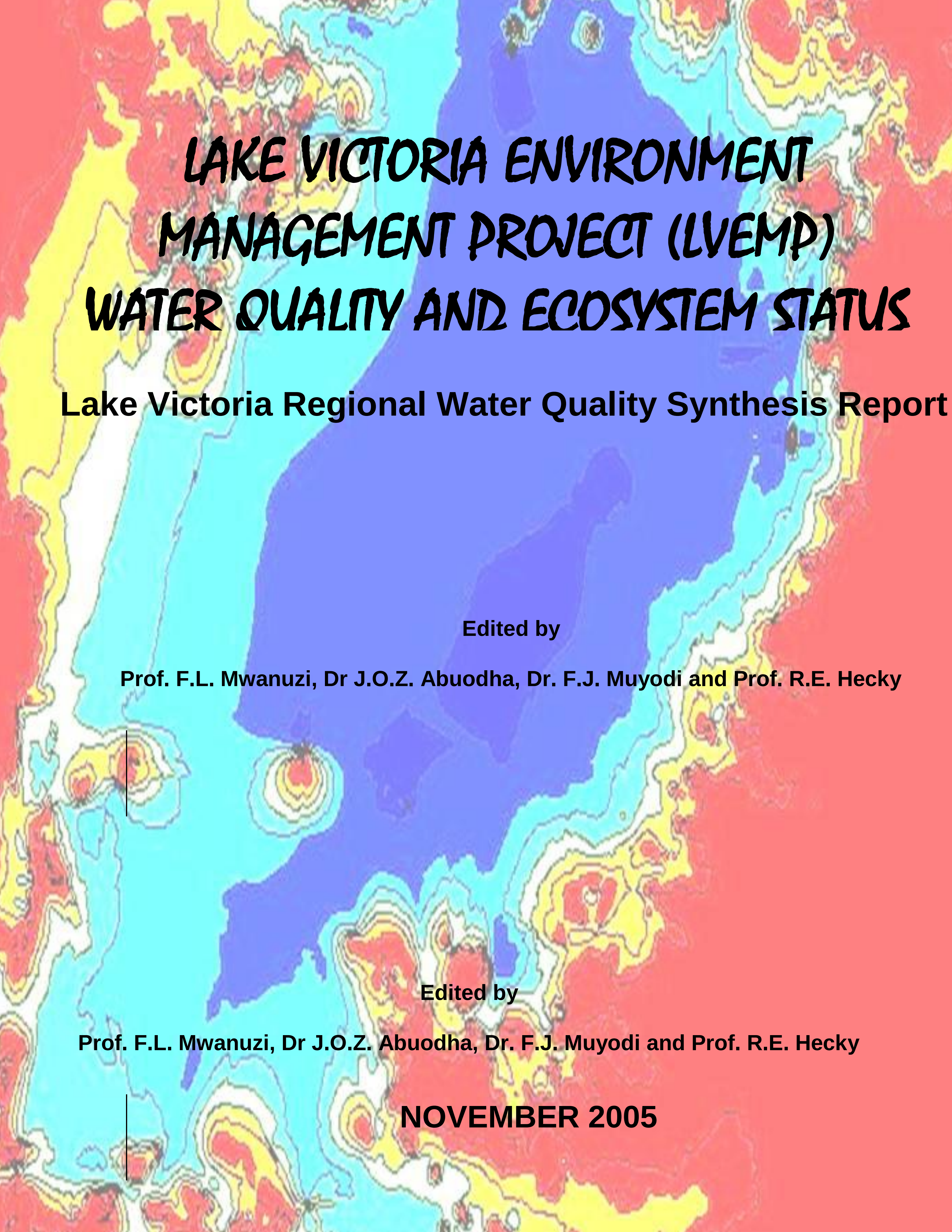

LAKE VICTORIA ENVIRONMENT MANAGEMENT PROJECT (LVEMP)
WATER QUALITY AND ECOSYSTEM STATUS

Lake Victoria Regional Water Quality Synthesis Report

Edited by

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Executive Summary

The Water quality and Ecosystem Management Components of the Lake Victoria Environmental Management Project (LVEMP) in the three riparian countries (Kenya, Tanzania and Uganda) have made considerable progress towards understanding Lake Victoria water quality and its ecosystem as well as effects of resource utilization and exploitation on the lake and in its catchment. In order to achieve LVEMP objectives and Water Quality and Ecosystem Management objectives, in particular, a well-coordinated analysis, synthesis and interpretation of all relevant data was required. This report documents and explains the changes that have taken place over the recent decades, and provides an overview of the present water quality status of the lake as well as identifying past changes and continuing trends that may require remedial action.

The report provides detailed information and spatial resolution at the regional scale to support environmental decision making in regards to possible remediation of undesirable changes that have reduced beneficial uses of Lake Victoria biological and water resources. This regional synthesis report was written by regional scientists and technical experts under the guidance of an international consultant, Prof. Robert Hecky of the University of Waterloo, Canada, together with the National consultants; Dr. Joseph Abuodha of the Maseno University, Prof. Fredrick Mwanuzi of the University of Dar es Salaam and Dr. Fredrick Muyodi of Makerere University. It brings together data, interpretations and recommendations from three national water quality reports. A number of national and regional working sessions were conducted to enable the scientists to complete these reports, and all these were facilitated by the National Executive Secretariats of LVEMP who were supportive through out the process.

Background

LVEMP is a comprehensive program conducted by the three countries aimed at maintenance and rehabilitation of the lake ecosystem for the sustainable benefit of the 30 million people who live in the catchment, their national economies and the global community.

The overall objectives of the LVEMP are to maximize the sustainable benefits to riparian communities from using resources within the basin to generate food, employment and income, supply safe water and sustain a disease free environment, to conserve biodiversity and genetic resources for the benefit of the riparian communities and global community, and to harmonize national management programs in order to achieve, to the maximum extent possible, the maintenance of a healthy Lake Victoria ecosystem and the reversal of increasing environmental degradation.

One of the critical components of LVEMP concerns Water Quality and Ecosystem Management which has the overall objectives of understanding the nature and dynamics of the lake ecosystem by providing detailed information on characteristics of the waters of the lake, establishing a water quality monitoring network throughout the catchment and lake, estimating the effects of changes in land use on pollution loads into the lake, developing policies, recommending programmes to control non-point source pollution and improving management of Industrial and Municipal effluents and assessing the contribution of urban runoff to lake pollution.

The Water Quality and Ecosystem Management Component has since the inception of the Project made considerable progress towards understanding the Lake Victoria water quality and the aquatic ecosystem as well as effects of resource exploitation within the lake and its basin. The component has collected considerable amounts of new data and information.

The component, using historical data and the data it initially collected produced a preliminary report in 2002, which provides a baseline for water quality status at the start of the project and indications of possible change from historic conditions. The data have also been used in scientific fora within the region. But, in order to achieve LVEMP objectives in general and Water Quality and Ecosystem Management objectives in particular, a well-coordinated analysis, synthesis and interpretation of all relevant data are required. This report will document and explain the changes that have taken place over the recent decades, and it provide a definitive overview of the present water quality status and continuing trends that may require remedial action. The report provides enough detailed information and spatial resolution to support environmental decision making in regards to spatial allocation of possible remediation of undesirable changes that have reduced beneficial uses of Lake Victoria biological and water resources.

Approach to synthesis Report

All the available data and reports generated by the component since the start of the project were first collected, collated, updated, reviewed and incorporated to National Water Quality Reports. The National Reports and the analyses contributing to them form the basis of this regional synthesis addressing the following issues:

i) Determine the current state of knowledge of the Lake Victoria water balance
ii) Use the components of the water budget to estimate current water and nutrient loads and balances of the lake,
iii) Define trends in limnology and water quality, and provide quantitative information on past, and if possible future, nutrient loading, nutrient losses and nutrient availability within the lake,
iv) Identify the sources of micro/macro nutrients promoting eutrophication in a spatially explicit manner that can guide remedial action and demonstrate how these inputs are affecting lake productivity;
v) Summarize what is known about the presence and concentrations of contaminants in lake water and biota and, if possible, define trends in these contaminant loadings over time,
vi) Describe the phytoplankton communities, their composition and their effects on beneficial uses of the lake ecosystem, in particular addressing algal bloom dynamics within the lake in relation to current and past rates of primary production

vii) Determine the trophic interrelationships of the lake's biological communities and especially address how eutrophication and food web alterations are affecting fisheries of Lake Victoria;
viii) Determine the role of lake consumers e.g. zooplankton, zoobenthos, microbes and lake flies in the ecosystem dynamics;
ix) Using the available information on the horizontal and vertical circulation of waters determine its effect on the spatial distribution of nutrients, algae, oxygen, contaminants and organisms in Lake Victoria;
x) Relate the water quality findings with the findings of other Components of LVEMP
xi) Assess effects of poor water quality on the socio economic aspect of the riparian communities
xii) Provide data for eventual use in the Lake Victoria Water Quality Model to simulate the future effect of different interventions and management options for the lake.

The above issues are grouped and summarised in different chapters addressing specific issues. Chapter 2 on Capacity Building for Water Quality Management addresses how LVEMP has addressed critical constraints in infrastructure, programmes and technical capacity to improve regional capacity for management of the water quality of Lake Victoria. Chapter 3 presents the water balance of the lake quantifying inputs, outputs and how they affect lake level changes. Increasingly the water balance of the lake is serving management objectives that can affect riparian uses around Lake Victoria and also downstream along the Nile. Chapter 4 addresses the critical meteorological processes that set the waters of the lake into motion and change their vertical circulation over the seasons. These movements dictate the transport and mixing of incoming materials through out the lake.

Chapter 5 of the report describes the results of the monitoring program on Lake Victoria that for the first time allows comparison with earlier data that were more constrained to specific locations while providing a comprehensive description of present conditions on the lake that will provide a baseline for future assessments and trends. Chapter 6 examines the lake's most urgent water quality problem, eutrophication, and explains its causes, its severity and possible solutions. Chapter 7 quantifies the sources of nutrients and sediments to Lake Victoria and determines the fate of those materials within the lakes. Chapter 8 describes how changing water quality affects the communities around the lake dependent on that water quality. The lake provides many beneficial services to the communities, but many of these uses are degraded or at risk. Similarly haphazard, poorly planned and unsustainable development will continue to degrade the lakes' uses. Rehabilitation of degraded resources will require an action plan to restore and preserve the beneficial uses of the lake for all the riparian communities sharing Lake Victoria.

The State of Lake Victoria Environment Before 1997

Prior to the initiation of LVEMP activities in 1997, the regional capacity to plan, implement and evaluate water quality management activities in a realistic manner had been relatively weak. Since there was no comprehensive water quality-monitoring programme in place, information on the lake's water quality was based on spatially limited and infrequent data collected by local and international researchers mostly on an *ad hoc* basis. Most of the research at that time was undertaken in the northern and eastern sectors of the lake in Uganda and Kenya, and only a few were carried out in the western and southern sectors of the lake (Tanzania). But nonetheless, we should be very thankful to the early European, American and the few east African scientists whose work during the period under review has farmed a springboard for the future work aiming to sustainably address the lake Victoria ecosystem problems. As Hecky (1993) rightly said, we are indeed fortunate at Lake Victoria received the attention of some excellent limnologists and fisheries scientists in the 1950's and 1960's so that we have perspective on the lake's modern condition.

The Lake Victoria ecosystem has increasingly degenerated since early 1960s both in water quality and in the diversity of its fishery. These changes were driven by high population increase and their associated activities and economic development and species introductions both planned and unplanned. Population growth and the activities required to sustain the increasing population resulted in increased flows of pollutants and nutrients to the lake and its tributaries from the catchment leading to pollution, siltation, eutrophication of the lake and water-related public health problems. The lake has also, since the late 1980's, been invaded by the water hyacinth which presented a challenge to the coastal activities and environmental managers through chocking of waterways and intakes and interrupting the fishery. These in combination with other problems in turn resulted into decline in biodiversity, deoxygenation of the deeper waters of the lake, dominance of toxic algal species and increased water-borne and other water related diseases.

Water Pollution

During the period, it was observed that some of the rivers and streams feeding the lake and the near-shore areas were particularly polluted by raw and partially treated municipal and industrial effluents, contaminated urban surface runoff, and the unsanitary conditions of the shoreline settlements. These introduced into the lake increased coliforms of faecal origin, oxygen demanding organic substances, heavy metals such as chromium, lead and mercury and pesticides. Also some inflow of residues from the use of chemical herbicides and pesticides in some areas in the lake catchment, and specialized industries such as gold mining, were viewed as potential sources of heavy metal and pesticides pollution. The small-scale gold mining activities in Mwanza and Mara regions increased and the use of mercury in recovery of gold posed potential contamination of waterways (leading to the lake). Modern mining activities using closely controlled cyanide-based processes for gold extraction have also grown alongside the increasing artisanal mining activities. The increased faecal contamination of the nearshore lake waters was associated with increased cases of water-borne and other water related diseases including diarrhoea, intestinal worms, cholera, typhoid and dysentery. Proliferation of water hyacinth also increased the habitat for the snails which are the host for the parasite *Schistosoma*, responsible for bilharzias in humans.

The lake water quality problems primarily are driven by land based activities and secondarily from lake-based activities. They were actually a result of increased population pressure and the associated increased human activity. It was observed that populations of urban areas along the lake were growing at an estimated 6 percent per annum or more and rural areas near the lake shore were experiencing in-migration which was causing faster growth of their populations (World Bank 1996).

Because the level of fertilizer uses in agricultural areas around the catchment was generally low, the main rural source of the nutrients was obviously soil erosion, which released nitrogen and phosphorus held in the natural soil profile. In many instances such nutrients are not available to agriculture, but are released by changes in the chemical forms of these compounds once the soil is washed into the lake (World Bank 1996). In urban areas and shoreline settlements, the main sources of nutrients were human wastes especially from raw and partially treated sewage and the obtaining unsanitary conditions.

High population growth coupled with poverty and lack of appropriate agricultural methods also increased pressure on land and natural resources in general. The small scale farmers and even larger plantations resorted to cultivating in areas with steep slopes, riverbanks, forests and wetlands. These activities contributed to increased soil erosion, decreased nutrient retention in soils and wetlands, and thus increased mineral and biogenic sedimentation in the lake. Overgrazing and deforestation also contributed significantly to soil erosion. Deforestation, mainly related to clearing of land for agriculture, the rising need for timber used for construction, demands for wood fuel for cooking and smoking fish increased in proportion to the population growth. The loss in permanent vegetation cover has accelerated runoff and increased exposure of soils to sheet and gully erosion. The clearing of forests is largely done by burning and demands for fuel wood also require burning. Consequent to the burning is the mobilization into the atmosphere of many compounds including those of nitrogen and phosphorus in gaseous and particulate forms that can be transported from the catchments and deposited to the lake. Increasing tillage of the land also exposes the soils for periods of the year to wind erosion which can also contribute to nutrient transport from the catchments.

Eutrophication

In Lake Victoria, eutrophication has been the result of increased inflow of nutrients particularly nitrogen and phosphorus. During the period under review, the concentration of total phosphorus rose markedly all over the lake, and total nitrogen and total phosphorus rose in the near shore areas. Stimulated by these nutrients algal growth increased (Fig. 1) and its composition shifted towards domination by heterocystous blue-green Cyanobacteria (Hecky 1993). This led to, decline of transparency from 5 meters in the early 1930s to one meter or less for most of the year in the early 1990s (Mugidde 1993). By the early 1990's, the lake algal growth was nutrient saturated as high phosphorus concentrations enable nitrogen fixing Cyanobacteria to dominate and algal growth became light limited due to self-shading effects of the increased algal abundances (Mugidde 1993; Mugidde *et al* 2003). Algal blooms, through the oxygen demand as this excessive growth of algae decayed, led to deoxygenation of deep waters (Hecky *et al* 1994) and increasing reports of fish kills associated with these blooms (Ochumba and Kibaara 1989). Apart from the increased abundance of algae dominated by potentially toxic species, the water hyacinth since 1989 began to choke important waterways and landings (World Bank 1996). The waterweed (water hyacinth) mostly infested the relatively shallow sheltered bays and gulfs receiving high nutrient loads from the catchment. Because it floats on the surface, the plant cannot be light limited as the algae are, and can therefore out-compete the algae in nutrient-rich areas. The dense cover of water hyacinth can shade algal populations but also these stands can also cause deoxygenation of waters beneath them and cause shallow water conditions of low or no oxygen.

FIG. 1. Typical Algal Blooms in Mwanza Gulf.

Increased algal growth caused de-oxygenation of water, increased sickness for humans and animals drawing water from the lake, clogging of water intake filters, and increased chemical treatment costs for urban water supplies (World Bank 1996). Apart from the near-total loss of deepwater fish species, the de-oxygenation of the lake bottom posed threat even to fish in shallower portions of the lake, as periodic up welling of hypoxic water caused massive fish kills. (Ochumba 1998; Ochumba and Kibaara 1989). These symptoms of environmental degradation were known already in the late 1980's based on limited studies available the extent of these conditions throughout the great expanse of Victoria were not know. Also, although the causes of eutrophication were known from international experience and research, the rates of enrichment, its sources and its numerous effects in the Lake Victoria basin were not well quantified so it was not possible to estimate economic and ecological costs nor to determine if and what restoration activities would be necessary to reverse the undesirable trends.

LVEMP Implementation

Lake Victoria Environmental Management Project is as a multidisciplinary environmental project funded by the World Bank and Global Environmental Facility. One of the components of LVEMP is the Water and Ecosystem Management. The component comprises of three sub-components namely In-lake Water Quality Monitoring, Management of Industrial and Municipal Waste and Management of

Pollution Loading into Lake Victoria. The objectives of this report are to provide: 1) the first detailed regional synthesis of data generated during LVEMP by national components and published in the LVEMP National Water Quality Reports in order to inform and guide regional policy development, 2) to present a regional consensus on the current state of the lake and identify any negative trends affecting the beneficial uses of the Lake Victoria, and to recommend possible and appropriate actions for regional implementation to restore or improve those beneficial uses. This document will provide a critical benchmark for environmental management of Lake Victoria by providing a comprehensive baseline against which the effects of future management or neglect can be evaluated.

Major Findings from Each Chapter

Capacity Building for Water Quality Management

Apart from training, elaborate infrastructure for water quality monitoring has been established in the region. In Kisumu, Mwanza, Bukoba and Musoma laboratories were rehabilitated and equipped, whereas the Entebbe laboratory was equipped with more sophisticated equipment. There is now a regional network for data collection in the in the catchments, inshore and offshore areas of the lake, and for atmospheric deposition. Quality control and quality assurance protocols are now practiced and coordinated among the three countries. LVEMP has put emphasis on establishment of internal and regional quality assurance mechanisms, enhancement of laboratory performances and efficiency, and data generation and management.

Training programs were designed to provide scientists with strengths in applied limnology, monitoring and the environment. In addition, the training provided scientists with a firm background in data analysis, interpretation and synthesis procedures, including statistics, numerical analysis, programming and conceptual modelling methods. Most hydrologists and water chemists in public and private employment were formerly educated in a tradition that emphasized qualitative schooling, and this project therefore has managed to train a new type of scientist who can apply quantitative methods to their research, monitoring or operational undertakings. The scientists also benefited from adequate training in computer analytical techniques, most notable in the area of model applications, graphics; including map, contour plotting, remote sensing interpretation, GIS; and interpretation of water quality data.

The scientists obtained both practical and theoretical knowledge, thus they are now able to integrate and apply a number of scientific disciplines to problems of relating to the water quality monitoring of the lake and its ecosystem, in addition to environmental management and conservation of the catchment. By participating in high level courses in addition to computer training and fieldwork, the scientists have now acquired an in-depth understanding of the fundamental principles of limnology and water quality monitoring. The scientists of this programme are now well-grounded field specialists, who apart from their specialization in water related issues appreciate the exigencies of other related disciplines. Their specializations within an inter-disciplinary/trans-disciplinary framework have resulted in versatile international scholars armed with knowledge, awareness and skills to assess and solve pertinent environmental issues and problems afflicting the lake.

Although research vessels were obtained from each country's research institute, this arrangement was not efficient since the vessels were obtained only at their discretion and convenience; it would probably be better if the regional component could acquire its own vessel to guarantee effective implementation of logistics and monitoring.

Water Balance

One of the principal objectives of the Water Quality and Quantity Components is to find the reasons for the changes observed in the lake water quality, quantity and ecosystem, and to identify remedial measures. To identify the reasons for the changes one requires a knowledge of the changes in the pollution loadings to the lake, which, in turn, depends on the discharges into the lake from the catchments and the atmosphere and lake outflow to River Nile i.e. hydrology and meteorological characteristics in and around the lake.

Hydro-metrological data for the period running 1950-2004 was analysed which form the basis for computing the pollution loadings (catchment and atmospheric) into the lake and lake water balance. Continuous rainfall and evaporation records were generated. Full records of land discharges were obtained through modelling using the NAM model. Model performance was evaluated on the ability to simulate the total flow rather than the peak and minimum flows for pollution estimation.

Results indicate that Tanzania's unshared land catchment annual discharge contribution to Lake Victoria is approximately 5,430 BCM[1], while Uganda's one is approximately 1,062 BCM and Kenya's one is approximately 9,271 BCM which in percentage are 21.4%, 4.2% and 37% respectively. Rivers Mara and Kagera that are shared between Kenya and Tanzania and Tanzania, Rwanda, Burundi and Uganda respectively had total flows of 1,151 BCM and 8,215 BCM accordingly representing 4.6% and 32.7% of the total catchment discharges. The mean annual rainfall over the Ugandan side of the lake is about 62,539 BCM, Tanzania is about 60,682 BCM and Kenya is about 4,541 BCM. These forms 48.9%, 47.5%, and 3.6% respectively of the total mean annual lake rainfall into Lake Victoria. There was a 10.7% decrease in rainfall over the Lake in the period 1972-1993. In the period 1994-2004 there was a 2.2% increase in the amount. However there was a 14.7% decrease in catchment inflows into the lake and a 1.64m drop in water level in the period 1998-2004. Analysis of the components of the hydrological balance of the lake indicated that the recent decline in lake level is primarily the result of excessive withdrawals at the Nile outflow during a period of falling river discharges to the lake.

The Lake in Motion

The waters of Lake Victoria are set into motion by energy exchange processes across its surface. The overlying air-mass through radiant energy and heat exchange can

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[1] Billion Cubic Metres

heat and cool lake waters and effect changes in density that can encourage or constrain vertical circulation. Winds blowing over the surface can set near surface waters into motion and cause horizontal circulation (currents) as well as generating wave-related turbulence that can mix waters more deeply into the depths of the lake. Where rivers enter, both horizontal transport and vertical mixing can be set in motion by the momentum and physical characteristics of the entering rivers. The Kagera river is exceptional in the dominance of open lake processes affecting the behaviour and mixing of its plumes as it enters into the lake directly. Most of the other rivers entering Lake Victoria enter behind islands or into protected gulfs and embayments where the hydrodynamics of river mixing are governed by local coastal process and the dynamics of the bays. The water motions that result from the net affect of all these energetic inputs determine the distribution of the dissolved and suspended materials in the water as well as affecting even the free swimming biota. Thus, it is necessary not only to determine the vertical transport of nutrients but also the horizontal transport of matter throughout the lake. The strength of horizontal circulation will also determine how widespread events such as pollution spills will be.

Coordinated observations overall of Lake Victoria have confirmed that phases 2 and 3 of the annual thermal and stratification cycle as defined by Talling (1966) for the north-eastern sector of the lake. Phase 2 is the development of the deep (40 m) thermocline in the period February to May, and phase 3 is the total vertical mixing that occurs in July-August. Phase 1 (September-December) is less obvious, i.e. the gradual warming of the water column is weak, and almost total mixing occurs in December-January at some stations. All three phases are less obvious on the western side of the lake. The western part of Lake Victoria is much more influenced by the wind forces and therefore experiences more mixing and cooling patterns. The eastern part of the Lake is much more influenced by persistent thermal stratification, and therefore vertical mixing is mainly by seasonal temperature dependent density currents. The implications are that the potential for nutrient transfer, sediment re-suspension is higher in the western part of the lake, which yields favourable conditions for species having high oxygen requirements e.g. the Nile perch.

Main processes determining the fate and transport of pollutants are mixing (dispersion) and flow (advection) were also studied. These were modelled/simulated using the hydrodynamic module which is based on the generic DELFT3D-FLOW simulation package. The only wind data which could be used in the model was the global winds for 1998 which were delivered together with the framework model. The results from the model agree quite well with the measured currents during the month of September.

The Changing Lake

Water quality monitoring was carried out in the harmonised monitoring network of Lake Victoria between August 2000 and March 2005. The programme was designed to evaluate the spatial and temporal variability of the various water quality parameters, enable comparison of these data with historical records, and provide a comprehensive lake-wide baseline against which future changes and management of the lake can be evaluated. Littoral areas (0-20m) showed higher temperatures, pH, turbidity and electrical conductivity, while Secchi depths and dissolved oxygen concentrations were lower compared to pelagic areas. Pelagic sites experience thermo-stratification, leading to strong differences between surface and deep-water layers especially in terms of temperature and dissolved oxygen except for the June-August period when the lake mixes completely. On average, littoral stations have higher total nitrogen, chlorophyll, organic matter as well as total particulate carbon. Phytoplankton production and biomass in shallow inshore sites are light-limited due to self-shading. Nitrogen often limits algal growth except for some species of Cyanobacteria that can fix atmospheric nitrogen to meet their N demand. The higher algal biomass accounts for the higher TN concentrations, chlorophyll and organic matter at littoral sites.

During thermal stratification, TP and SRP concentrations are comparable in littoral and pelagic sites while during and just after mixing, both fractions of P are higher in the littoral areas. Continuous excess SRP and the ability of Cyanobacteria to fix atmospheric nitrogen create nutrient saturated conditions that result in light limitation for algal growth. Annual rainfall characterised by two peaks (April-May and June-August) appears to be the main source of nutrient enrichment in the open lake, particularly TP. Decomposition of organic matter at the lake bottom during the stratification results into release of TP and Si which build up to much greater concentrations than in surface waters. TN reaches annual minimum during mixing and is associated with the addition of N-poor deep waters reducing N concentrations in surface waters. Chlorophyll concentrations also reach their annual minimum at this time as deep mixing imposes strong light limitation on algal growth and nitrogen fixation.

Comparison with historical records shows that the lake is changing. Today it is warmer than in the 1960s but with lower oxygen and pH in the deeper waters; severe hypolimnetic oxygen deficit in deeper waters during thermal stratification has led to loss of habitat for fish and other aquatic biota. Chlorophyll levels; phosphorus concentrations and electrical conductivity in both littoral and pelagic stations have increased; Nitrogen concentrations around marginal bays and gulfs have not shown a marked increase; and Dissolved silica in the pelagic areas has decreased 5-20 times as eutrophication has increased Si demand by diatoms relative to rather constant supply from the catchment. In line with increased turbidity, Secchi depths have decreased two-fold since the 1960s. In this regard, the need for lake wide regular water quality monitoring and basin developments in support of appropriate management interventions cannot be overemphasized.

Eutrophication and its Effects

Between 2000 and 2005 water quality and limnological studies were carried out in Lake Victoria in order to establish the lake eutrophication effects on ecosystem health. Comparison between littoral and pelagic areas of the lake showed marked spatial and temporal differences between and within the zones.

Nitrate nitrogen (NO_3-N) and phosphate phosphorus (PO_4-P) concentrations ranged between 16.2 - 87.9 µg/l and 39.6 - 92 µg/l respectively and were both higher in the northeast sector of the lake. Silica (SiO_2-Si) concentrations ranged between 0.525 and 0.902 mg/l and the values were higher in the northeast and southwest compared to mid-lake stations. Nyanza Gulf had lower PO_4-P concentrations (16.2 to 21.1µg/l) than the

Mwanza and Napoleon Gulfs (54.8 to 68.7µg/l) but registered higher SiO_2-Si concentrations (4.5 to 5.2 mg/l) than the other two gulfs. NO_3-N concentration in the gulfs ranged between 25 and 93 µg/l with Napoleon Gulf having higher values than the other two gulfs. Total phosphorus (TP) in the pelagic waters ranged between 78 and 100 µg/l and total nitrogen (TN) ranged between 530 and 830 µg/l l. The TN: TP ratio in the main lake (<20) indicate that phytoplankton growth in the lake is nitrogen deficient; a situation favouring dominance of nitrogen fixing Cyanobacteria. This low TN: TP ratio is probably associated with the increased phosphorus loading as well as selective nitrogen loss through denitrification and enhanced recycling of P associated with increased anoxic conditions in the deep pelagic waters. Comparison with Tallling's 1961 values, SiO_2-Si concentrations in the lake have generally decreased by a factor of 3 and up to 8 at the Talling's historical station of Bugaia (UP2).

Chlorophyll *a* concentrations in the pelagic areas ranged between 3.6 and 11.7 µg/l and were generally higher in the littoral than in the pelagic areas. The phytoplankton community was dominated by Cyanobacteria (>50%) especially the species *Microcystis*, *Anabaena* and *Cylindrospermopsis* in both the littoral and pelagic waters. Relatively high diatom biomass was recorded in the pelagic compared to the littoral areas and *Aulacoseira* (*Melosira)*, the formally dominant diatom species, was rarely encountered. Compared to previous records, the invertebrate community composition has remained relatively stable despite drastic changes in water quality and fish stocks. Zooplankton densities were generally higher in the littoral than pelagic zones. The abundance of *Caridina nilotica,* lakes fly larvae, and other invertebrates have increased in the lake with eutrophication and the decline of haplochromine stocks. Comparison of present zooplankton densities with previous records indicates no marked differences in abundance patterns over the past 15 years suggesting a stable and dependable resource to as a prey base especially for juvenile fishes. The OECD indicators of trophic status indicate that the pelagic waters range from mesotrophic to eutrophic and the littoral zones are hypertrophic. In order to stem further deterioration of lake water quality and to eventually restore the beneficial uses of the lake, management of phosphorus loading into the lake should be given urgent priority.

The Nutrient Balance

It is now recognized by most of the scientific community that Lake Victoria is enriched with nutrients. There are, however, conflicting reports on the magnitude of nutrients received from different sources and the dynamics of nutrients in the Lake. Studies were carried out to determine the lake nutrient balance and suggest strategies for sustainable utilization of the resources. Lake nutrient balance is essential for understanding primary productivity and ecosystem function and for planning nutrient management strategies.

The current findings identify major point and non point sources of nutrients and estimate the rates of sedimentation into Lake Victoria. The determination of pollution loads from point sources was limited to the Biochemical Oxygen Demand (BOD5), Total-Nitrogen (TN), and Total-Phosphorus (TP). For the non-point pollution sources emphasis was given to TN, TP and TSS, the loads from rivers and atmospheric deposition have been calculated, both due to their relevance as quality indicators and their contribution to eutrophication of the Lake. For the purpose of determining the nutrient balance of the lake, the sedimentation rates in the lake have also been calculated both fluxes per unit area and total lake bottom accumulation.

Municipal effluent load was higher than industrial one, but they both represent a threat to the community downstream the discharge point and the littoral zone of the lake. Atmospheric deposition was the overall dominant source contributing about 39,978 and 167,650 tons of TP and TN respectively to the lake annually. The riverine loads are estimated at 9,270 of TP and 38,828 tons/y of TN respectively, and represented in both cases 80% of the total non-point load. Point sources are estimated to contribute about 4.3 of TN and 1.9 tons/year of TP. The cores dated and analyzed show dry weight accumulation rates of 100 $g.m^{-2}y^{-1}$ to 300 $g.m^{-2}y^{-1}$. Linear regression indicates sedimentation rates of 0.5 to 1 mm per year. Furthermore, highest rates of permanent sediment accumulation occur in the deepest areas of the lake. However, the study indicates that rate of nutrients regeneration is 90% for C and N and 60% for P. It is therefore recommended that pollution loading into the Lake be controlled by reducing point sourcing and providing tertiary treatments for removal of P, use of phosphorus free detergents, cleaner production technologies, and addressing non-point sources by improved land management. An initial goal of reducing the anthropogenic phosphorus loading to the lake by 30% would reverse the current upward trend and achieve water quality conditions that occurred in the 1980’s when fish production was at its maximum. Trans-boundary efforts may be required to control atmospheric deposition into water bodies.

Changing Water Quality and its Effects to the Communities

The impact of water quality changes in the Lake Victoria basin on beneficial uses is discussed. Beneficial uses of resources from the lake basin are very significant for the livelihoods of the riparian communities and the respective states. The basin is also a source of fish and fish-products to the international market. The paper presents the relationship between water quality, ecosystem health and socio-economic implications on the riparian communities. Valuation of impacts and need for action in response to the impacts are addressed.

Findings showed that banned organochlorines e.g. DDT is still being used in the catchments. It is also shown that mercury contamination of soil and watercourses occurs but is highly localized. The levels of heavy metals in Lake Victoria waters and fish are within the acceptable limits of the international standards. Waterborne/water-related diseases including diarrhoea, dysentery, amoebiasis, typhoid, intestinal worms, bilharzia, malaria, skin diseases and eye infections have increased in the basin. HIV/AIDS and other STDs were also common at landing sites. Agriculture, urban runoff, municipal, domestic and industrial wastes are the major sources of pollution that contributes to the flourishing of water borne pathogens. In most fishing villages, sanitary conditions were poor, and even latrines were inadequate. Some major towns along the shores such as Bukoba and Musoma (Tanzania) have no sewerage systems. Destruction of wetlands has aggravated the situation by removing buffering capacity for pollution loads. Highly toxic blue-green algal blooms consisting of *Microcystis* and *Anabaena* spp. dominate the nearshores of bays and gulfs.

It was noted that water quality change in the basin has adversely affected the beneficial uses of Lake Victoria basin waters by the riparian communities. These trends need to be controlled or reversed; hence the need for action. Cause-effect relationships between specific activities and their impacts on Lake Victoria are also presented. Recommendations for LVEMP phase 2 to undertake in order to restore the lake basin to pre-1980s conditions to improve on the beneficial uses are offered.

RECOMMENDED ACTIONS

1. To capture fully seasonal variations of the Lake Victoria ecosystem at least one year of systematic continuous monitoring should be implemented during LVEMP II there after the frequency can be revised to once every three or four months throughout all of the years

2. Basic and contracted research should remain a component during the LVEMP II so that the results are scientifically justified and published

3. Enhance or put in place: legislative, regulatory, and compliance enforcement.

4. Educate, train, and raise awareness for stakeholder

5. Sustain the attained capacity during LVEMP 1through a timely maintenance of the infrastructure and put in place the staff retention scheme to minimize “greener pasture” migration.

6. Employ or establish the GIS/data base/information management so as to keep record of all the data gathered

7. Pilot projects that are aiming at reducing pollution to the lake should be implemented; for example catchment managements and urban sanitation management, etc

8. Mapping the lake area quality against fish abundance thus study the environmental influence on fish ecology

9. Emphasis should be put on measurement of lake circulation (ADCP should be made available to all countries) so that the lake hydrodynamic can be studied as this is the major driving force for pollutants and fish migration

10. Some studies on global and micro climate change should be conducted to determne their possible role in the reduced and declining lake levels.

11. Multi-purpose management of Owen falls and other consumptive use of Lake Victoria waters should be embedded in an ecosystem approach to lake management to ensure optimum results for the beneficial uses of the lake

12. Proper lake management can not be achieved only by water quality monitoring but also require simulation/modeling of possible interventions and meterorological processes, thus a need for training in modeling especially hydrodynamic and quality modeling

13. More studies on hot spot areas and establish the levels of pollution from industries and municipalities in the near shore areas include also hazardous pollutants not only eutrophication causing parameters. Lake water and fish heavy metal, pesticides and fungicides pollution/contamination

14. Study the role of sediment in transportation of pollutants from the catchment via the river up to the lake and the role of land use in determining rates of erosion, transport and nutrient yield

15. More studies on algal toxin and their effect to health are required

16. In view of the vulnerability of planktons to environmental degradation, future research efforts should emphasize on regular monitoring of the communities in response to water quality changes –these are the major food for the fish and inputs to models that can predict fish production.

17. Conduct social economic studies of water quality of the lake in relation to health and beneficial uses Beneficial uses of lake water include

    - Domestic, Agricultural, and Industrial water
    - Energy generation
    - Tourism -Aquatic life
    - Transport
    - Recreation
    - Waste Disposal
    - Cooperation
    - Regulating climate

18. Efforts should be made to put a monetary value for each of these beneficial use and their impacts on Lake Ecosystem be established.

19. Using a stakeholder consultative approach, the new Lake Victoria Basin Commission of the EAC should establish water quality objectives for Lake Victoria.

20. Once water quality objectives are set, then a strategic action plan should be developed by the commission for pollution reduction to meet those objectives and a monitoring program put in place to evaluate progress.

ISSUES AT THE FINAL STAKEHOLDER WORKSHOP

- How can we make the data obtained meaningful and acceptable to the community?
- How can we modify the methodology in the future to make researchers interact more with communities?
- How to reduce vandalism of the scientific equipments put in monitoring sites?
- Water balance is facing problems of reduced inflow and increased outflow. The issue is, how can the outflow at Jinja be holistically regulated.
- Lake Victoria water quality model has been developed but is yet to be implemented. The issue is, when will the implementation of the model take place?
- Data and information have revealed that nutrient loading have been excessive. The issue is, how to address the increase of N & P in the lake?
- How to introduce and implement polluters-pay principle, and
- how can the data be used to predict water level in the coming years?

WAY FORWARD

- Use the data and information generated during LVEMP I to make proper strategies for Management of the Lake Basin Ecosystem. Research should continue to fill identified gaps as indicated in the Synthesis and Lessons Learned Reports
- Efforts should be stepped up to address poverty currently affecting the majority of the people in the basin. Focus should be on sustainable use of available natural resources and alternative livelihood activities other than fishing.
- The excessive fishing effort should be addressed through appropriate measures urgently.
- Implementation of the Phase II should be internalized to the Local Government Authorities for Local Community ownership, local capacity building and sustainability of project activities.

- In order to fight poverty (income generation) investment from outside the basin and the countries is very necessary. It is therefore essential for LVEMP II to come up with strategies for attracting investments into the basin.

- The staff trained under LVEMP I should be retained to avoid going for greener pastures.

- There are priority areas of concern – e.g. inflow of water hyacinth through Kagera, untreated waste from municipalities and industries in the major cities and towns.

CHAPTER 1

The changing water quality of Lake Victoria; current conditions, trends and required action

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INTRODUCTION

The Water quality and Ecosystem Management Components of the Lake Victoria Environmental Management Project (LVEMP) in the three riparian countries (Kenya, Tanzania and Uganda) have made considerable progress towards understanding Lake Victoria water quality and its ecosystem as well as effects of resource utilization and exploitation on the lake and in its basin. In order to achieve LVEMP objectives and Water Quality and Ecosystem Management objectives, in particular, a well-coordinated analysis, synthesis and interpretation of all relevant data was required. This report documents and explains the changes that have taken place over the recent decades, and provides an overview of the present water quality status of the lake as well as identifying past changes and continuing trends that may require remedial action.

The report provides detailed information and spatial resolution at the regional scale to support environmental decision-making in regards to possible remediation of undesirable changes that have reduced beneficial uses of Lake Victoria biological and water resources. This regional synthesis report was written by regional scientists and technical experts under the guidance of an international consultant, Prof. Robert Hecky of the University of Waterloo, Canada, together with the National consultants; Dr. Joseph Abuodha of the Maseno University, Prof. Fredrick Mwanuzi of the University of Dar Es salaam and Dr. Fredrick Muyodi of Makerere University. It brings together data, interpretations and recommendations from three national water quality reports. A number of national and regional working sessions were conducted to enable the scientists to complete these reports, and all these were facilitated by the National Executive Secretariats of LVEMP who were supportive through out the process.

Background

LVEMP is a comprehensive program conducted by the three countries aimed at maintenance and rehabilitation of the lake ecosystem for the sustainable benefit of the 30 million people who live in the basin, their national economies and the global community.

The overall objectives of the LVEMP are to maximize the sustainable benefits to riparian communities from using resources within the basin to generate food, employment and income, supply safe water, and sustain a disease free environment; to conserve biodiversity and genetic resources for the benefit of the riparian communities and global community and to harmonize national management programs in order to achieve, to the maximum extent possible, the maintenance of a healthy Lake Victoria ecosystem and the reversal of increasing environmental degradation.

One of the critical components of LVEMP concerns Water Quality and Ecosystem Management which has the overall objectives of elucidating the nature and dynamics of the lake ecosystem by providing detailed information on characteristics of the waters of the lake, establishing a water quality monitoring network throughout the catchment, estimating the effects of changes in land use planning on pollution loads into the lake, developing policies and programmes to control non-point source pollution, improving management of Industrial and Municipal effluents and assessing the contribution of urban runoff to lake pollution.

The Water Quality and Ecosystem Management Component has since the inception of the Project made considerable progress towards understanding the Lake Victoria water quality and the aquatic ecosystem as well as effects of resource exploitation within the lake and its basin. The component has collected considerable amounts of new data and information.

The component, using historical data and the data it initially collected produced an initial report in 2002, which provides a baseline for water quality status at the start of the project and indications of possible change from historic conditions. The data have also been used in scientific fora within the region. But, in order to achieve LVEMP objectives in general and Water Quality and Ecosystem Management objectives in particular a well-coordinated analysis, synthesis and interpretation of all relevant data are required. This report will document and explain the changes that have taken place over the recent decades, and it will provide a definitive overview of the present water quality status and continuing trends that may require remedial action. The report provides enough detailed information and spatial resolution to support environmental decision making in regards to spatial allocation of possible remediation of undesirable changes that have reduced beneficial uses of Lake Victoria biological and water resources.

Approach to Synthesis Report

All the available data and reports generated by the component since the start of the project were first collected, collated, updated, reviewed and incorporated to National Water Quality Reports. The National Reports and the analyses contributing to them form the basis of this regional synthesis addressing the following issues:

i) Determine the current state of knowledge of the Lake Victoria water balance;
ii) Use the components of the water budget to estimate current nutrient loads and balances of the lake;
iii) Define trends in limnology and water quality, and provide quantitative information on past, and if possible future, nutrient loading, nutrient losses and nutrient availability within the lake;
iv) Identify the sources of micro/macro nutrients promoting eutrophication in a spatially explicit manner that can guide remedial action and demonstrate how these inputs are affecting lake productivity;
v) Summarize what is known about the presence and concentrations of contaminants in lake water and biota and, if possible, define trends in these contaminant loadings over time;
vi) Describe the phytoplankton communities, their composition and their effects on beneficial uses of the lake ecosystem, in particular addressing algal bloom dynamics within the lake in relation to current and past rates of primary production;
vii) Determine the trophic interrelationships of the lake's biological communities and especially address how eutrophication and food web alterations are affecting fisheries of Lake Victoria;
viii) Determine the role of lake consumers e.g. zooplankton, zoobenthos, microbes and lake flies in the ecosystem dynamics;
ix) Using the available information on the horizontal and vertical circulation of waters determine its effect on the spatial distribution of nutrients, algae, oxygen, contaminants and organisms in Lake Victoria;
x) Relate the water quality findings with the findings of other Components of LVEMP;
xi) Assess effects of poor water quality on the socio economic aspect of the riparian communities;
xii) Provide data for eventual use in the Lake Victoria Water Quality Model to simulate the future effect of different interventions and management options for the lake.

The above issues are grouped and summarised in different chapters addressing specific issues. Chapter 2 on Capacity Building for Water Quality Management addresses how LVEMP has addressed critical constraints in infrastructure, programmes and technical capacity to improve regional capacity for management of the water quality of Lake Victoria. Chapter 3 presents the water balance of the lake quantifying inputs, outputs and how they affect lake level changes. Increasingly the water balance of the lake is affected by multiple use management objectives that can affect riparian uses around Lake Victoria and also downstream along the Nile. Chapter 4 addresses the critical meteorological processes that set the waters of the lake into motion and change their vertical circulation over the seasons. These movements dictate the transport and mixing of incoming materials through out the lake. Chapter 5 of the report describes the results of the monitoring program on Lake Victoria that for the first time allows a full spatial analysis of conditions throughout the lake. This facilitates comparison with earlier data that were more constrained to specific locations while providing a comprehensive description of present conditions on the lake that will provide a baseline for future assessments and trends. Chapter 6 examines the lake's most urgent water quality problem, eutrophication, and explains its causes, its severity and possible solutions. Chapter 7 quantifies the sources of nutrients and sediments to Lake Victoria, estimates a nutrient balance for the lake for the first time, and determines the fate of incoming nutrients within the lake. Chapter 8 describes how changing water quality affects the communities around the lake that are dependent on that water quality to meet their daily needs. The lake provides many beneficial services to the communities, but many of these uses are degraded or at risk. Similarly haphazard, poorly planned and unsustainable development will continue to degrade the lakes' uses. Rehabilitation of degraded resources will require an action plan to restore and preserve the beneficial uses of the lake for all the riparian communities sharing Lake Victoria.

The State of Lake Victoria Environment before 1997

Prior to the initiation of LVEMP activities in 1997, the regional capacity to plan, implement and evaluate water quality management activities in a realistic manner had been relatively weak. Since there was no comprehensive water quality-monitoring programme in place, information on the lake's water quality was based on spatially limited and infrequent data collected by local and international researchers mostly on *ad hoc* basis. Most of the research at that time was undertaken in the northern and eastern sectors of the lake in Uganda and Kenya and only a few were carried out in the western and southern sectors of the lake (Tanzania). But nonetheless, we should be very thankful to the early European, American and the few east African scientists whose work during the period under review has provided a baseline for the future work aiming to sustainably address the Lake Victoria ecosystem problems. As Hecky (1993) rightly said, we are indeed fortunate at Lake Victoria received the attention of some excellent limnologists and fisheries scientists in the 1950's and 1960's so that we have perspective on the lake's modern condition.

The Lake Victoria ecosystem has increasingly degenerated since early 1960s both in water quality and in the diversity of its fishery. These changes were driven by high population increase, their associated activities and economic development and species introductions both planned and unplanned. Population growth and the activities required to sustain the increasing population resulted in increased flows of pollutants and nutrients to the lake and its tributaries from the catchment leading to pollution, siltation, eutrophication of the lake and water-related public health problems. This has been the experience of lake basins around the world that have experienced rapid population growth and economic development. The lake has also since the late 1980s been invaded by the water hyacinth which presented a challenge to the coastal activities and environmental managers through choking of waterways and intakes and interrupting the fishery. These in combination with other problems in turn resulted into decline in biodiversity, deoxygenation of the deeper waters of the lake, dominance of toxic algal species and increased water-borne and other water related diseases.

Water Pollution

During the period, it was observed that some of the rivers and streams feeding the lake and the near-shore areas were particularly polluted by raw and partially treated municipal and industrial effluents, contaminated urban surface runoff, and the unsanitary conditions of the shoreline settlements. These introduced into the lake increased faecal coliform bacteria, oxygen demanding organic substances, heavy metals such as chromium, lead and mercury and pesticides. Also some inflow of residues from the use of chemical herbicides and pesticides in some areas in the Lake Catchment, and specialized industries such as gold mining, were viewed as potential sources of heavy metal and pesticide pollution. The small-scale gold mining activities in Mwanza and Mara regions and increased use of mercury in recovery of gold by artisanal miners posed potential contamination of waterways (leading to the lake). Modern mining activities using closely controlled cyanide-based processes for gold extraction have also grown along side the increasing artisanal mining activities. The increased faecal contamination of the near shore lake waters was associated with increased cases of water-borne and other water related diseases including diarrhoea, intestinal worms, cholera, typhoid and dysentery. Proliferation of water hyacinth also increased the habitat for the biomphilaria snails, which are the host for schistosoma responsible for bilharzias.

The lake water quality problems primarily are driven by land based activities and secondarily from lake-based activities. They are a result of increased population pressure and the associated increased human activity. It was observed that populations of urban areas along the lake were growing at an estimated 6 percent per annum or more and rural areas near the lake shore were experiencing in-migration which was causing faster growth of their populations (World Bank 1996).

Because the level of fertilizer uses in agricultural areas around the catchment was generally low, the main rural source of the nutrients was soil erosion, which released nitrogen and phosphorus held in the natural soil profile. In many instances such nutrients are not available to agriculture, but are released by changes in the chemical forms of these compounds once the soil is washed into the lake (World Bank 1996). In urban areas and shoreline settlements, the main sources of nutrients were human wastes especially from raw and partially treated sewage and the obtaining unsanitary conditions.

High population growth coupled with poverty and lack of appropriate agricultural methods also increased pressure on land and natural resources in general. The farmers resorted to cultivating in areas with steep slopes, riverbanks, forests and wetlands. These activities contributed to increased soil erosion, decreased nutrient retention in soils and wetlands, and thus increased mineral and biogenic sedimentation in the lake. Overgrazing and deforestation also contributed significantly to soil erosion. Deforestation, mainly related to clearing of land for agriculture, the rising need for timber used for construction, demands for wood fuel for cooking and smoking fish increased in proportion to the population growth. The loss in permanent vegetation cover has resulted accelerated runoff and increased exposure of soils to sheet and gully erosion. The clearing of forests is largely done by burning and demands for fuel wood also require burning. Consequent to the burning is the mobilization into the atmosphere of many compounds including those of nitrogen and phosphorus in gaseous and particulate forms that can be transported from the catchments and deposited to the lake. Increasing tillage of the land also exposes the soils for periods of the year to wind erosion which can also contribute to nutrient transport from the catchments.

Eutrophication

In Lake Victoria, eutrophication has been the result of increased inflow of nutrients particularly nitrogen and phosphorus. During the period under review, the concentration of total phosphorus rose markedly in the deeper lake waters and total nitrogen and total phosphorus rose in the near shore areas. Stimulated by these nutrients algal growth increased (Fig. 1) and its composition shifted towards domination by heterocystous blue-green Cyanobacteria (Hecky 1993; Hecky and Bugenyi 1992). This led to, decline of transparency from 5 meters in the early 1930s to one meter or less for most of the year in the early 1990s (Mugidde 1993). By the early 1990's, the lake algal growth was nutrient saturated as high phosphorus concentrations enable nitrogen fixing Cyanobacteria to dominate and algal growth became light limited due to self shading effects of the increased algal abundances (Mugidde 1993; Mugidde *et al.* 2003). Algal blooms and increased primary production can lead to higher oxygen consumption as excessive growths of algae decay and cause deoxygenation of deep waters (Hecky et al 1994) and increasing reports of fish kills associated with these blooms (Ochumba and Kibaara 1989). Apart from the increased abundance of algae dominated by the potentially toxic species, the water hyacinth since 1989 began to choke important waterways and landings (World Bank 1996). The waterweed (water hyacinth) mostly infested the relatively shallow sheltered bays and gulfs receiving high nutrient loads from the catchment. Because it floats on the surface, the plant cannot be light limited as the algae are, and can therefore out compete the algae in nutrient-rich areas. The dense cover of water hyacinth can shade algal populations but also these stands can also cause deoxygenation of waters beneath them and cause shallow water conditions of low or no oxygen.

FIG. 1. Typical Algal Blooms in Mwanza Gulf.

Increased algal growth caused de-oxygenation of water, increased sickness for humans and animals drawing water from the lake, clogging of water intake filters, and increased chemical treatment costs for urban water supplies (World Bank 1996). Apart from the near-total loss of deepwater fish species, the de-oxygenation of the lake bottom posed threats even to fish in shallower portions of the lake, as periodic up welling of hypoxic water caused massive fish kills. (Ochumba 1990, Ochumba & Kibaara 1989). These symptoms of environmental degradation were known already in the late 1980's based on limited studies available the extent of these conditions throughout the great expanse of Victoria were not know. Also, although the many of the causes of eutrophication were known from international experience and research, the rates of enrichment, its sources and its numerous effects in the Lake Victoria basin were not well quantified so it was not possible to estimate economic and ecological costs nor to determine if and what restoration activities would be necessary to reverse the undesirable trends.

LVEMP Implementation

Lake Victoria Environmental Management Project is as a multidisciplinary environmental project funded by the World Bank, the Global Environmental Facility and the three riparian states of Kenya, Tanzania and Uganda. One of the components of LVEMP is Water Quality and Ecosystem Management. The component is comprised of three sub-components namely In-lake Water Quality Monitoring, Management of Industrial and Municipal Waste, and Management of Pollution Loading into Lake Victoria. The objectives of this report are to provide: 1) the first detailed regional synthesis of data generated during LVEMP by national components and published in the LVEMP National Water Quality Reports in order to inform and guide regional policy development, 2) to present a regional consensus on the current state of the lake and identify any negative trends affecting the beneficial uses of the Lake Victoria, and 3) to recommend possible and appropriate actions for regional implementation to restore or improve those beneficial uses. This document will provide a critical benchmark for environmental management of Lake Victoria by providing a comprehensive baseline against which the effects of future management or neglect can be evaluated.

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CHAPTER 2

Capacity Building: Training, Infrastructure, Equipment and Monitoring Programmes for Conservation of Lake Victoria

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ABSTRACT. *Training programs were designed to provide scientists with strengths in applied limnology, monitoring and the environment. In addition, the training provided scientists with a firm background in data analysis, interpretation and synthesis procedures, including statistics, numerical analysis, programming and conceptual modelling methods. Most hydrologists and water chemists in public and private employment were educated in a tradition that emphasized qualitative schooling, and this project therefore has managed to train a new type of scientist who can apply quantitative methods to their research, monitoring or operational undertakings. The scientists also benefited from adequate training in computer analytical techniques, most notable in the area of model applications, graphics; including mapping, contour plotting, remote sensing interpretation, GIS; and interpretation of water quality data.*

The scientists obtained both practical and theoretical knowledge, thus they are now able to integrate and apply a number of scientific disciplines to problems of relating to the water quality monitoring of the lake and its ecosystem, in addition to environmental management and conservation of the catchment. By participating in high level courses in addition to computer training and fieldwork, the scientists have now acquired an in-depth understanding of the fundamental principles of limnology and water quality monitoring. The scientists of this programme are now well-grounded field

specialists, who apart from their high specialization in water related issues appreciate the exigencies of other related disciplines. Their specializations within an inter-disciplinary/trans-disciplinary framework have resulted in versatile international scholars prepared with knowledge, awareness and skills to assess and solve pertinent environmental issues and problems afflicting the lake.

Apart from training, elaborate infrastructure for water quality monitoring has been established in the region. In Kisumu, Mwanza, Bukoba and Musoma laboratories were rehabilitated and equipped, whereas the Entebbe laboratory was equipped with more sophisticated equipment. There is now a regional network for data collection in the inshore and offshore areas in addition to establishment of a precipitation network. Monitoring programs have involved placement and utilization of the harmonized monitoring network. Quality control and quality assurance mechanisms are now practiced and coordinated among the three countries. LVEMP has put emphasis on establishment of internal and regional quality assurance mechanisms, enhancement of laboratory performances and efficiency, and data generation and management.

Although research vessels were obtained from each country's fisheries research institute, this arrangement was not efficient since the vessels were obtained only at their discretion and convenience. It is recommended that this component acquire its own vessel dedicated to water quality research to guarantee effective implementation of the monitoring program in the future.

Introduction

To ensure a sustainable use of resources of this unique ecosystem there was need to collect quantitative and qualitative information to assist in formulation of environmental assessment, policy and management strategies. Generation of this information necessitated building capacity, which was lacking for understanding the water quantity and quality of the lake. It was realized that there were big gaps in capacity for handling the study especially in data generation and interpretation. Therefore, the national components, in planning LVEMP, identified human resource, laboratory and field infrastructure, monitoring networks, and database development as capacity building areas. In return, specific capacity building objectives were developed and addressed during implementation of LVEMP activities.

Human resources

The training programmes mounted during the project strengthened the knowledge base of scientists, enabling them to raise awareness of important environmental management issues concerning the lake, to conduct and co-ordinate multi/trans-disciplinary research, and to disseminate information and data for sustainable use of the lake's natural resources. The knowledge gained by those specialists has enabled adequate assessment, monitoring and modelling of environmental degradation in the catchment and the lake. This capacity will facilitate and serve effective mitigation measures in the expected Phase II of LVEMP and enable sustainable development and utilization of the lake basin resources by the riparian countries.

Requirements

The capacity building program aimed to produce people possessing an integrated combination of knowledge, awareness, skills, problem-solving capabilities and with commitment to transform the scientists into specialists, professionals, water resource managers and advocates. The capacity building programme was meant to develop the highest level of scholarship, research capability, and creative thinking skills in the scientists' area of specialization. The world-class scientists and researchers produced through this programme will strengthen and motivate research in this field. Such trained expertise will enhance the national goals of having a clean lake environment and managing not only lake's, but the entire Victoria basin's, natural resources in sustainable ways. The trained professionals in various fields of water research and management will provide innovative ideas and solutions appropriate to our local problems and the availability of resources. While providing solutions to local problems, these specialists are nevertheless well prepared to face the world challenges such as global warming.

Training Achievements

Human resources, laboratory infrastructure, field equipment, monitoring network, and database development were targeted for building capacity in the Water Quality and Quantity component. Modeling was also identified among highlighted areas of concern with inadequate skilled capacity.

In order to achieve the project performance targets, to build professional competence of the staff to handle the planned activities and produce credible outputs, personnel capacity building was undertaken as a priority. The project trained its staff to various levels, which included undergraduate, postgraduate, diploma and short studies. For the long term training the Project sponsored officers for further training at degree levels. During the seven years of LVEMP, three (3) scientists had been trained to PhD level, 23 scientists to MSc level and 2 Scientists to BSc level within component staffs. Nine officers were trained to Diploma level, as medium term training. This was to further improve on the other training the personnel had undergone in their fields of expertise prior to the project. Various specialized short courses were conducted in-house and in various institutions, through which all officers benefited by attending courses of their professional focus and areas of discipline. A number of specialized training consultancies were procured including outreach through workshops relevant to water quality and ecosystem management, which helped to improve the capacity of scientists in data generation, management, interpretation and quality assurance as well as modelling.

Laboratory and Field Infrastructure

The water quality components were able to construct and equip laboratories in Kisumu, Entebbe, Mwanza and Musoma, which enabled them to perform a number of analyses on potable water, river and lake water, wastewater and sediments as required achieving the project objectives. All these laboratories had limited capacity in terms of space and equipment at the start of the project.

Laboratory capacity

The capacities of the laboratories have been built so that they can do analyses of many physical and chemical parameters and also to undertake microbiological examination. Where immediate capacity did not exist, other competent laboratories were used for specific parameters.

Improvement on the efficiency of analysis to generate reliable and comparable data was achieved through implementation of an inter-laboratory calibration using international certified reference material and regional inter-laboratory comparisons.

In addition to improving the skills of scientists and staff using the laboratories, the staff were monitored and evaluated for compliance to the agreed harmonized procedures for in-lake water quality analysis adopted during the 18-month consultancy on integrated water quality/limnology study (LVEMP 2002). Efforts were made to understand and correct any discrepancies whenever they were noted to ensure the laboratories produced comparable data, which could be used for production of a credible regional report.

The national laboratories upgraded by LVEMP now have capacity to analyze the parameters as listed below.

Some of the strategies used to improve capacity in water quality and quantity were as follows:

1) Preparation of a set of regionally harmonized field forms with instructions for field data collection and for recording both field data and laboratory analysis results. Emphasis was put on on-job training of field staff in monitoring procedures, clean methods and routines. Checking and adjustment of the laboratory analysis methods was also addressed to improve the efficiency of analysis and capacity to handle a large number of samples.
2) Four regional working sessions on data collation, verification and hands-on validation were conducted. During these sessions, all the data from the three countries was subjected to intensive quality assurance procedures for acceptability to be retained on the respective national databases and used in the regional reports.
3) Regional Laboratory Performance Evaluation exercise for the three participatory laboratories of Mwanza, Kisumu and Entebbe was initiated, to further improve on the credibility and comparability of the data generated in the laboratories. One regional laboratory performance evaluation exercise was held and subjected to

statistical analysis to check whether there was any scientific significant difference in the data generated. It was found out that there was no significant difference in the parameters considered after any calculation errors were eliminated.

TABLE 1. Parameters and methods of analysis.

Parameter	**Method of analysis**
COD	- Closed reflux method
BOD	- Winkler method
Total Organic Carbon	- Instrumental (TOC analyser)
Total Nitrogen	- Persulphate method
Nitrate	- Cadmium reduction column method
Nitrite	- Colorimetric method
Silica	- Heteropoly blue method
Ammonia	- Phenate method
Total Phosphorus	- Ascorbic acid method
Phenol	- Distillation followed by spectrophotometric method
Chlorophyll a	- Methanol acetone extraction
Alkalinity	- Titrimetric method
Total Suspended Solids	- Gravimetric method
Total Dissolved Solids	-Calculated from E. Conductivity values and gravimetric analyses
pH	- Electrometric method
Conductivity	- Conductivity meter
Dissolved Oxygen	- Electrode method
Chlorides	- Titrimetric method (Argentometric)
Sulphates	- Turbidimetric method
Potassium and sodium	- Flame photometer
Manganese	- Persulphate method
Iron	- Phenanthraline method
Calcium and magnesium	- Titrimetric
Total hardness	- Titrimetric (EDTA) method
Fluoride	- Visual comprision
Orthophosphate	- Ascorbic acid method
Turbidity	-Turbudimetric method
Sulphides	- Iodometric method
Faecal coliforms	- Multi-tube method
Total bacterial counts	- Microscopy
Total coliforms	- Microscopy
Photosynthetic activity	- Measure oxygen using Winkler method
Zooplankton and benthos	- Microscopy

Note: Most of the above methods are based on the Standard methods for the Examination of Water and Wastewater -19th Edition.

Laboratory QA/QC procedures

The laboratory quality assurance mechanisms encompass good performance of staff, sample handling, laboratory practice, and appropriate equipment and siting.

Staff

All technical staff working in the water quality laboratory are well trained with relevant qualifications and have gained experience over the years regarding water and wastewater analysis. In-house training programmes are continuously carried on as part of the routine activity whereby skills are passed over from one analyst to another enhancing continuous improvement. Furthermore, training programmes are regularly carried out and staff encouraged in updating their professional capacities through such training courses, workshops and seminars appropriate to their needs. New employees are trained to prepare them for the duties they are to undertake. Professional technical and managerial capacities are also improved through attendance of short training courses, workshops, and seminars whereby knowledge and experience are shared and exchanged.

Sample handling

The sample chain of custody was documented to insure proper handling, to uniquely identify samples, to record conditions of samples, and permit tracing of samples through all steps from collection to analysis and display of results.

Proper sample handling and documentation ensures that deterioration and damage to test and reference samples before analysis are avoided as much as possible. Good storage of samples was maintained for all items as far as practicable and samples were disposed of according to standard procedures.

Methods validation

National laboratories agreed to adopt published methods mostly from *Standard Methods for Water and Wastewater Analysis, 18th edition, 1998.* Laboratory methods were drawn from these published methods to suit the laboratory equipment and then method performance tested to ascertain precision, accuracy, specificity, sensitivity, applicability and range. Analysts in the national laboratories established the limits of detection for analysis, which were documented and used to guide in analysis and reporting of results. In the process of method validation, repeated analyses of certified reference materials (CRM) are carried to characterize the performance of the method including the equipment.

Field access and deployment

A number of field instruments were installed including automatic water level recorders, automatic weather stations, staff gauges and rain gauge stations. Remote water quality data loggers were purchased but infrequently used for fear of vandalism experienced during the project period; this was later addressed through community participation and training. To facilitate data collection from the field, both land (cars and motorcycles) and water transport facilities (fibreglass boats and dinghies powered by outboard engines) were acquired and operated by LVEMP components. Other facilities such as mobile cableway system, current meters, global positioning receivers and satellite telephone were established as required to meet program objectives.

Research Vessels

The research vessels RV TAFIRI II, RV IBIS, and RV FWANI were used in Tanzania, Uganda and Kenya respectively. The vessels were made available from National Fisheries Research Institutes (TAFIRI, FIRRI and KMFRI) on the basis of memoranda of understanding with the components and through inter-institutional linkages with these collaborating institutions.

RV TAFIRI II was used for the regional cruise in 2002 as it is the most modern and is equipped with a video output sounder, VHF radio, hydrographic winch, a compartment for laboratory work, a deep freezer for storage of samples, kitchen facilities, toilet and bathroom and ten (10) beds. Other equipment includes a standby generator, radar, global position receiver, navigation compass, and a life raft.

Monitoring Networks and Databases

River catchment monitoring networks

The national components established river discharge-monitoring networks covering all major catchments of the whole of Lake Victoria catchment. Although the catchment has hundreds of hydrological stations, for the project work, only 66 stations were used due to logistical reasons. The stations were all geo-referenced using GPS.

Lake wide monitoring networks

The lake wide network of monitoring stations was agreed to by the national components and became operational during the training consultancy training of COWI in 2002. Locations of stations are in Fig. 1 and GPS coordinates provided in Appendix 2.

The sampling network became operational with specific protocols developed including the scheduled regimes of sampling and data collection. Two sampling regimes were instituted as quarterly and monthly sampling stations. During the quarterly cruise all stations were sampled, however during the monthly cruises only a selected few stations were sampled (Appendix 2). The monitoring stations were distributed between pelagic (deeper than 20 m depth) and littoral (<20 m depth) to capture the spatial variability of parameters. This network provides the first spatially extensive program of sampling with adequate frequency of sampling to capture all seasons on the lake. Prior studies were either based on single localities or single transects from inshore to offshore locations.

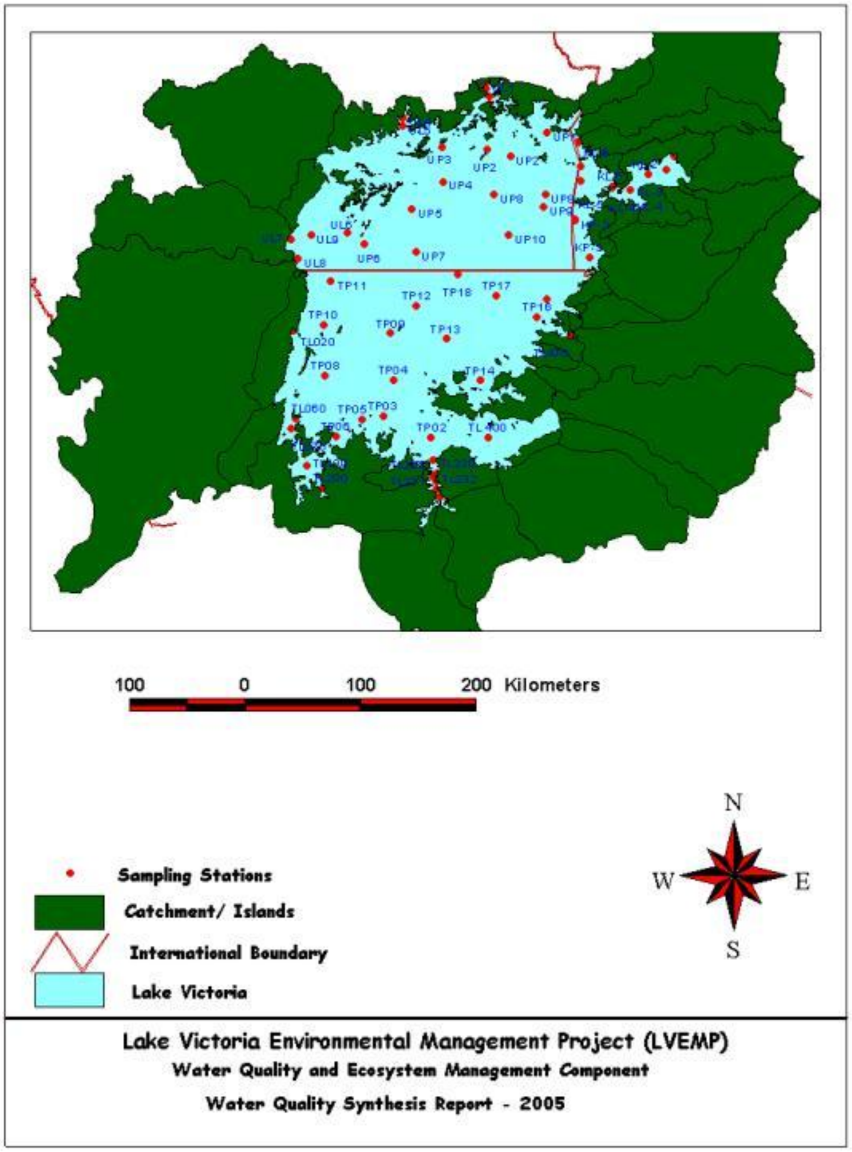

FIG. 1. Location map of the study area showing location of littoral and pelagic sampling sites in Lake Victoria and the number of times stations were sampled during LVEMP up through July 2005.

Urban lake station (impact) monitoring

In-lake impact stations are located along the main lakeshore urban centers. Selection of the stations was based on potential environmental impacts from these cities and towns known with point sources of pollution. Some of the stations are located near effluent outfalls and river mouths while others are distributed through impacted embayments.

Atmospheric Deposition monitoring Stations

Atmospheric deposition refers to elements deposited directly from the atmosphere to the lake and has two components wet deposition added during rain events and dry deposition. Wet deposition is an important component of non-point source loading because over 80% of the water input to the lake comes as direct rainfall. Even in areas of the lake with low rainfall, dry deposition continuously loads nutrients to the lake as fallout of fine particles and aerosol deposition. The study established several stations for both wet and dry depositions stations at Entebbe, Bukasa Island, Lolui Island, Bukoba, Mwanza, Kisumu, Kadenge, Bungoma, Homa Bay, Muhuru Bay, Webuye, Kitale, Rusinga Isaland and Kisii. Wet and dry deposition estimates focused on nitrogen and phosphorus for the purpose of comparing atmospheric loading with riverine non-point source loading.

Databases and Modelling efforts

During the project period, the Lake Victoria Water Quality Model (LVWQM) which is a model framework for simulation of the physical processes and water quality in Lake Victoria was developed. The model was developed by a consortium consisting of Delft Hydraulics, HydroQual and IHE. The framework model is a preliminary or pilot model since it was based on existing data which was insufficient to support a full calibration or verification of the models. The model was intended to serve as Decision Support Tool from LVEMP for policy making formulation to allow analysis of management scenarios of the lake that can be used to predict responses to possible management actions for the remediation of water quality problems to ensure sustainable economic development.

Lake Victoria is a large and complex system, and it is hard to determine the effective measures for environmental management of the lake basin and to select measures that are in good balance with the (economic) needs of the people, who are living at its shores. In view of this, it is clear that the formulation of common environmental policies is a demanding task models can effectively support the process of informing and optimizing management policies and modelling capacity would be invaluable and cost effective in guiding management of the lake's resources.

However, the use of hydrodynamic models and linked water quality models for environmental management and decision-making is a relatively new science which requires trained experts and availability of extensive input data usually on a large number of parameters. Modelling has its own demands for monitoring, data collection, and knowledge development. During the term of LVEMP, on-job training has been conducted using local experts on modelling basics including the data requirements and formats. Among the topics covered in the orientation/training were;

- the usefulness and possible uses of the modelling framework for lake basin management and decision making;
- the need to develop monitoring, data collection and research programmes adequate for modelling and which are at the same time cost-effective and sustainable;
- introduction to some basics in water quality modelling and day to day usage of the existing LVWQM in its form

Other Modelling Efforts Contributing to the Report

Two models, SMAP and NAM were used to generate information necessary hydrological dating relating rainfall and runoff required for water balance calculations and also to assure quality of data through comparisons of model expectations with the observed data. Details of these models are shown in chapter 3 on water balance.

RECOMMENDATIONS

Great progress has been made in capacity building for water quality management during LVEMP 1 and the minimum requirements are in place. There are however still constraints that should be addressed during the next stage of LVEMP. As scientific studies and monitoring activities on the lake increase, availability of ship and crew time becomes more limited. This is especially true as the current vessels are accessed from fisheries research institutions with their own mandated programs. Therefore it is recommended that a dedicated, regionally shared vessel suitably equipped to serve all aspects of the water sampling and monitoring programs be acquired. Equipment should include appropriate safety equipment including communication and positioning technology to allow continuous tracking and communication as well as adequate personal safety equipment. Additional recommendations include:

- A Water Quality Model Framework was developed using example data in the early years of the project. Now that sufficient data has been generated for the lake, there is urgent need to use the actual data to calibrate and validate simulation runs;

- A regional water quality laboratory dedicated to Lake Victoria and its catchment is recommended for the next phase because the current national laboratories are facing increasing national demand from other national programmes. The new regional laboratory could serve as a reference laboratory for the region;

- Performance evaluation exercises should be carried out on quarterly basis as part of the regular regional quality assurance and not on an ad hoc basis. Dedicated funds must be put in place to insure that QA/QC is not sacrificed to meet program sampling needs;

- There should be regular meetings of the scientists of the three laboratories to analyze the QC results and design ways of improving the performance of the laboratories;
- Laboratories should be equipped with analytical instruments appropriate for detecting levels of concentrations expected in the samples/environment. This is especially true for metal and pesticide measurements that pose environmental risk to biota and humans even at very low concentrations in the water environment;
- There is need to consolidate the critical mass of scientists developed during this project and to insure that future capacity building meets outstanding regional needs.
- The national governments should incorporate LVEMP activities into their national programs to support and ensure sustainable development in the Victoria basin;
- The national governments should apply these findings from LVEMP into planning and assessing future developmental activities in the Lake Victoria Basin which has been declared as an economic growth zone;
- The EAC should a regional research vessel dedicated to monitoring water quality in Lake Victoria.

REFERENCES

APHA. 1995. Standard Methods for the Examination of Water and Wastewater, 19th Edition, American Public Health Association (APHA), American Water Works Association (AWWA), Water Pollution Control Federation (WPCF), Washington D.C. APHA 1995.

LVEMP. 2002. Integrated Water Quality and Limnology Study for Lake Victoria. COWI

APPENDIX 1. River monitoring stations- coordinates.

TANZANIA

HFStationID	HFNationalID	HFName	Lon	Lat	HFRiver	
*90001	5A1	Ngono at Kyaka Rd. Brg	31.61	-1.28	Ngono	
90002	5A2	Ngono at Muhutwe Brg	31.77	-1.58	Ngono	
90003	5A3	Ngono at Kalebe	33.67	-1.48	Ngono	
90004	5A5	West Ngono at Kyakakyera	31.46	-1.35	West Ngono	
90005	5A8	Lake Rushwa at Kyerwa Syndicate	30.83	-1.42	Lake Rushwa	
*90006	5A9	Kagera at Kyaka Ferry	31.42	-1.26	Kagera	
90007	5A13	Kagera at Nyakanyasi	31.20	-1.18	Kagera	
90008	5A15	Mwisa at Kyehara	31.37	-1.25	Mwisa	
90009	5A16	Ruvuvu at Mumwendo Ferry	30.55	-2.63	Ruvuvu	
90010	5A17	Kagera at Kasingabitaraka	30.85	-1.82	Kagera	
90011	5A18	Rubare at Katoro Rd. Brg	31.47	-1.37	Rubare	
90012	5A19	Kyamato at Kibengwe	31.77	-1.20	Kyamato	
90013	5B1	L. Victoria at Bukoba Pier	31.82	-1.33	Lake Victoria	
90014	5B3	L. Victoria at Bukembe Island	32.02	-1.08	Lake Victoria	
90015	5C3	Moame at Pambani Bridge	33.10	-2.97	Moame	
*90016	5C4	Magogo at MZA/SHY Rd. Brg	33.16	-2.93	Magogo	
90017	5C6	L. Victoria at Mwanza S. Port	32.83	-2.52	Lake Victoria	
90018	5D1	Simiyu at Ndagalu Pr. School	33.57	-2.63	Simiyu	
*90019	5D2	Duma at Sayaka	33.48	-2.58	Duma	
*90020	5D3	Simiyu at MZ/Musoma Rd. Brg.	33.45	-2.58	Simiyu	
90021	5D4	Simiyu at Nkololo	33.90	-3.08	Simiyu	
90022	5D5	Bariadi at Bariadi	33.98	-2.77	Bariadi	
90023	5E1	Mbalagheti at Hadajega	34.17	-2.33	Mbalagheti	
*90024	5E2	Mbalagheti at DS MZ/Musoma Rd	33.17	-2.33	Mbalagheti	
90025	5F2	Grumet at Kilawira	34.17	-2.17	Grumeti	
*90026	5F3	Grumet at MZ/Musoma Rd.	33.93	-2.05	Grumeti	
90027	5G1	L. Victoria at Nansio Port	32.55	-2.17	Lake Victoria	
90028	5G2	Suguti at Suguti Village	33.68	-1.68	Suguti	
90029	5G3	L. Victoria at Bugorola	33.03	-1.98	Lake Victoria	
90030	5H1	L. Victoria at Musoma Port	30.80	-1.48	Lake Victoria	
90031	5H2	Mara at Mara Mines	34.55	-1.65	Mara	
*90032	5H3	Mara at Kirumi Ferry	33.95	-1.53	Mara	
*90033	5F1	Grumet D/S at MZ/Musoma Rd.	33.95	-2.07	Grumeti	
*90034	5J1	Mori at Utegi Village	34.02	-1.28	Mori	
90036	5C5	Magogo at Ngudu	33.37	-2.90	Magogo	

KENYA

Rgs No	Station Name	Latitude	Longitude	Alt. M Asl	Remarks
1. IAHI *	Sio	N 00 23.005	E 34 08.745	1181	Gauge Zero
2. 1AH Misc	Suo at Kusumo	N 00 27.123	E 34 20.998	1217	WL
3. 1AH Misc	Walatsi	N 00 28 40	E 34 08 30		
4. IBAI	Moiben				
5. IBB1 *	Nzoia (M/Bridge)	N 00 55.127	E 35 07.953	1811	Gauge Zero
6. IBB2	Losorua				
7. IBB3	Chepkaitit				
8. IBC1	Noigamet				
9. IBD1	Litle Nzoia				
10. IBD2 *	Nzoia (At M/Tatu)	N 00 45.622	E 35 03.756	1752	Gauge Zero
11. IBE4	Kaibei				
12. IBE5	Kwoittobos				
13. IBE6 *	Kwoittobos/Sabwani	N 00 57.763	E 35 05.384	1805	Gauge Zero
14. IBG1	Chebusani				
15. IBG7 *	Ewaso Rongai	N 00 46.309	E 34 55.617	1662	Gauge Zero
16. IBG3	Kabeyani				
17. IBG4	Kisawai				
18. IBG5	Rongai	N 00 46.309	E 34 55.617	1662	Gauge Zero
19. IBH1 *	Kamukuywa	N 00 47.045	E 34 48.198	1659	Gauge Zero
20. IBH2	Kimilili	N 00 44.680	E 34 46.446	1631	Water Level
21. ICA2 *	Sergoit	N 00 37.877	E 35 03.928	1835	Gauge Zero
22. ICB4	Sosiani				
23. ICB5 *	Sosiani	N 00 37.570	E 35 03.405	1838	Gauge Zero
24. ICB8	Endoroto				
25. ICB9	Elgerine				
26. ICC3	Olare Nyoike				
27.	Kipkarren	N 00 24.766	E 35 13.587		
28. ICEI *	Kipkarren	N 00 36.404	E 34 57.892	1661	Gauge Zero
29. IDA2 *	Nzoia (Webuye)	N 00 35.157	E 34 48.411	1479	Gauge Zero
30. IDB1/A *	Kuywa	N 00 34.377	E 34 40.831	1437	Water Level
31. IDB1	Kuywa				
32. IDB2	Bokoli				
33. IDC1	Chwele				
34. IDD1 *	Nzoia (Mumias)	N 00 22.165	E 34 28.962	1284	?
35. IDD2	Khalaba				
36. IEB2 *	Isiukhu	N 00 15.273	E 34 45.029	1479	?
37. IED1 *	Lusumu	N 00 18.383	E 34 28.761	1275	Gauge Zero
38. IEE1 *	Lower Nzoia	N 00 10.400	E 34 13.346	1195	Gauge Zero
39. IEF1 *	Nzoia (Rwambwa)	N 00 07.280	E 34 05.452	1166	Gauge Zero
40. IEG2	Wuoroya	N 00 08.937	E 34 14.606	1194	Gauge Zero
41. IFC1	Kimondi	N 00 11.782	E 35 02.983	1893	?
42. IFD2 *	Mokong	N 00 08.138	E 35 07.515	1923	Gauge Zero
43. IFE1	Yala				
44. IFE2 *	Yala (At Tindinyo)	N 00 10.875	E 34 56.238	1724	Gauge Zero

Rgs No	Station Name	Latitude	Longitude	Alt. M Asl	Remarks
45. IFF3 *	Edzawa	N 00 18.344	E 34 34.169	1419	Gauge Zero
46. IFG1 *	Yala (Yala Mkt)	N 00 05.083	E 34 32.544	1416	Gauge Zero
47. IFG3 *	Yala (Daraja Mkt)	S 00 00.128	E 34 08.401	1162	Gauge Zero
48. 1FGMisc	YALA (D/S Power Stn)	N 00 04.000	E 34 31.000		
49. 1FGMisc	Yala Diversion	N 00 05.400	E 34 31.000		
50. IGB3 *	Ainamotua	S 00 04.536	E 35 03.358	1177	Gauge Zero
51. IGB5	Ainamotua	S 00 01.742	E 35 10.449	1438	?
52. 1GBMisc	Ainpngetuny	S 00 01.780	E 35 10.758	1338	?
53. 1GBMisc	Kapng'oriam				
54. 1GBMisc	Chemwanabei	N 00.06519	E 35.18810		
55. 1GBMisc	King'wal	N 00.00689	E 35.18949		
56. IGB6/A	Mbogo	S 00 04.542	E 35 03.356	1200	?
57. IGB11	Ainapisiwa	S 00 01.742	E 35 10.479	1328	?
58. IGC4 *	Tugunoni	S 00 15.284	E 35 24.926	1996	Gauge Zero
59. IGC5	Masaita	S 00 28.471	E 35 32.535		
60. 1GCMisc	Kedowa	S 00 14.009	E 35 32.692	2125	?
61. 1GCMisc	Timbililwet	S 00 12.284	E 35 31.773	2035	?
62. 1GCMisc	Kipchorian/Tuyobei	S 00 11.428	E 35 30.736	2003	?
63. 1GCMisc	Cheboror/Kimoson	S 00 12.410	E 35 27.811	1934	?
64. IGD3 *	Nyando	S 00 07.544	E 35 00.003	1179	Gauge Zero
65. IGD7 *	Nyando	S 00 09.929	E 35 09.739	1265	Gauge Zero
66. IGG1 *	Namuting	S 00 12.245	E 35 20.873	1516	Gauge Zero
67. 1GGMisc	Pararget	S 00 13.183	E 35 18.348	1457	?
68. 1HAMisc	Oroba Ahero	S 00 07.400	E 34 47.500		
69. 1HAMisc	Luanda				
70. 1HAMisc	Kundos				
71. IHA1	Great Oroba				
72. IHA2	Little Oroba				
73. IHA6	Awach Nyangori	S 00 02.879	E 34 48.339	1194	Gauge Zero
74. IHAMisc	Nyamasaria	S 00 07.047	E 34 47.343	1171	WL
75. IHA14 *	Awach Kibos	S 00 02.879	E 34 48.339	1194	Gauge Zero
76. IHA16	Kibos	S 00 02.792	E 34 48.824	1192	?
77. IHB5 *	Awach Seme	S 00 05.705	E 34 28.489	1201	Gauge Zero
78. IHD1	Awach Kibuon				
79. IHD3 *	Awach Kabondo	S 00 27.100	E 34 53.058	1434	Gauge Zero
80. IHD9 *	Awach Kibuon	S 00 22.929	E 34 38.208	1172	WL
81. IHD5 *	Awach Kasipul	S 00 30.230	E 34 50.325	1519	Gauge Zero
82. IHE1 *	Awach Tende	S 00 28.087	E 34 32.968	1141	?
83. 1EHMisc	Oluch Tende	S 00 28.2	E 34 33		
84. IHE2 *	Mogusii	S 00 37.188	E 34 45.438	1526	?
85. IJAMisc *	Jamji				
86. IJA2 *	Kiptiget	S 00 06.101	E 35 15.257		
87. IJC19 *	Kimugu	S 00 28.664	E 35 10.524	1732	Gauge Zero
88. 1JC13	Sambret	S 00 24.263	E 35 18.745	1614	?
89. 1JC15	Sambret	S 00 22.100	E 35 23.347	2270	?
90. IJDMisc*	Chemosit	S 00 28.666	E 35 10.523	1734	WL
91. IJD3 *	Yurith	S 00 29.036	E 35 04.750	1651	?
92. IJF8 *	Kipsonoi	S 00 30.847	E 35 04.770	1621	Gauge Zero

Rgs No	Station Name	Latitude	Longitude	Alt. M Asl	Remarks
93. IJG4 *	Sondu Miriu	S 00 21.267	E 34 48.330	1156	Gauge Zero
94. IJG5	Sondu	S 00 23.707	E 35 00.956	1508	Gauge Zero
95. IKA(Msc)	Riana				
96. IKA5 *	Nyakomisaro				
97. IKA9 *	Riana (At Lwala)	S 00 41.227	E 34 32.291	1341	WL
98. IKA10	Misadhi				
99. IKB1/A *	Gucha (Macalder)	S 00 58.267	E 34 15.652	1177	?
100. IKB3 *	Gucha (Rakwaro)	S 00 48.556	E 34 34.325	1359	Gauge Zero
101 IKB4	Gucha-Nyambunde	S 00 47.018	E 34 48.132	1710	Wl
102. IKB5 *	Gucha Migori	S 00 57.004	E 34 12.582	1158	Gauge Zero
103. IKB7	Gucha				
104. IKB9 *	Sare	S 00 54.274	E 34 32.103	1426	Gauge Zero
105. IKB11 *	Oyani	S 00 54.276	E 34 32.100	1426	?
106. IKB13 *	Mogunga	S 00 51.698	E 34 45.860	1701	?
107. IKC3 *	Migori	S 00 04.295	E 34 28.331	1358	Gauge Zero
108. IKC4	Migori				
109. ILA3 *	Nyangores	S 00 47.383	E 35 20.794	1906	Gauge Zero
110. ILA4 *	Mara	S 01 13.380	E 35 02.178	1601	WL
111. ILB2 *	Amala	S 00 26.247	E 35 26.247	1869	WL
112. NH/F1	Kaplelmet	N 00 05.051	E 35 11.003		
113. NH/F2	Kibegelek	N 00 05.188	E 35 09.525		
114. NH/F3	Cheptaburbur	N 00 02.473	E 35 08.176		
115. TN/F1	Tirigemet	N 00 02.314	E 35 19.809		
116. TN/F2	Chebirirkut	S 00 02.259	E 35 20.858		

* Stations which were identified as LVEMP network for continuous monitoring.

UGANDA

Stn No.	Station Name	Latitude	Longitude		
101032/IAH01	River Sio	0.387	34.142		
117022/81259	River Katonga	-0.098	31.940		
115022	River Kagera	-1.280	31.427		
81270	River Bukora	-0.817	31.583		
	River Kisoma				
	River Kibale				
	Nakivubo Channel				
90034	Mori at Utegi	34.02	-1.28		

APPENDIX 2. Lake Monitoring stations- coordinates and maximum depth.

STATIONS	LONGITUDE	LATITUDE	AV. MAXIMUM DEPTH (m)	NO. OF TIMES VISITED (n)
KP 1	33° 59’ 40’’ E	00°18’ 48’’ S	47.0	22
KP 2	33° 57’ 3’’ E	00° 36’ 56’’ S	56.0	22
KP 3	34° 03’ 49’’ E	00° 54’ 18’’ S	33.0	18
KL 1	34° 43’ 14’’ E	00° 07’ 15’’ S	3.5	22
KL 2	34° 39’ 46’’ E	00° 13’ 25’’ S	3.0	22
KL 3	34° 31’ 11’’ E	00° 15’ 21’’ S	5.5	22
KL 4	34° 22’ 43’’ E	00°22’ 48’’ S	12.0	22
KL 5	34° 14’ 17’’ E	00° 20’ 58’’ S	23.0	22
KL 6	33° 58’ 23’’E	00° 00’ 42’’ S	14.0	22
UL1	33°15' 23" E	00°26’ 60" N	7.5	16
UL2	33°14' 52" E	00°24’ 10" N	18.0	16
UL3	33°17' 00" E	00°20’ 56" N	23.0	16
UL4	32°37' 05" E	00°11’ 02" N	12.2	11
UL5	32°37' 01" E	00°07’ 01" N	12.0	11
UL6	32°11’06 " E	00°07’ 01" S	9.0	4
UL7	31°45' 05" E	00°46’ 02" S	9.0	6
UL8	31°48' 08" E	00°55’ 05" S	11.0	6
UL9	31°54' 06" E	00°44’ 01" S	16.0	4
UP1	33°44' 02" E	00°04’ 00" N	27.0	4
UP2	33°16' 08" E	00°04’ 08" S	68.0	16
UP3	32°55' 03" E	00°03’ 04" S	47.0	8
UP4	32°55' 05" E	00°19’ 10" S	55.0	8
UP5	32°41' 06" E	00°32’ 04" S	51.0	16
UP6	32°19' 03" E	00°47’ 56" S	47.0	16
UP7	32°43 '05" E	00°52’ 02" S	60.0	16
UP8	33°19' 02" E	00°25’ 01" S	67.0	10
UP9	33°42' 04" E	00°31’ 02" S	67.0	10
UP10	33°26' 00" E	00°44’ 01" S	69.0	16
TL-002	31º 51' 30" E	01º 00' 40" S	9.4	6
TL-020	31º 46' 02" E	01º 28' 51" S	11.0	6
TL-060	31º 52' 59" E	02º 06' 39" S	7.0	5
TL-070	31º 44' 54" E	02º 14' 43" S	11.5	6
TL-100	31º 51' 32" E	02º 32' 05" S	11.0	6
TL-200	31º 59' 29" E	02º 42' 19" S	4.6	5
TL228	32º 50' 58" E	02º 29' 26" S	17.5	14
TL-230	32º 52' 06" E	02º 35' 26" S	9.5	15
TL-231	32º 51' 12" E	02º 37' 04" S	8.0	13
TL-232	32º 50' 22" E	02º 39' 26" S	5.5	14
TL-233	32º 52' 06" E	02º 42' 42" S	4.8	12
TL-234	32º 53' 51" E	02º 46' 26" S	4.8	14
TL-400	33º 16' 16" E	02º 18' 37" S	21.5	6
TL-470	33º 43' 31" E	01º 30' 43" S	3.5	6
TP-02	32º 50' 18" E	02º 18' 36" S	43.1	14
TP-03	32º 27' 53" E	02º 08' 27" S	52.4	7
TP-04	32º 46' 51" E	01º 51' 39" S	60.0	10
TP-05	32º 16' 11" E	02º 07' 44" S	50.2	7
TP-06	32º 05' 42" E	02º 17' 59" S	27.0	7
TP-08	32º 07' 12" E	01º 49' 36" S	50	8
TP-09	32º 21' 07" E	01º 33' 54" S	59	13
TP-10	31º 59' 58" E	01º 25' 51" S	41.7	6
TP-11	32º 03' 31" E	01º 05' 46" S	38.0	7
TP-12	32º 43' 24" E	01º 16' 56" S	68.6	11
TP-13	32º 12' 00" E	01º 51' 52" S	70.0	1
TP-14	32º 12' 34" E	01º 51' 57" S	43.6	6
TP-16	33º 39' 12" E	01º 22' 17" S	48	6
TP-17	33º 20' 16" E	01º 12' 11" S	70.5	4
TP-18	33º 05'18’’ E	01º 08' 36" S	68.5	9

CHAPTER 3

Water Balance

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ABSTRACT. *One of the principal objectives of the Water Quality and Ecosystem Management Components is to find the reasons for the changes observed in the lake water quality and quantity in order to establish causes of change in the lake ecosystem and to identify remedial measures. To identify the reasons for the changes one requires a knowledge of the changes in the pollution loadings to the lake, which, in turn, depends on the discharges into the lake from the catchments and the atmosphere and the outflow to River Nile i.e. hydrology and meteorological characteristics in and around the lake.*

Hydro-metrological data for the period running 1950-2004 were analysed and form the basis for computing the pollution loadings (catchment and atmospheric) into the lake and as well as calculation of the lake water balance. Continuous rainfall and evaporation records were applied and data gaps filled were necessary. Full records of land discharges were obtained from rainfall records using the NAM model. Model performance was evaluated on the ability to simulate the total flow rather for catchments, rather than the peak and minimum flows, for pollution estimation.

Results indicate that Tanzania's land unshared catchment annual discharge contribution to Lake Victoria is approximately 5,430 BCM[1], while Uganda's one is approximately 1,062 BCM and Kenya's is approximately 9,271 BCM which in percentage are 21.4%, 4.2% and 37% respectively. Rivers Mara and Kagera that are shared between Kenya and Tanzania and Tanzania, Rwanda, Burundi and Uganda respectively had total flows of 1,151 BCM and 8,215 BCM accordingly representing 4.6% and 32.7% of the total catchment discharges. The mean annual rainfall over the Ugandan side of the lake is about 62,539 BCM, Tanzania is about 60,682 BCM and Kenya is about 4,541 BCM. These constitute 48.9%, 47.5%, and 3.6% respectively of the total mean annual lake rainfall into Lake Victoria. There was a 10.7% decrease in rainfall over the Lake in the period 1972-1993. However in the period 1994-2004 there was a 2.2% increase in the amount However there was a 14.7% decrease in catchment inflows into the lake and a 1.64m drop in water level in the period 1998-2004.

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[1] Billion Cubic Metres

INTRODUCTION

The principal objectives of the LVEMP Water Quality Components include understanding the changes observed in the lake water quality and the dependent aquatic ecosystem as well as identifying remedial measures where necessary. To identify the reasons for the changes requires also knowledge of the changes in the pollution loadings to the lake, which, in turn, depends on the discharges to the lake from the catchment and the atmosphere and outputs at the outlet to River Nile. Provision of this information requires a network of river and lake monitoring stations in order to:

- Establish short and long term fluctuations in water quantity in relation to basin characteristics and climate.
- Determine the water quality criteria required to optimise and maintain water uses and
- Determine seasonal short and long-term trends in water quantity and quality in relation to demographical changes, water use changes and management interventions for the purpose of water quality protection.

To have confidence in the measures of input and output of water, it must be demonstrated that they can predict changes in the amount of water in the lake over time. If a balance cannot be achieved then the input and/or the output data are suspect and using them for predicting water quality changes would leave large uncertainties in the estimates of inputs and outputs. Therefore, the total water balance for the lake over the past 50 years was computed in the first phase of LVEMP to establish the quality of data available for water balance computations. The data considered were: lake level as the response variable and rainfall onto and evaporation from the lake surface, discharges to the lake from all rivers and catchments around the lake and discharge from the lake into the Nile River at Jinja as independent variables that were measured or estimated over time.

To compute the water balance, historical hydrometeorological data was initially collected, collated, analysed, quality controlled and shared among the three riparian countries. The historic data achieved an excellent water balance for the period 1950-2000 (LVEMP 2002). Within the LVEMP period of data acquisition a further four years of data were gathered to further determine the robustness of the data for calculating a successful water balance. Extending the period of observation through 2004 has also revealed a dramatic downward trend to lake levels that has not occurred since 1961. In order to document and explain the hydrologic changes that have taken place over the past few decades, the newly collected data is included in the analysis to demonstrate the present status and to highlight the need for careful allocation of the lake’s water resources. With confidence gained from the water balance in the accuracy of river flows and atmospheric inputs, these inputs can then be used to estimate water-borne loadings of nutrients, contaminants and sediments to the lake. Quantifying these loadings presented in Chapter 7 allows prioritisation of important sources of pollution and choice of remedial measures.

Meteorology

In this study additional data covering LVEMP period 2001-2004 was used to extend the data from the previous period of 1950-2000. A limited number of rainfall stations were selected depending on their representativeness of each of the sub catchments in relation to the geographical coverage, data quality and rainfall characteristics. Fig. 1 shows the location of rainfall stations that were selected for data collection. The data was subjected to quality control checks including, visual examination of raw and plotted data, descriptive statistical tests (means, running means, maximum, minimum, standard deviation).

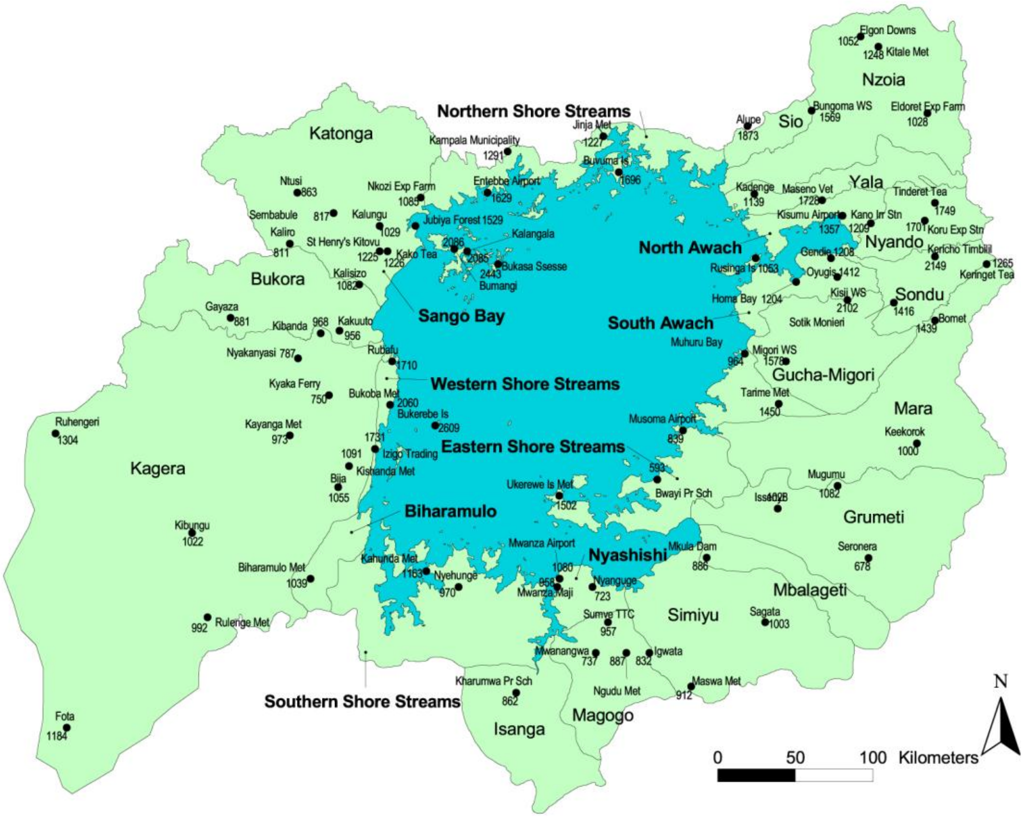

FIG. 1. Locations of rainfall stations.

For each river catchment, one or more reference stations were chosen. These are normally the stations with the longest, continuous, high quality record in the area. A "double mass" curve was evaluated for the subject station and the reference station, and a trend line fitted to the curve. The equation of the trend line is used to fill as many gaps as possible in the subject station record.

Temperature

Index stations from the three countries were used to examine the changes in mean, maximum and minimum temperature for the entire period of record, including the LVEMP period. Records show that temperature reaches maximum in February, just before the March equinox (date when sun is overhead equator) and reaches its lowest records in July after the June equinox. Maximum temperature ranges from 28.6-28.7°C while minimum temperature is from 14.7°C in Tanzania to 18.2°C in Uganda.

Although it is expected that the highest temperatures should occur after the March equinox when the sun is overhead the equator, the highest temperatures have been observed to occur before the March equinox. One possible explanation is that the dry North-east winds from the Ethiopian highlands exert their greatest influence towards the end of the dry season in February. This probably creates the highest temperatures that are manifested in the records.

The same can explain the low temperatures observed in July. This is when the sun is overhead the tropic of cancer and a predominance of maritime breeze is felt in the lake basin from the cool waters of Lake Victoria as well as monsoonal winds from the Indian Ocean. These observations are useful in understanding the limnology of Lake Victoria as well as the quantitative variations of hydraulic and limnological processes in the basin.

Comparison of temperature records of the period 2001-2005 to 1950-2000 show that maximum temperature has increased by an average of 1°C during May to September for the western part of the lake and October to January for the North eastern part around Kisumu. The minimum temperature level has also risen by 1°C during February to May in the west and increased by 0.5°C in Kisumu area during June to August. For the eastern part of the lake minimum temperature has increased by 0.5°C during September to November. The LVEMP period of observations was unusually warm compared to historic data.

Wind

Wind over Lake Victoria closely follows the pattern of the apparent movement of the sun across the equator through the Inter Tropical Convergence Zone (ITCZ). The ITCZ and its influence affect the regime of most of the meteorological parameters including rainfall, wind speed and direction, and temperature.

Fig. 2 indicates two strong seasonal wind patterns that influence the hydraulic processes of the lake. In January-February and June-September, the wind pattern is predominantly East to West, parallel to the equator, with origins from the Nandi hills in western Kenya. These are fairly dry winds. The moisture they pick over the lake are deposited to the western catchments especially Bukora catchment.

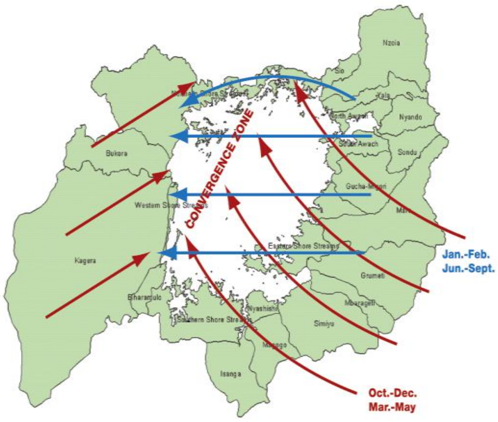

FIG. 2 Seasonal wind patterns influencing hydrological processes in Lake Victoria Basin (adopted from LVEMP 2002)

In the period March-May and October-December, the wind pattern changes shifts towards the north with a convergence zone over the western area of the lake.

Monthly Rainfall

Monthly rainfall data was considered for the period 1950-2004 and compared to the previous period 1950-2000 considered (LVEMP 2002) and that of LVEMP period 2001-2004. Maximum monthly rainfall mainly occurs in April and November for the long and short rain season respectively. The extreme maximum monthly mean rainfall has been registered in Bukerebe at 424.2mm in the west for the period 2001-2004. Minimum monthly rainfall is observed during the month of July with lowest amounts found in stations that are on land and away from the lake. Mwanza has a minimum of 5mm, Kahunda 3.5mm and Muhuru 9.6mm.

Meteorology Trends in Lake Victoria Basin

Index meteorological stations to cover Kenya, Uganda and Tanzania were used to check for any trends in mean values of temperature, rainfall, and wind speed.

Rainfall records show that there are two wet season that occur from March to May and October to December. Maximum rainfall is recorded during April and November, while the driest months are observed during July-August and January-February. Over the years, driest years have been observed in 1953, 1965 and 1996. Wettest years were recorded in 1961, 1968 and 1997.

Annual rainfall from the selected index stations for the long-term period and the period 2001-2004 did not show significant changes in trend (Fig. 3). However, there is some change in seasonal rainfall pattern. The LVEMP period, 2001-2004, for two index stations, Mwanza and Musoma, on the eastern side of the lake indicate that there is slight increase in rainfall over the wet season and a decrease in rainfall during dry season (Fig. 4). As for the western part of the lake, Bukoba meteorological station showed that there is no change in trend. In general, rainfall amount increases from east to west on the lake.

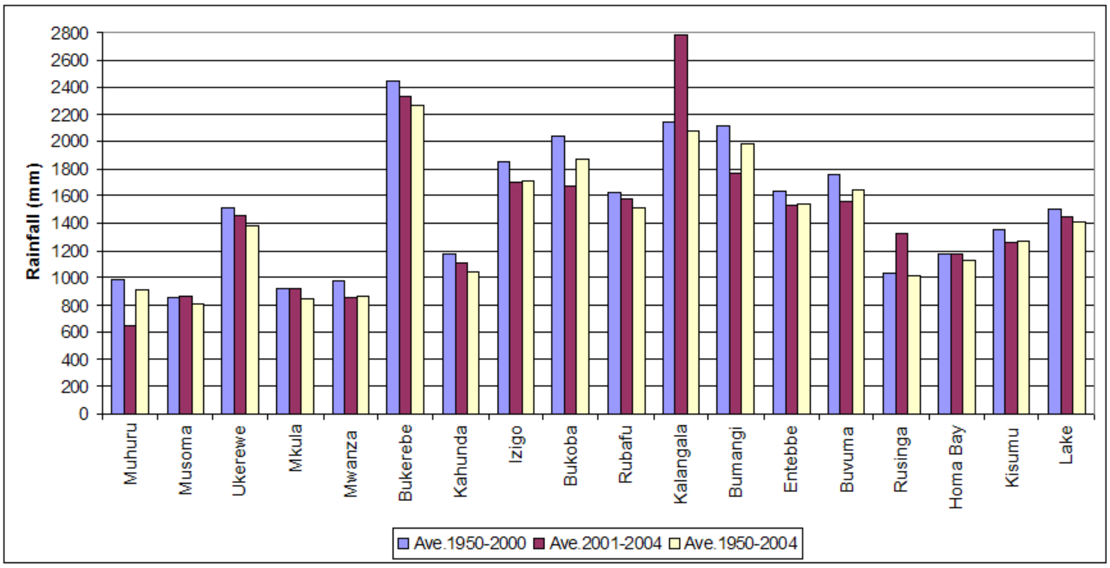

FIG. 3. Mean annual rainfall in Lake Victoria for different periods.

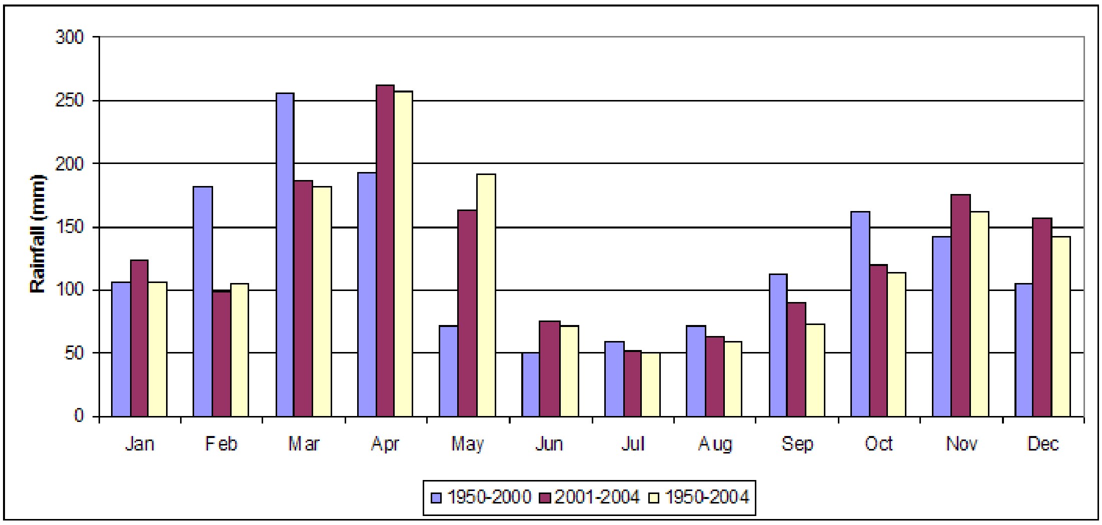

FIG. 4. Mean monthly rainfall pattern for Lake Victoria.

Hydrology of Lake Victoria

Estimation of Lake Rainfall

In the estimation of rainfall over the lake, the lake area was divided into polygons (boxes) representing rainfall influences from the stations selected. In this method, each rain polygon (box) had a reference rainfall station. Table 2 shows the rainfall boxes for the Lake Victoria. The mean annual rainfall in each box was computed using the rainfall isohyetal curves derived by drawing curves that link stations with similar average rainfall totals. Table 1 summarises the contribution of Lake Rainfall to the storage of Lake Victoria.

Table 1. Rainfall input into the lake by country.

Country	**Rainfall M**	**% Area**	**Lake area km^2**	**Rainfall BCM**	**%**
Uganda	2.02	45	30,960	62,539	48.9
Tanzania	1.8	49	33,712	60,682	47.5
Kenya	1.1	6	4,128	4,541	3.6
		100	**68,800**	**127,762**	**100.0**

A total of about 127,762 BCM[2] with the relative country contributions indicated in table 1 above.

Estimation of Rainfall over Lake Victoria

The convergence of south-easterly and south-westerly winds over the lake in March-May and October-December accounts for the heavy rainfall amounts in the western and northern shores of the lake. This influence extends in Uganda from the

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[2] Billion Cubic Metres

Ssesse Islands to Katonga Catchment leaving Bukora Catchment a bit arid. The highest rainfall in Uganda is received around the Ssesse Islands. This reaches totals of about 2,400 mm annually, while in Tanzania Bukerebe receives an average of 2447mm while Bukoba has 2020mm of rainfall. In Kisumu the average maximum rainfall is around 1358mm. On the Northern and Western Shores, the lacustrine effects on rainfall do not extend for more than 40 km in most places where arid climate typical of the cattle corridor sets in.

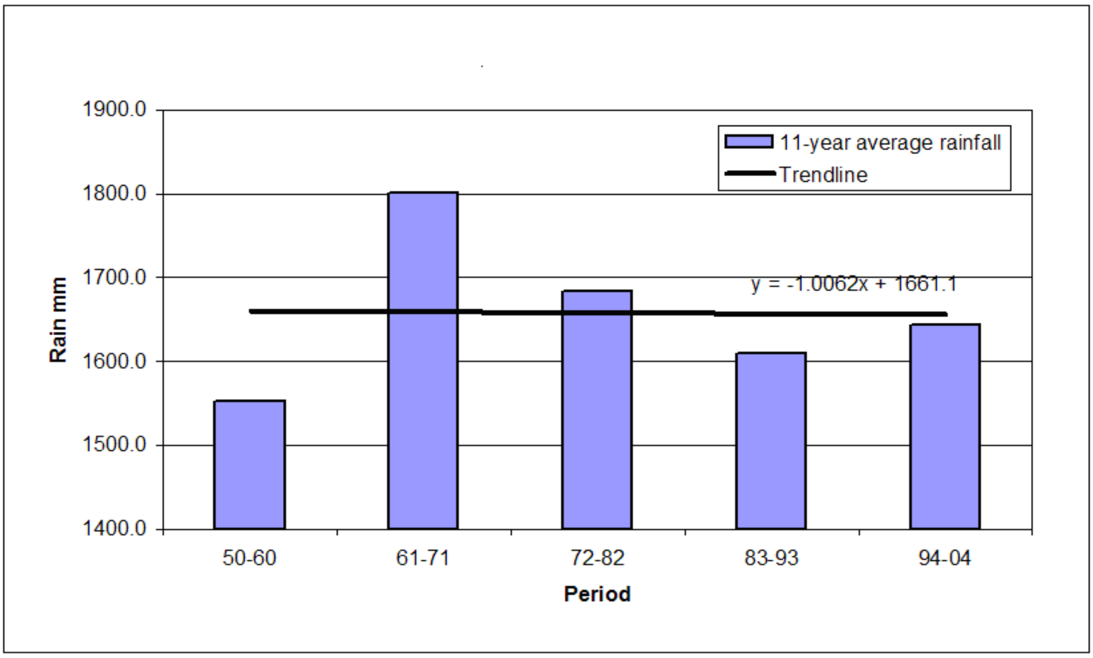

FIG. 5. Long term rainfall trend over Lake Victoria.

Fig. 5 shows annual rainfall data represented in five blocks of 11-year average annual rainfall total with the aim of determining whether there is any temporal change in rainfall pattern in the basin over time. Results show that there was a 10.7% decrease in rainfall amounts over Lake Victoria in the period 1972-1993. However in the period 1994-2004 there was a 2.2% increase in the amount. The 1950-60 period had by far the lowest rainfall in the periods considered.

In general there is an increment in annual total rainfall by 0.9% for the LVEMP period 2001-2004 compared to the previous period of 1950-2000, this make the average annual rainfall for the long-term period 1950-2004 to be increased by 0.065%. This drop is probably attributed to the changes in seasonal rainfall pattern noted above. When considering three seasons in a year, February to May (FMAM) accounts for 48.6% of annual rainfall for the LVEMP period (2001-2004) while the period June to September (JJAS) accounts for only 16.7% of annual rainfall and the period October to January (ONDJ) accounts for 35% of annual rainfall. There is an increase of 5% seasonal rainfall for FMAM, decrease of 13.8% rainfall for JJAS and an increase of 2.2% in ONDJ in the LVEMP period.

Lake Evaporation

A number of stations within the basin have been selected for estimation of evaporation. Data gaps were identified and gap filling was necessary to create continuous record data sets that could be used to derive statistical and analytical values.

A similar approach as for rainfall was used for quality control and gap filling of evaporation time series. Firstly, the use of correlation is limited by the fact that evaporation is mainly measured at synoptic meteorological stations, which are few, and as a result the stations are scattered far apart. Secondly, there is no well-defined method for assertion of an average, dry or wet year for evaporation.

Pan Evaporation data was used in all the three countries for the pre-LVEMP period. Whereas for major part of LVEMP period, Uganda used data from Automatic Weather Stations (AWS), the other two countries (Kenya and Tanzania) continued to use pan evaporation data except in a few cases where the AWS are in operation.

Estimation of Evaporation over the Lake

A similar approach to that used for estimating lake rainfall was applied in the estimation of the lake evaporation. To calculate evaporation over the lake therefore, boxes similar to those used for estimation of total rainfall over the lake are used. Each box has a reference evaporation station where mean evaporation is estimated on the basis of isohyet (equal rainfall) curves respectively. Each box also has a weight attached to it according to the size of the lake area it represents.

Comparatively, the highest Lake evaporation (Fig. 10) is recorded on the eastern and northeastern shores of the lake (i.e. Mwanza, Musoma, Muhuru, Rusinga and Kisumu), while the islands, western and southwestern shores have the lowest evaporation rates (i.e. Ukerewe, Kahunda, Bukoba, Bukasa, Entebbe and Koome).

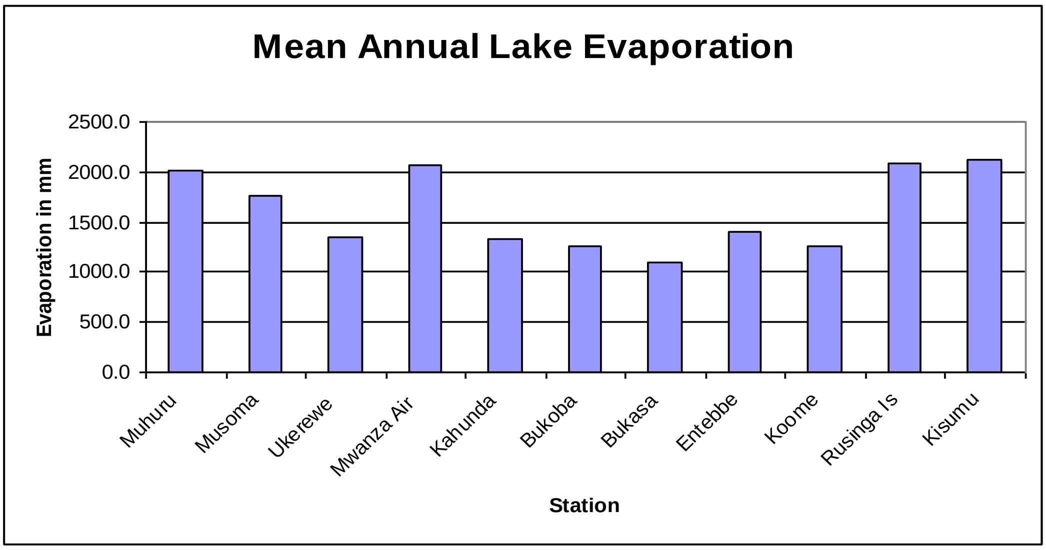

FIG. 6. Mean Annual Lake Evaporation for selected stations.

The relative pattern of evaporation by country portion of the lake is illustrated below:

Tanzania

During the LVEMP period of 2001-2004, the average annual evaporation for Musoma Met station increased slightly by 1% and this value was further smoothened in the combined long-term period of 1950-2004 to only 0.1%. As for Mwanza Airport evaporation decreased by 8.3% for the LVEMP period but overall the increment was reduced to 0.6% for the period 1950-2004. Although there was an increase of 13.3% in evaporation for Bukoba Airport during LVEMP, the long-term period of 1950-2004 shows a decrease in evaporation by only 1%.

Uganda

Computation of lake evaporation suggests that evaporation tendencies are relatively homogeneous compared to rainfall. The deviation from the mean annual evaporation boxes is 155mm as compared to 270mm for the mean annual rainfall boxes. For that reason the effect of the box size influences the total lake evaporation to a small extent. Results show that evaporation from the Uganda part is less than rainfall by a factor of 0.66 and accounts for 29.9% of the total lake evaporation. Since the estimated mean annual evaporation is far less than the mean annual rainfall and considering that evaporation and, it can be deduced that the Ugandan portion plays an important part in determining the positive net basin supply for the lake.

Kenya

Kenya had to rely on long-term daily average evaporation figures, as much of the required observed data for the reference stations was not available. According to the data gathered, average annual evaporation from the catchment is 1751.4 mm compared to that from lake surface, which is 2072.1 mm.

In the catchment, highest evaporation rates are recorded in the lower elevation basin stations (i.e.Kano, Kisumu, Muhuru and Rusinga), medium evaporation in the middle elevation zone (i.e. Alupe, Chemelil, Bungoma, Eldoret) and lowest in the highland areas (i.e. Kericho and Kisii).

Flows into Lake Victoria

Time series of aggregate catchment discharges

Because there is an apparent seasonal spatial homogeneity in the data sets depending on the runoff-generating pattern, catchments were grouped into 4 zones namely:

[A] ***North eastern zone***
  (i) Sio
  (ii) Yala
  (iii) North Awach
  (iv) South Awach
  (v) Nyando
  (vi) Sondu
  (vii) Nzoia and
  (viii) Gucha-Migori

[B] ***South eastern zone***
- (i) Mara
- (ii) Eastern Shores
- (iii) Grumeti
- (iv) Mbalageti
- (v) Simiyu
- (vi) Magogo and
- (vii) Isanga

[C] ***South western shores***
- (i) Southern Shores
- (ii) Biharamulo
- (iii) Western shores and

[D] ***North western shores***
- (i) Bukora
- (ii) Katonga and
- (iii) Northern shores.

[E] ***Kagera***

Monthly flow data from each zone were summed up and averaged over the years to get mean aggregate flows (figure 12), which was subjected to 6 month moving average in order to remove noise. The aim of this approach is to examine the average flow trends over the years in order to detect any significant variations in the time series in these different sectors of the land catchment.

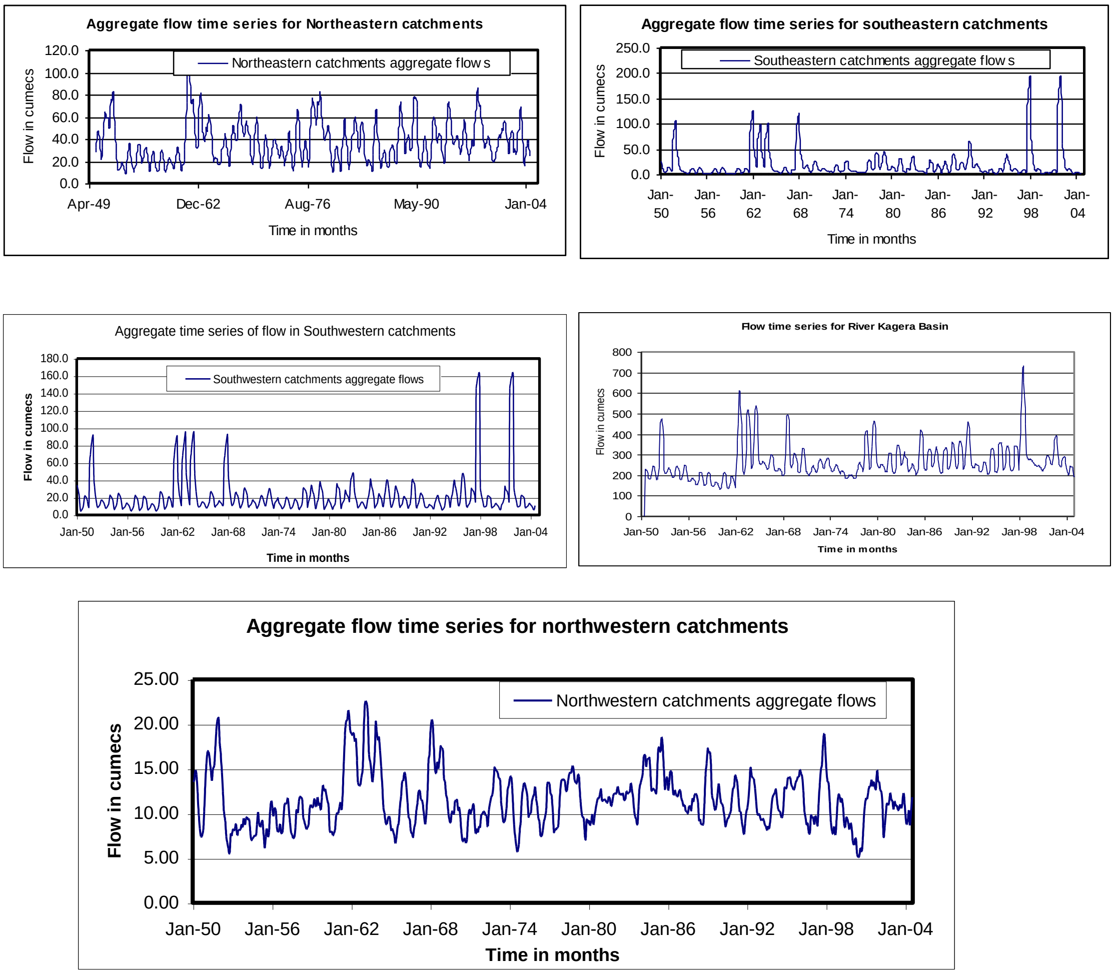

FIG. 7. Mean aggregate flows.

The catchment flow time series show striking revelations about some periodic events. Not only does the time series exhibit nearly all the peak annual events associated with the *El Niño* event years, but also does correspond to periods of low flows associated with below normal rainfall performance. The *El Niño* rains of the 1961-62 and the 1998-99 are well replicated in zonal charts (Fjg. 7). All the time series have shown declines in catchment discharges in the last 5 years from 2000. The Kagera basin yield has also declined from the 33.5% of all catchment discharges to only 30.7% in the last 5 years giving a total decline of 8.4 % of relative catchment contribution.

TABLE 2. Mean flows from catchments around the lake (also expressed as percentages of total flow in the period.

Country	**Drainage Basin**	**LVEMP Study[3] (1950-2000)**		**LVEMP (2001-2004)[4]**		**Long term 1950-2004[5]**	
		Flow in Cumecs[6]	%	Flow in Cumecs	%	Flow in Cumecs	%
Kenya	Sio	11.4	1.4	9.8	1.4	11.3	1.4
	Nzoia	116.7	14.5	107.4	15.7	116.1	14.6
	Yala	37.7	4.7	47.9	7.0	38.4	4.8
	Nyando	18.5	2.3	41.9	6.1	20.3	2.6
	North Awach	3.8	0.5	3.3	0.5	3.7	0.5
	South Awach	5.9	0.7	5.5	0.8	5.9	0.7
	Sondu	42.2	5.2	43.9	6.4	42.4	5.3
	Gucha-Migori	58.0	7.2	39.9	5.8	56.6	7.1
Kenya and Tanzania	Mara	37.5	4.7	23.1	3.4	36.5	4.6
Tanzania	Grumeti	11.5	1.4	4.6	0.7	11.0	1.4
	Mbalageti	4.3	0.5	3.5	0.5	4.2	0.5
	E. Shore Streams	18.6	2.3	11.3	1.6	18.1	2.3
	Simiyu	39.0	4.8	12.2	1.8	37.0	4.6
	Magogo-Maome	8.4	1.0	1.6	0.2	7.8	1.0
	Nyashishi	1.6	0.2	0.3	0.0	1.5	0.2
	Issanga	31.0	3.9	4.3	0.6	29.0	3.6
	S. Shore Streams	25.7	3.2	3.5	0.5	24.1	3.0
	Biharamulo	17.8	2.2	18.3	2.7	17.9	2.2
	W. Shore Streams	20.7	2.6	18.9	2.7	20.6	2.6
Burundi, Rwanda, Tanzania & Uganda	Kagera	261.1	32.4	252.5	36.8	260.5	32.7
Uganda	Bukora	3.1	0.4	2.0	0.3	3.0	0.4
	Katonga	5.1	0.6	2.1	0.3	4.9	0.6
	N. Shore Streams	25.6	3.2	28.2	4.1	25.8	3.2
	Total	**805.3**	**100**	**686.2**	**100**	**796.6**	**100**

Mean flows from individual catchments into Lake Victoria

An examination of the mean flows was made by splitting the data sets for catchment inflows into three periods as follows: 1950–2000 period (LVEMP 2002), 2001–2004 period data collection was done under LVEMP; and 1950–2004 period

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[3] Integrated Water Quality and Limnology Study of Lake Victoria
[4] Data collection period under LVEMP
[5] Long term mean flows by catchments
[6] Unit of flow in cubic metres per second

showing long term averages. Results show that on average, there was a significant decline in catchment inflows into Lake Victoria of 14.7% (Table 3) for the LVEMP period relative to the 1950-2000 period or record. Table 2 shows a summary of the mean flows in the above categories including the proportion of total basin inflow from each river for each time period.

Results show that on average, there is a significant decline in catchment inflows into Lake Victoria to the tune of 14.8% for the 2001-2004 period compared to the long term mean period of 1950-2000.

River Nile Outflow

During the period 1950-1954, River Nile outflow was naturally occurring until the commissioning of the Owen Falls Dam in 1954. The Dam was built to operate on the "Agreed Curve" Policy that determines the amount of water to be released by using the prevailing water levels in order to maintain natural flow. The operationalization of this policy maintained a natural pattern up to 2000. During the period 2001-2004, disparities began to occur between lake levels and Nile outflow. The hydrograph in Fig. 8 for the period 2001-2004, show that Nile outflows have increased while lake levels have fallen. This can partly be attributed to increasing outflow at Jinja and other climatic factors, e.g. periods of lower rainfall and river discharge into the lake than has occurred over the historic period.

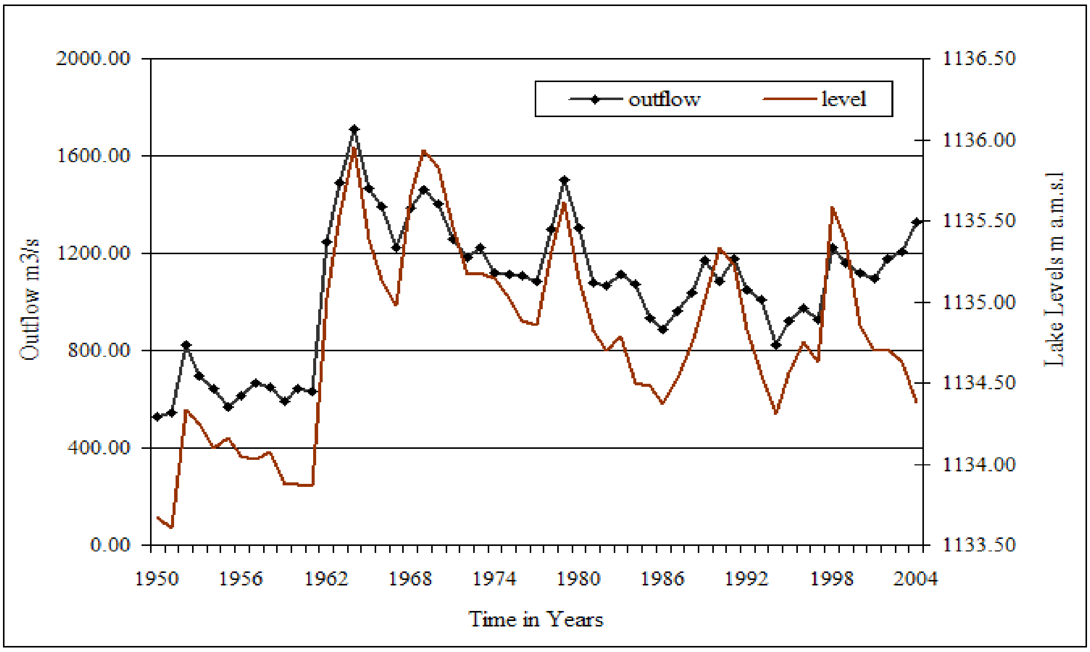

FIG. 8. Comparison of Nile outflow and lake level hydrograph.

The summary of flow characteristics for River Nile outflow in Table 3 indicate an increase in average flow out of the lake by 15% to 1057.6 Cumecs in the period 2001-2004 as compared with the long term average of 1046 Cumecs in the period 1950-2000 including the per cent of all losses with the remaining loss being evaporation. But this increase in outflow occurred during a period of falling water levels which is a departure from the long term relation between level and outflow.

Although the recent record is for a shorter period than the long term period, it nevertheless gives a general pointer to the new hydrologic trend that may emerge. The lake cannot maintain its water level if outflows of the past five years are maintained; unless substantial increases in rainfall and river discharge are realized.

TABLE 3. Nile outflow statistics summary also expressed as percent of total basin outputs (Nile plus evaporation).

	LVEMP Study (1950-2000)		**LVEMP (2001-2004)**		**Long term (1950-2004)**	
	Flow in Cumecs[7]	% of Output	Flow in Cumecs	% of Output	Flow in Cumecs	% of Output
Nile Outflow	1,046	24	1,201.9	26.5	1,057.6	24.1

Water levels of Lake Victoria

The water levels of Lake Victoria over the last 104 years have exhibited striking changes in regimes that have long escaped detailed explanation. From 1900 to 1961, the lake was at a different hydrologic regime from the 1961-2002 regimes. The post 2002 regime has tendencies towards the pre 1961 regime. What concerns people is whether there may be another regime shift.

Data on the levels of Lake Victoria has been collected consistently since 1896. But the focus of this study is from 1950 to 2004. During this period the levels have fluctuated in response to natural processes of input and output of the lake. Of all the above, it is evaporation over Lake Victoria, that is generally assumed to vary the least because the lake lies astride the equator. However, evaporation varies with temperature, wind speed, humidity, sunshine, etc., and it can also be affected by climatic variation. Evaporation estimates are necessarily based on pan evaporation measurements made at land meteorological stations and may only be approximate as conditions over the lake can be quite different.

Rainfall is generally recognized as the most variable component in the water budget with the further assumption that changes in rain over the lake will be similar to changes in rain falling on the land catchment. With stable climate, lake levels can be stable year to year as the lake level adjusts to the balance of those inputs and outputs. However the long term record shows variability from year to year and particularly higher levels in the latter part of the twentieth century compared to the earlier half.

Lake levels have followed a general but variable downward trend since 1964's May 12th historic peak. But that long term trend has reversed several times over the last half century, e.g. the later 1970's, the early 1990's and the E*l Nino* rains of 1997 when periods of high rainfall occurred and lake levels rose. Since the *El Nino* rains of 1997/98 when lake levels peaked in April of 1998 at 1135.77 metres above mean sea level (mamsl), the trend of the lake level has been dropping steadily.

The 2004 levels were the lowest experienced since the flood of 1961-62 but the current low level condition is well above the recorded historic low level of the lake in March 1923 (Table 4) shows some key low flow periods in order of ascent (but the lowest ever recorded level was in March 1923 followed by the September 2004 lows).

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[7] Unit of flow in cubic metres per second

TABLE 4. ***Historical lake level low periods.***

No.	Year	Month/Day	Level in m.a.m.s.l.
1	1923	March	1133.19
2	1961 (before the famous flood)	January	1133.7
3	2004	September	1133.99
4	1994	February	1134.18
5	1997	October	1134.21
6	1986	September	1134.26

High and low levels recur in an approximately cyclic manner both in the post-1961 level and earlier in the century. However, the most recent drop in level is a record for the post-1961 period.

Reasons for the current drop

To understand this, cumulative deviations from the normal regimes of rainfall, Nile outflow, evaporation and catchment discharges were developed. It was found that of all the processes above, rainfall and Nile outflow varied significantly to warrant their use in explaining the drop in levels. The following summarize the situation.

1. The lake system is such that the inputs (rainfall + river inflows+ groundwater input) and output (Nile outflows + Evaporation+ groundwater) affect the lake level (lake storage). Increase / decrease of any of the components of the system, specifically, rainfall, river inflows or Nile outflows either raises or lowers the lake level.

2. After analysis, it can be concluded that the observed fall in lake level is a result of a combination of two factors (a) reduced input in terms of rain and inflows into the lake system and (b) increased outflows caused by excess releases at Jinja.

3. General absence/ limited rains on the lake in recent years (compared to the long term record) resulted in falling of lake levels by 1.64m from 1998 to November 2004 with the year 2004 having been severely hit by this shortage of input.

4. Increased outflows for power generation resulted in a further fall in lake levels by 0.34m for the period June 2001, when the lake was in balance, to 3rd November 2004, when the lake was at its lowest (Fig. 9).

5. Excess releases accounted for 45% of the total fall in the period 2001-2004. Years 2003 and 2004 accounted for 77% of the extra lake drop with over 50% occurring in 2004 alone.

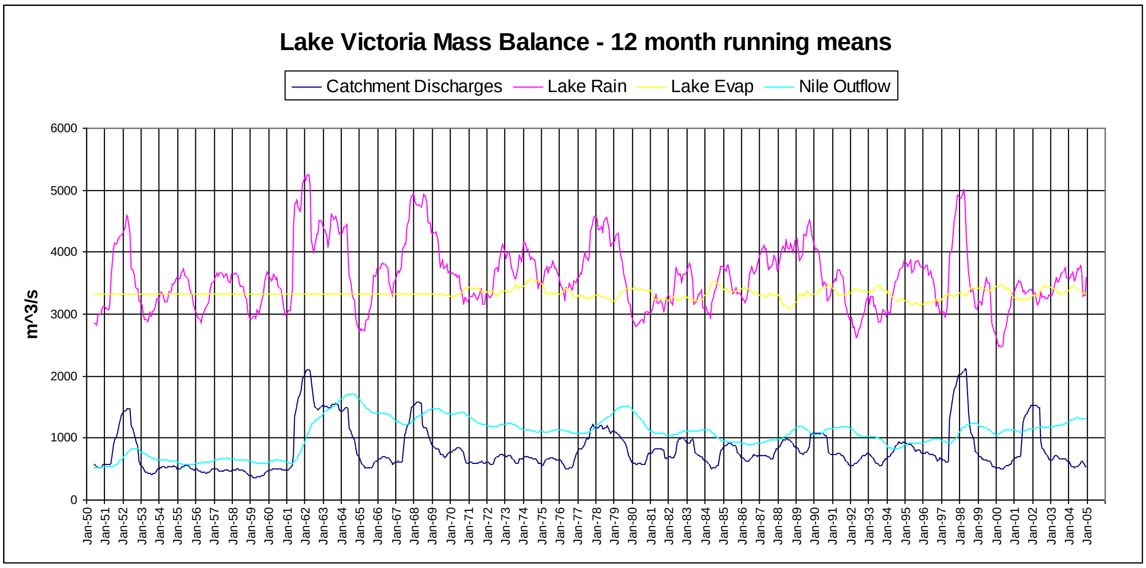

FIG. 9. Long term series generated by the water balance model.

Future outlook

In summary, the drop being witnessed now is a result of below normal rainfall for most parts of 2004 and an increase in flow out of the lake at Jinja. It is likely that if the releases are reduced and with above-normal rainfall, the level will pick up. Alternatively, it can also be said that since the current levels are within the flow regimes of the pre 1961 flood, the lake could have completed the dissipation of the great flood waters from exceptionally high rainfall periods within the last 50 years and may be former regime. Continued monitoring and better understanding of the changes in components of the water balance are required in order to understand this issue further.

Water balance for Lake Victoria

The Lake Victoria water balance was done by measuring or estimating annual averages of rainfall, evaporation, catchment inflows and Nile Outflow at Jinja. The annual summaries were factors in the equation below:

$$\pm\Delta H = P + Q_{in} - E - Q_{nile} \qquad (1)$$

Where ΔH is change in water level;
P is rainfall over the lake;
Q_{in} is catchment inflow;
E is evaporation from the lake; and
Q_{nile} is Nile outflow from Jinja.

When the ΔH is positive, water levels in the lake rises over the period, and when it is negative, the opposite is true. For purposes of comparison, rainfall and evaporation that are normally expressed in millimetres were converted to flow units, that is expressed as the amount of water that would ordinarily flow into, for rainfall, and out of the lake, for evaporation. Table 6 summarizes the water balance for Lake Victoria in 3 different periods as indicated in the table.

TABLE 5. Summary of water balance for Lake Victoria.

Process	**1950-2000 Flow m^3/s**	**%**	**2001-2004[8] Flow m^3/s**	**%**	**1950-2004 Flow m^3/s**	**%**
Inflow						
Rainfall	3611.5	81.8	3644.0	84.2	3613.8	81.9
Basin discharge	805.3	18.2	686.2	15.8	796.6	18.1
Outflow						
Evaporation from lake	3329.8	76.1	3337.5	73.5	3330.3	75.9
Victoria Nile	1046.2	23.9	1,201.9	26.5	1057.6	24.1
Sum	**40.8**		**-209.2**		**22.5**	

The above table show that in the period 2001-2004, the lake lost on average -209.2 Cumecs from its storage. This accounts for the fall in levels in the same period amounting to 0.38m, as the model predicts, and 0.38m, as from measured data. The long term water balance shows also a decline in the net storage as compared to the 1950-2000 period. This decline is caused by the negative net storage for the 2001-2004 period that is mentioned above.

TABLE 6. Model evaluation, predicted from mass balance and actual level changes.

	1950-00	**2001-04**	**1950-04**
Change in Lake level – mass balance (m)	**0.95**	**-0.38**	**0.57**
Change in Lake level - actual Measurement (m)	**1.06**	**-0.39**	**0.61**

The accuracy of the water balance model was tested by comparing calculated level changes against actual measurements. The ΔH which was originally expressed as flows was expressed as depth over the lake area. The outcome for both model and measured data had a very high correlation coefficient of 0.999 showing that the model is accurate and can reproduce the levels of Lake Victoria, once given correct values of the input and output processes.

CONCLUSIONS

Although the outcome of the water balance in the long term period is positive since 1950 and current levels are still above the pre 1961 mean levels, the severity of the 2001-2004 trends if continued over the next few years. This calls for a closer interest on the lake level trends by all the riparian states and address the causes of the levels fall. This will require concerted efforts to reverse the factors causing the decline like, such as a resumption of the natural flow practice at Jinja and overall a political will to conserve Lake Victoria. The water budget method is a very important tool for monitoring and revealing the changes that are occurring in the water quantities of the

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[8] LVEMP Data collection period.

lake. Its application requires regular and more intense monitoring components of the water budget.

RECOMMENDATIONS

- There should be increased frequency and consistency of relevant data collection in all the three countries.
- There is need for the three countries to continue cooperating in updating the water budget for Lake Victoria.
- Efforts should be made to determine the role played by groundwater in the water budget of Lake Victoria although work to date including isotopic analysis suggest the role of ground water is minimal in the budget.
- Data collection equipment and instruments should be standardized so that uniform data can be collected and used.
- Stations should be established in ungauged catchments so that actual data is used in the balance other than estimates.
- Undertake intensive studies on the possibility of regulating the lake to optimize its multiple but potentially conflicting uses to achieve maximum and sustainable socio-economic benefits for the riparian states

REFERENCES

LVEMP. 2002. Integrated Water Quality and Limnology Study of Lake Victoria.

CHAPTER 4

Hydraulic/Hydrodynamic Conditions of Lake Victoria

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ABSTRACT. *The waters of Lake Victoria are set into motion by energy exchange processes across its surface. Winds blowing over the surface can set near surface waters into motion and cause horizontal circulation (currents) as well as generating wave-related turbulence that can mix waters more deeply into the depths of the lake. Where rivers enter, both horizontal transport and vertical mixing can be set in motion by the momentum and physical characteristics of the entering rivers The Kagera river is exceptional in the dominance of open lake processes affecting the behaviour and mixing of its plumes as it enters into the lake directly. Most of the other rivers entering Lake Victoria enter behind islands or into protected gulfs and embayments where the hydrodynamics of river mixing are governed by local coastal process and the dynamics of the bays. The water motions that result from the net affect of all these energetic inputs determine the distribution of the dissolved and suspended materials in the water as well as affecting even the free swimming biota. Thus, it is necessary not only to determine the vertical transport of nutrients but also the horizontal transport of matter throughout the lake. The strength of horizontal circulation will also determine how widespread events such as pollution spills will be. Coordinated observations overall of Lake Victoria have confirmed phases 2 and 3 of the annual thermal and stratification cycle as defined by Talling (1966) for the northeastern part of the lake. Phase 2 is the development of the deep (40 m) thermocline in the period February to May, and phase 3 is the total vertical mixing that occurs in July-August. Phase 1 (September-December) is less obvious, i.e. the gradual warming of the water column is weak, and almost total mixing occurs in December-January at some stations. All three phases are less developed on the western side of the lake. The western part of Lake Victoria is much more influenced by the wind forces, and therefore experiences more mixing and cooling patterns. The eastern part of the Lake is much more influenced by persistent thermal stratification, and therefore vertical mixing is mainly by seasonal temperature dependent density currents. The implications are that the potential for nutrient transfer, sediment re-suspension is higher in the western part of the lake, which maintains well oxygenated conditions favourable for fish species requiring high oxygen concentrations such as the Nile perch. Main processes determining the fate and transport of pollutant that are mixing (dispersion) and flow (advection) were also studied.. These were modelled/simulated using the hydrodynamic module which*

is based on the generic DELFT3D-FLOW simulation package. The only wind data which could be used in the model was the global winds for 1998 which were delivered together with the framework model. The results from the model agreed well with the measured currents during the month of September.

INTRODUCTION

The waters of Lake Victoria are set into motion by energy exchange processes across its surface. The overlying air mass through radiant energy and heat exchange can heat and cool lake waters and effect changes in density that can encourage or constrain vertical circulation. Winds blowing over the surface can set near surface waters into motion and cause horizontal circulation (currents) as well as generating wave-related turbulence that can mix waters more deeply into the depths of the lake. Where rivers enter, both horizontal transport and vertical mixing can be set in motion by the momentum and physical characteristics of the entering river course. All these processes are time dependent and their intensity changes continuously as the meteorologic properties of the overlying air mass change. In the tropics, seasonal variability in these meteorological is subdued compared to higher latitudes, but diel (24 h) cycles in radiant energy and related meteorological properties are intensified by the strong tropical solar radiation (MacIntyre *et. al*. 2002) . The water motions that result from the net affect of all these energetic inputs determine the distribution of the dissolved and suspended materials in the water as well as affecting even the free swimming biota. Nutrients are re-suspended into the photic zone from the nutrient-rich deeper waters of lakes through vertical mixing (Schladow *et. al.*, 2004). Even though dissolved nutrients are assimilated rapidly in the photic zone, recycling and retention of nutrients can result in chemical and biological effects that are spatially and temporally dissociated from the original vertical mixing event. Thus, it is necessary not only to determine the vertical transport of nutrients but also the horizontal transport of matter in throughout the lake. The strength of horizontal circulation will also determine how widespread events such as pollution spills will be.

Vertical transport of nutrients is carried out in two major ways, namely, by upward flow (or upwelling) and by water turbulence. The latter may further be classified into down gradient transport due to the weak turbulent mixing in the interior of the water column and vertical entrainment of higher nutrient concentrations into the near-surface mixed layer (Jo 1973). A substantial amount of work including LVEMP has been done on water column temperature and oxygen measurements, but relatively little has been done to understand the hydrodynamic and thermal cycles in Lake Victoria and its Gulfs and smaller embayments. An important objective for LVEMP Water Quality studies was to determine the spatial and temporal variation of thermal stratification that restricts vertical circulation and describe the behaviour of wind-driven water currents in Lake Victoria, compare and contrast the present day stratification and hydrodynamic regime with historical observations and understand the exchange mechanisms between the main lake and the gulfs.

MATERIALS AND METHODS

Littoral and pelagic stations were established in the entire water body of Lake Victoria (see Chapter 2 for stations) with essential observations on meteorology provided by land based stations at airports and other areas of interest. As frequent as monthly measurements of temperature and current profiles, wind speeds and directions were made in various parts of the lake from 1997 to 2004. Additional data from previous studies was collected and a set of data ranging from 1994 to 2005 examined. Current velocities were measured with an Acoustic Doppler Current Profiler (ADCP), temperatures were measured using Hydrolab multi-parameter sensors, and wind speeds and direction were measured using a digital anemometer. In 2001 and 2002, more intense and nearly continuous measurements were carried at Uganda stations UP8 and UP6 using two ADCPs and Brancker temperature loggers that recorded at 30 minutes intervals.

Vertical mixing and Stratification

Historical information on the physical limnology of Lake Victoria is limited and not easily accessible. Past studies made in September 1927-28 Graham (1929) and Worthington (1930) studied lake-bottom temperatures across the lake while in 1952-54 Fish (1957) and in 1961-62 (Talling 1966) monitored seasonal changes of thermal stratification of an offshore station of Bugaia in the northern main basin. Newell (1960) studied temperature transects across the main basin in 1957-8. These studies led to the conclusion that Lake Victoria had three phases of thermal stratification (Talling 1966). *Phase I* (Sep-Dec.) was marked by surface warming and small thermal gradients over most of the water column. *Phase II* (Jan –May) was characterized by a well-defined seasonal mixed layer with a deep thermocline while *Phase III* (Jun-Aug.) had occasional complete holomixis (mixing through out the lake's depth) at a particular location, and only very small temperature differences were observed within the water column. In 1989-1991, Hecky et al. (1994) measured water column temperatures and compared them with the 1960-61 observations by Talling (1966).

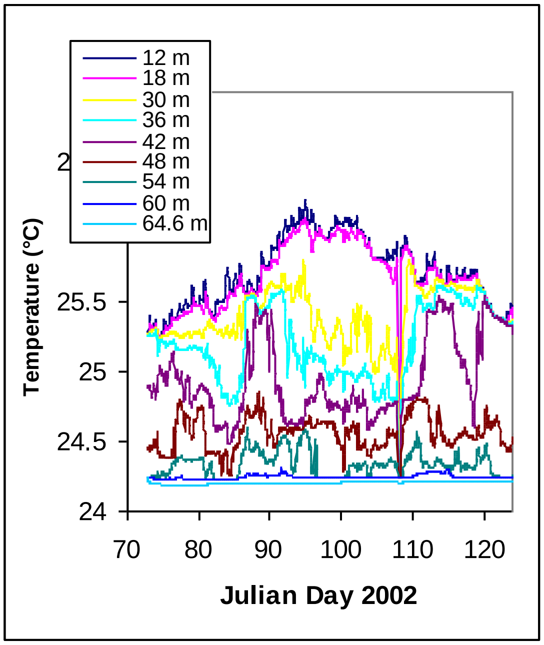

FIG. 1. Temperature profiles observed between Mar-May 2002 at 30 min interval at UP 6. In stage 3 stratification of Talling (1966)

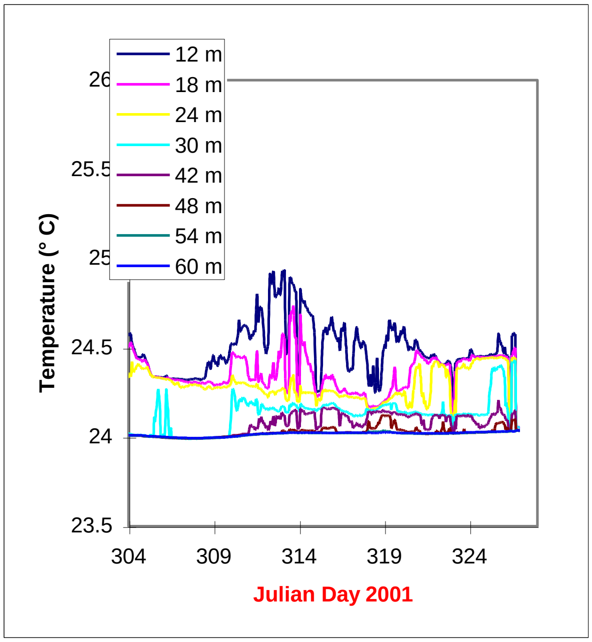

FIG. 2. Temperature profiles observed Nov 2002 at UP8 at 30 min interval in the early stratified period (stage 1).

High frequency observations of temperature profiles in the northern part of the lake at offshore stations indicate a similar pattern of thermal stratification (Figs. 1- 3) as reported by Talling (1966) in the pelagic stations. Observations in the north-eastern part of the lake off Kenya were also consistent with this pattern. However pelagic stations in the western and south western part of the lake show increased water temperatures, development of a significant temperature gradient (thermocline) only from February to May followed by cooling and nearly complete mixing for the rest of the year. Littoral stations on western part of the lake, for example Fig. 4, experience near complete mixing throughout the year; and more generally littoral stations, because they are shallower than the offshore thermocline, can mix throughout their depth in most seasons throughout the lake.

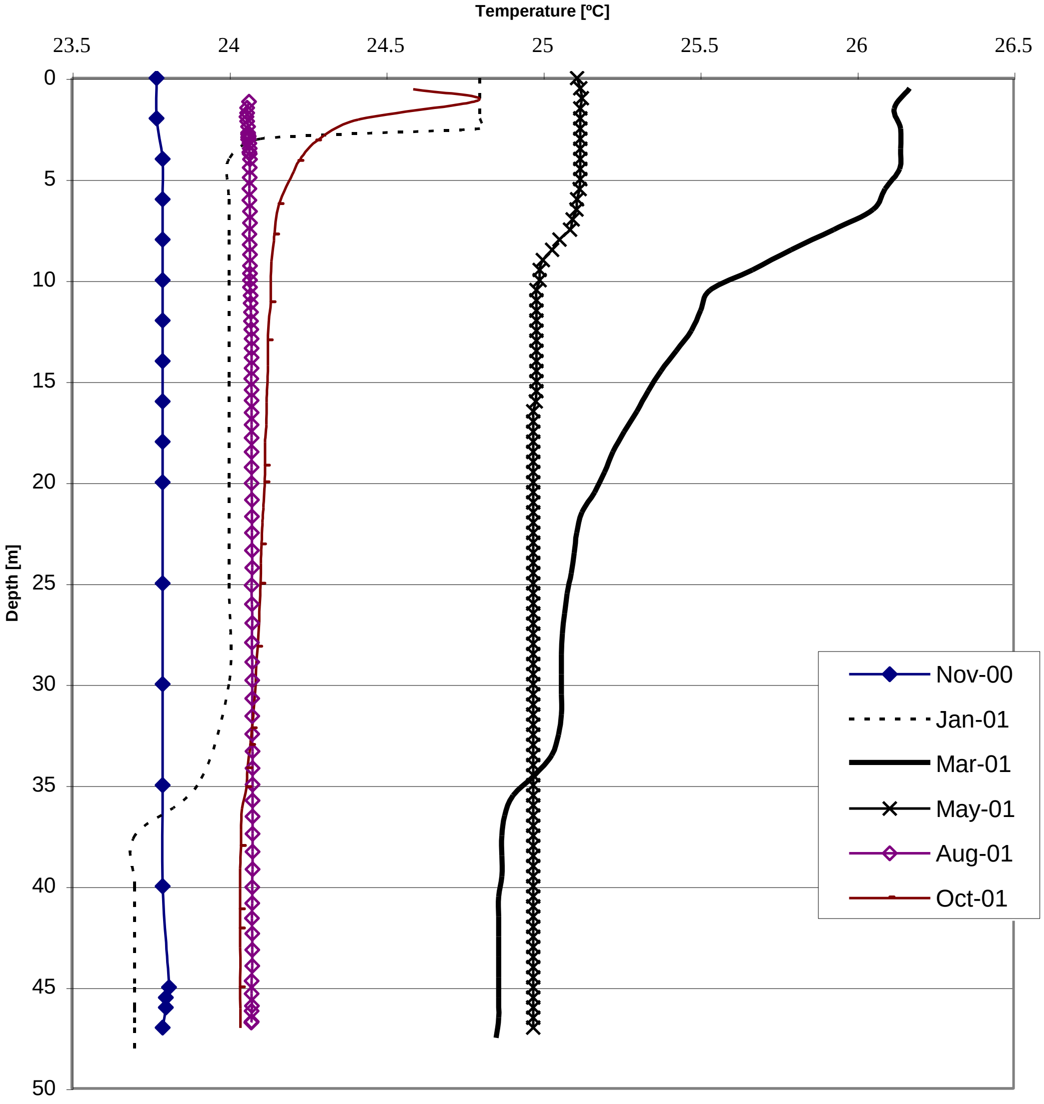

FIG. 3 Time series of temperature profiles at UP6, 2000-2001.

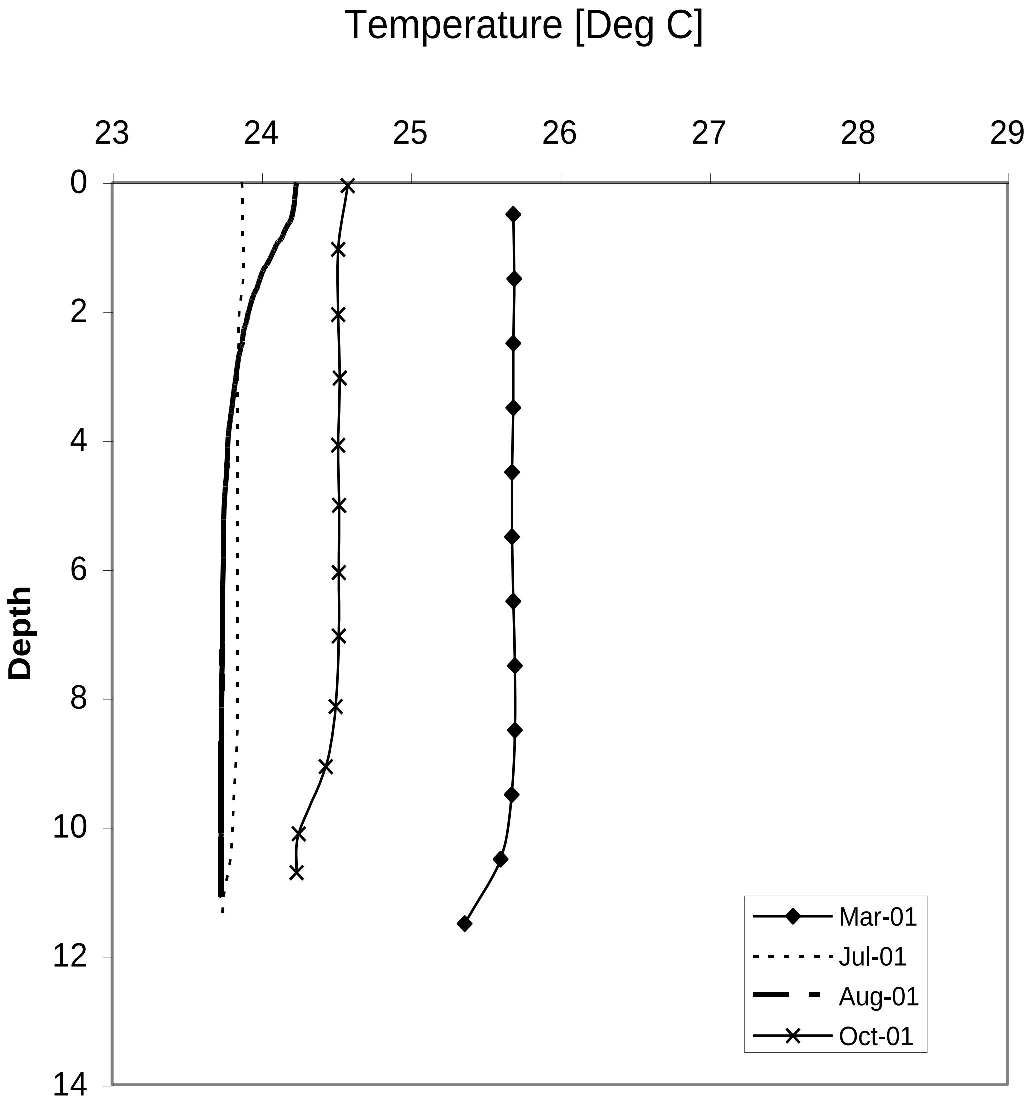

FIG .4 Temperature profiles at UL8 a shallow inshore station.

Horizontal Mixing

Horizontal water movement may be caused by three major phenomena, by drag caused by winds moving over the surface of the water body, by temperature differences that occur in different water masses that causes density driven circulation, and both can be affected by Coriolis forces. Lake Victoria is on the equator and the strength of the Coriolis forces are at minimum so water currents are only weakly affected by the Coriolis force. Average wind directions were plotted for Lolui Island, Yala (north-eastern shore of the lake) as well as Kome Island and Masaka on the northwestern shores of

Lake Victoria (Fig. 5). The Masaka station experiences westerly to south-westerly winds most times of the year while the rest of the stations experience easterly to south-easterly winds throughout the year similar to the global wind pattern (Fig. 6). This implies that the north-western part of the lake (north of Ssesse islands) might be influenced by different wind patterns. The global wind pattern shows that blow from October to December and March to May the winds approach the lake from southeast and, as they cross the lake, they turn north. At the same time there is a wind stream from Congo approaching the lake from southwest. These two wind streams meet in a convergence zone along the western side of the lake creating very strong surface waves on the western part of the lake.

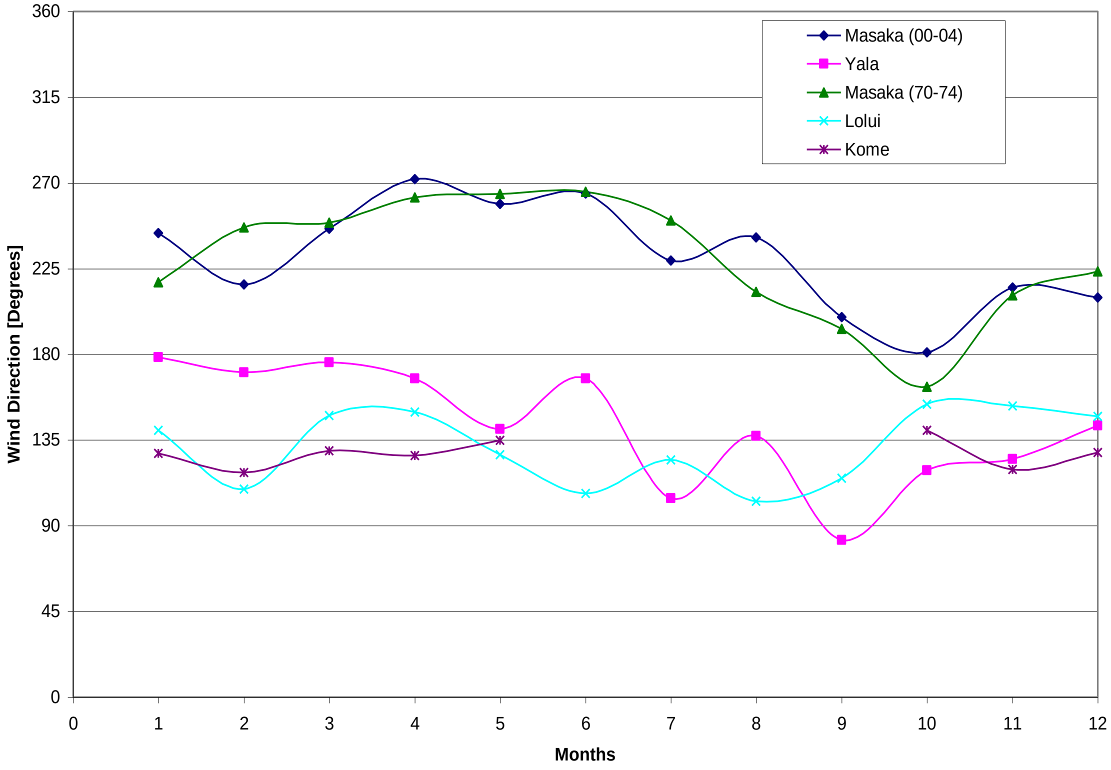

FIG. 5. Plot of monthly average wind directions at selected stations

Because of the long fetch these winds are capable of creating very high waves on the western part of the lake. As deep-water surface waves enter shallower waters on the western part, their velocity decreases proportional to the square root of depth. A reduction in wavelength occurs with a marked increase in wave height. With increased height the waves become asymmetrical and unstable and hence very turbulent. For example, a maximum wave height of 1.2 meters was recorded at UL9 (a station on the western side of the lake) with wind velocities of only 4.5 m/sec while a 0.5 m wave height was recorded at the more central UP10 from winds of maximum speed 4.7 m/sec. These strong wave movements cause very turbulent water mixing that can stir the bottom of the lake at littoral stations. In March, vertical velocity currents at UP6 record quite high velocities (Fig. 7) as deep as 45 m and can cause re-suspension of bed material and keep the water column well mixed. The turbulent mixing in this period of the year results in cooler water profiles in this part of the lake due to increased evaporative cooling. The strong currents force the suspended solids of River Kagera to move along the western and northern shores of the lake to join with the inflows from R. Bukora, both of which continue north-eastward and slowly mixing with the northern shore waters. From west to east, the wind fetch for these westerly winds decreases and so does the capacity to effect deep mixing. Also the lake deepens from west to east and the greater depths also make it difficult to effect complete mixing of the water column. The importance of these movements is enhanced by the fact that these are rainy months where increased loading from the rivers is highest. The result is wide distribution of the finer materials and nutrients contributed by the Kagera because of the strong currents and vigorous vertical mixing.

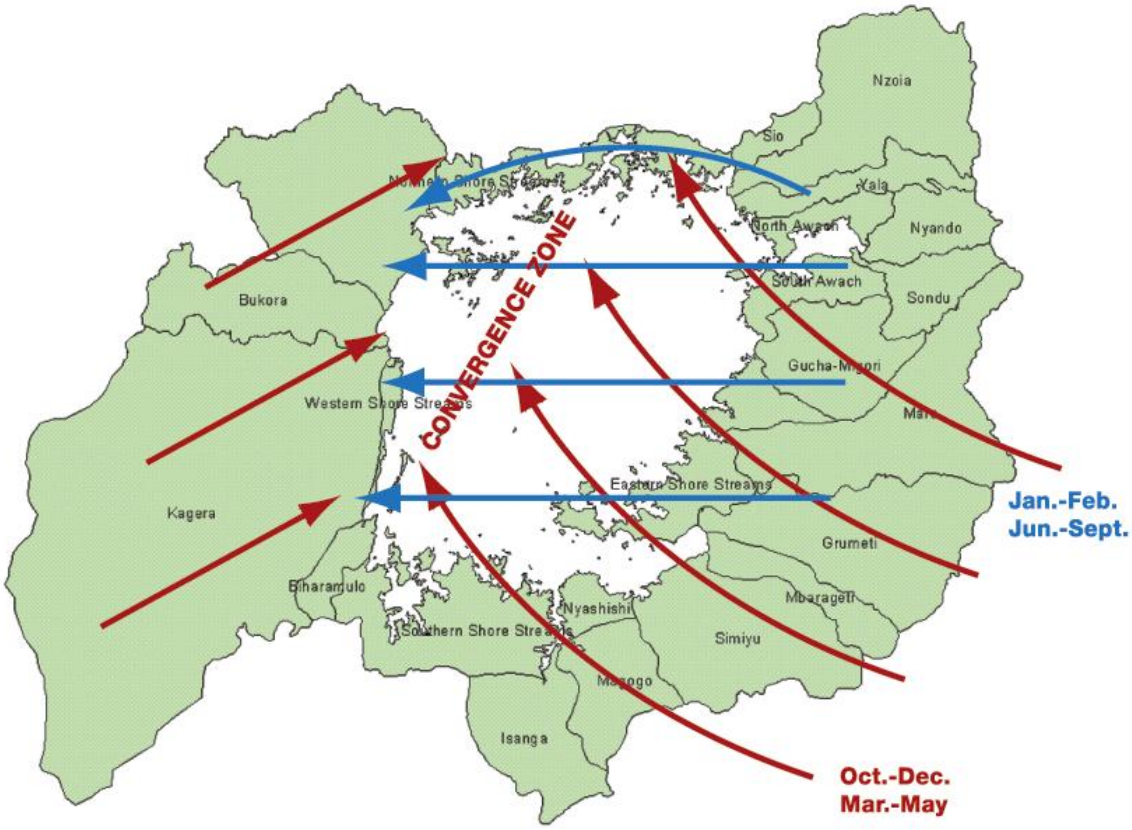

FIG. 6. Schematic showing global winds pattern (adopted from LVEMP 2002)

From January to February and June to September the main global winds flow from east to west. By the time these winds reach the western part of the lake, they have a long fetch and the high waves and turbulence discussed above occur. However, the extreme eastern part of the lake is shielded from the easterly winds by the Kenyan coast and islands. Development of very strong and high waves is largely hampered by short wind fetch and by the deep waters close to the Kenya coast. Wind movements at the lake surface in this area are largely due to alternating land and sea breeze phenomena. However, due to increased solar radiation between January and February, land-sea winds movements are much stronger, and therefore surface currents are more pronounced. Mixing is largely due to the cycloid movements due to surface waves and Langmuir circulations within the mixed layer. Mixing of the deep waters in this part of the lake is very minimal and heat transfer is largely due to horizontal advection due to the heating and cooling of the surface waters. Although the temperature gradients are only 1-2 C over the water column, this results into relative stability and persistent stratification isolating deep waters from surface waters.

The areas north of the Ssesse islands are shielded from the south-easterly winds by the islands and they are greatly influenced by the Congo westerly winds in the period between October-December and March-May. This creates a situation of strong westerly wind flow north of the island and inside the archipelago of islands along the northern coast (Fig. 9); and therefore, surface currents and waves move towards the east along Salisbury Channel. This is confirmed by observations made on the movement of the turbid River Kagera water and movement of the water hyacinths from the same river towards Dimo and Bukakata (Fig. 10) during these periods of the year.

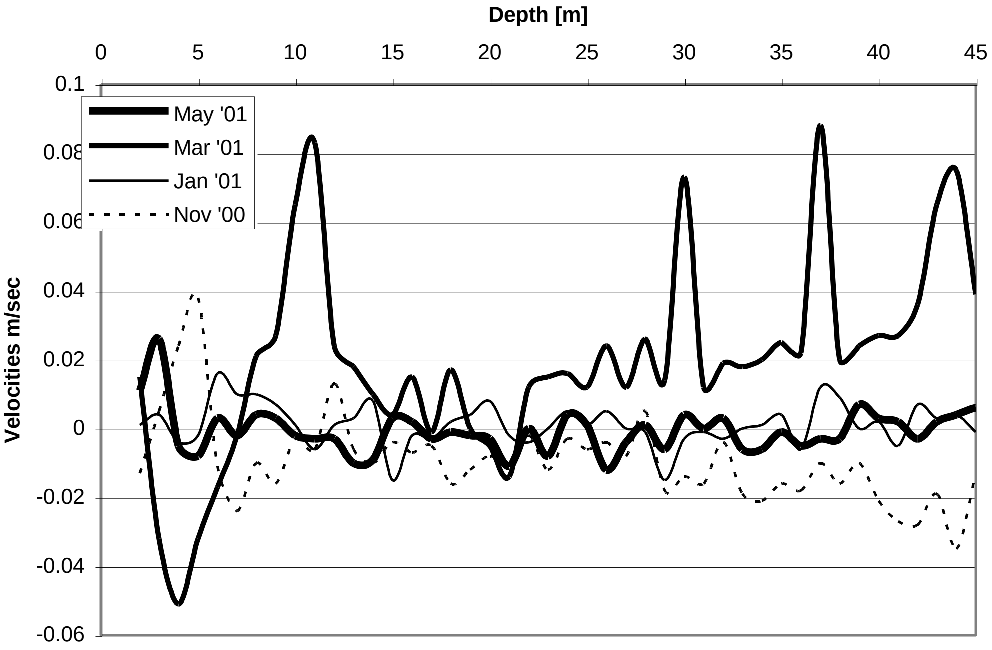

FIG. 7. Vertical velocity profiles observed at UP6 in selected months of 2000-2001.

Between January to February, and June to September, the easterly winds dominate forcing River Kagera waters to the west. This coupled with the wave strength described above, forces the River Kagera waters and transported hyacinth to mix with the main lake waters and pieces of squashed water hyacinths can be seen scattered along the western shoreline. The Kagera is exceptional in the dominance of open lake processes affecting the behaviour and mixing of its plumes as it enters into the lake directly. Most of the other rivers entering Lake Victoria enter behind islands or into protected gulfs and embayments where the hydrodynamics of river mixing are governed by local coastal process and the dynamics of the bays.

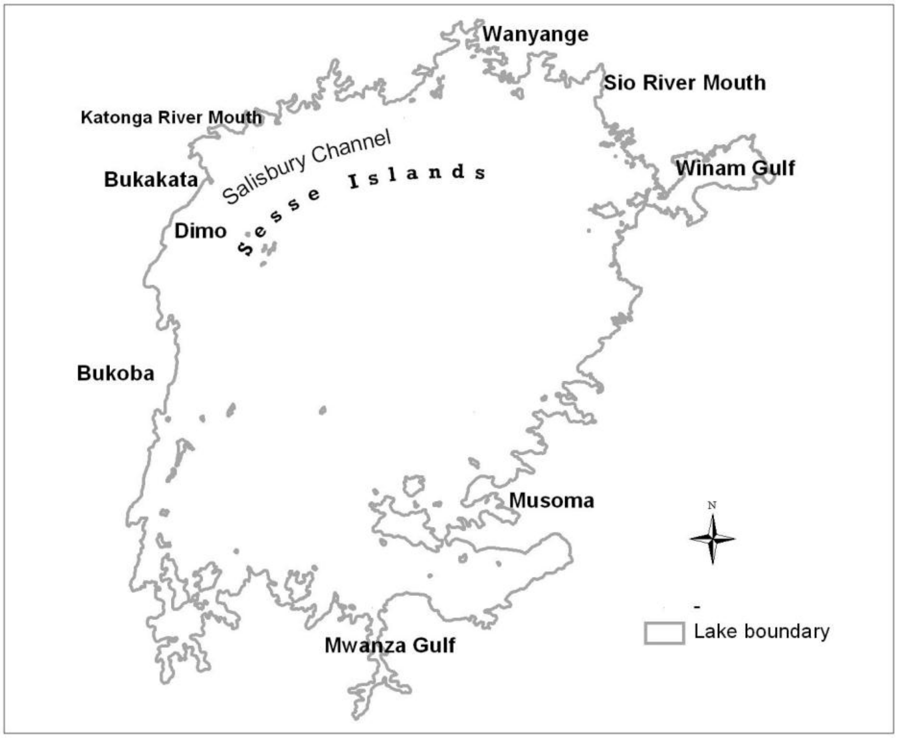

FIG. 8 Map showing selected locations along the north western coast.

Oxygen Distribution & Secchi Depth

Dissolved Oxygen is one of the most fundamental parameters of lakes. First, it is essential for aerobic aquatic organisms. Very low oxygen concentrations can cause environmental disasters such as fish kills. Secondly, in response to anoxic hypolimnion (bottom portion of the lake) aerobic decomposition ceases and anaerobic decomposition takes over releasing hydrogen sulphide, phosphorous, manganese, and iron can be released into water. Phosphorous is a nutrient which can increase the growth of algae. Elevated manganese and iron concentrations are a concern for water treatment and for aquatic life.

When oxygen levels are below 4 mg/l, fish and mobile animals migrate to areas of higher oxygen concentrations. At oxygen levels below 2 mg/l, fish and other animals that have not moved away begin dying (Wanink et. al. 2001). This results in loss of habitat for many species when low oxygen concentrations are persistent. Low oxygen levels may be a result of poor mixing of the water column which can add oxygen from the atmosphere or primary production and/or high levels of BOD loading that consumes oxygen.

The minimum depths at which oxygen concentration of 4 mg/l has been observed during samplings between 1994 and 2004 (Fig. 9) can extend into depths <5m where there are sources of BOD from the land or exceptional densities of algae. From the map, it is evident that the western part of the lake east of the entry of River Kagera has the most favourable oxygen conditions for fish and other animals throughout the year. This can be attributed among others to the good mixing conditions described above. The northern shores of Lake Victoria depict very low oxygen levels at shallow depth including areas near the influence of Rivers Katonga, Bukora and Sio as well as the Napoleon and Wanyange gulfs. This is due to the poor mixing conditions north of the Ssese islands described above because of the protection offered by the numerous islands along this coast. Shallow areas of the lake also have the highest abundance of algae on average (Chapter 5) and decomposition of these algae can cause low oxygen conditions especially during the night when the algae cannot produce oxygen from photosynthesis. In the deeper areas of the lake hypoxic and even anoxic conditions develop and persist under stratified conditions for longer periods of time compared to conditions in the 1960's (Hecky et al. 1994).

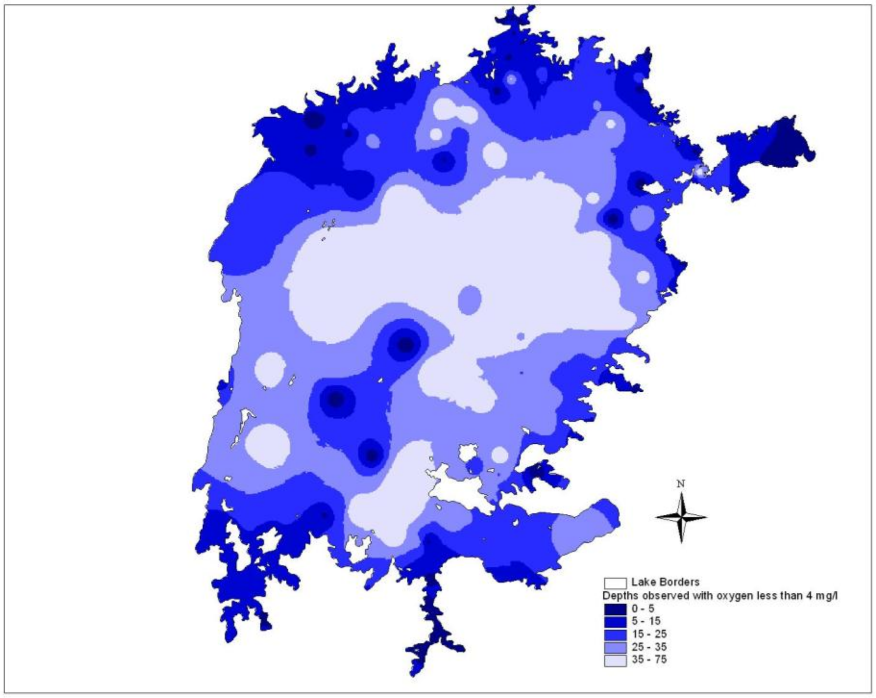

FIG. 9. Depths at which oxygen less than 4mg/l have been observed between 1994 to 2004.

Light attenuation in Lake Victoria is controlled by algal abundance. The Secchi depth responds to light transparency with low values indicating low light penetration and high algal abundance. In the vicinity of rivers the suspended sediment load can also cause reduce Secchi depths. Lower Secchi depths were recorded in inshore areas with the lowest being recorded along the northeast coast within the open lake during algal blooms. In general there is a good spatial agreement between the presence of low oxygen at shallow depths (Fig. 10) and the areas with low Secchi Depth. The high algal abundances in these inshore areas create an oxygen demand as they sink out of the water column and this together with the reduced vertical mixing in these areas results in hypoxia occurring in shallow inshore areas. The lower Secchi depths also indicate that radiant energy is absorbed rapidly to warm near surface waters. This intense warming during daylight creates a diurnal stratification that keeps the algae suspended in the upper well illuminated water and allow high rates of photosynthesis near the surface. For most of Lake Victoria the algal populations are light limited by self shading and the shallower parts of the lake sustaining the high abundances because of the reduced depth of mixing in the shallow areas (see Chapter 6 Eutrophication).

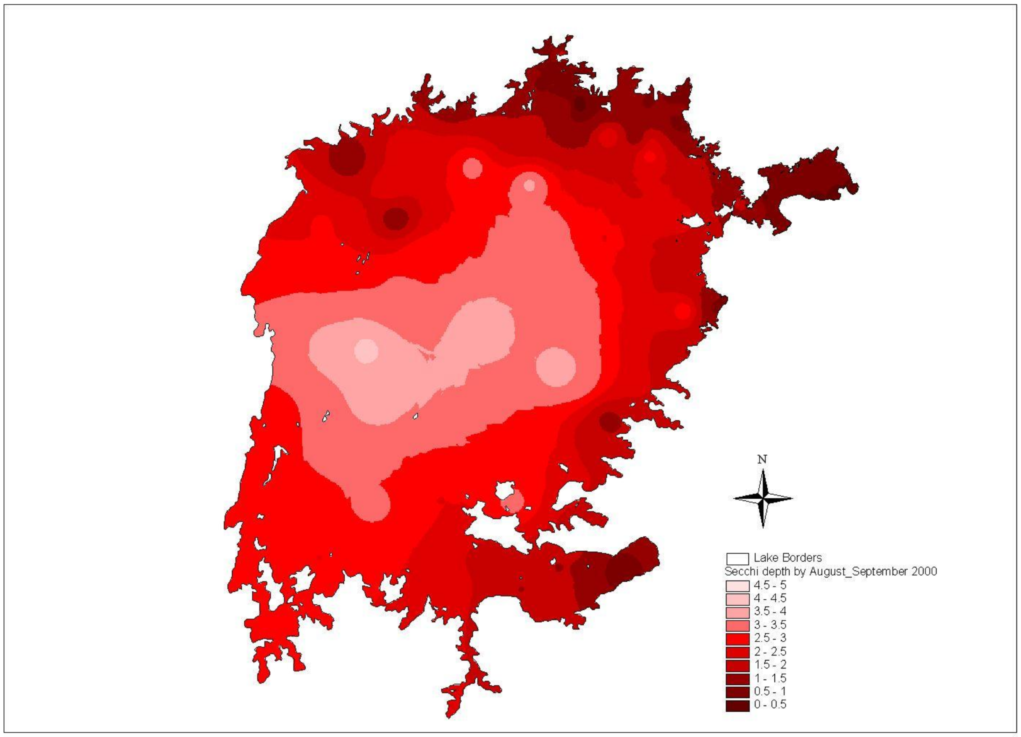

FIG. 10. Secchi depths observed in Aug/Sept 2002.

GULFS AND BAYS

Vertical mixing and stratification

Winam Gulf was intensively studied during the LVEMP period because of concern that it was highly eutrophied and might be a major nutrient source to open waters of Lake Victoria. The thermal structure at the deeper parts of the gulf (Rusinga Channel) that open to the open waters of Lake Victoria are significantly different from those observed in the shallow inner parts of the Gulf including bays such as Homa bay, Asembo bay, Kisumu bay and Nyackach bay (Fig. 11). While observations at the Channel exhibit diurnal and deeper persistent seasonal thermoclines at around 15 m depth, the bays show the presence of diurnal thermoclines only. This is due to the shallow depths of the bays which allow mixing to reach the bottom every day during nocturnal cooling.

Observations undertaken in the period 2000-2004, show that the diurnal cycle of thermal stratification is influenced by the local wind field, that consist of the westerly lake breeze and the reversing easterly land breeze (Fig. 12), as well as the intense daily solar radiation,. The thermal structure is characterized by near-isothermal conditions at night /morning and strong stratification in the afternoon.

During the morning hours there is hardly any vertical exchange between the surface and bottom waters because solar heating is still weak and the land breeze is calm (about 1m/s). As it approaches noon the upper mixed layer exhibited convective currents (about 5cm/s,) which responded to the strong lake breezes (about 3m/s) and increased heating of the surface waters (Fig. 13). The entire water column has a near-isothermal conditions overnight, which results from natural convective cooling that leads to the mixing of the cooler surface waters and the warmer bottom waters. The reversing winds (Fig. 12) are well known to fisherman and transporters who make use of the predictability of the winds to time their sailing excursions onto and from the lake.

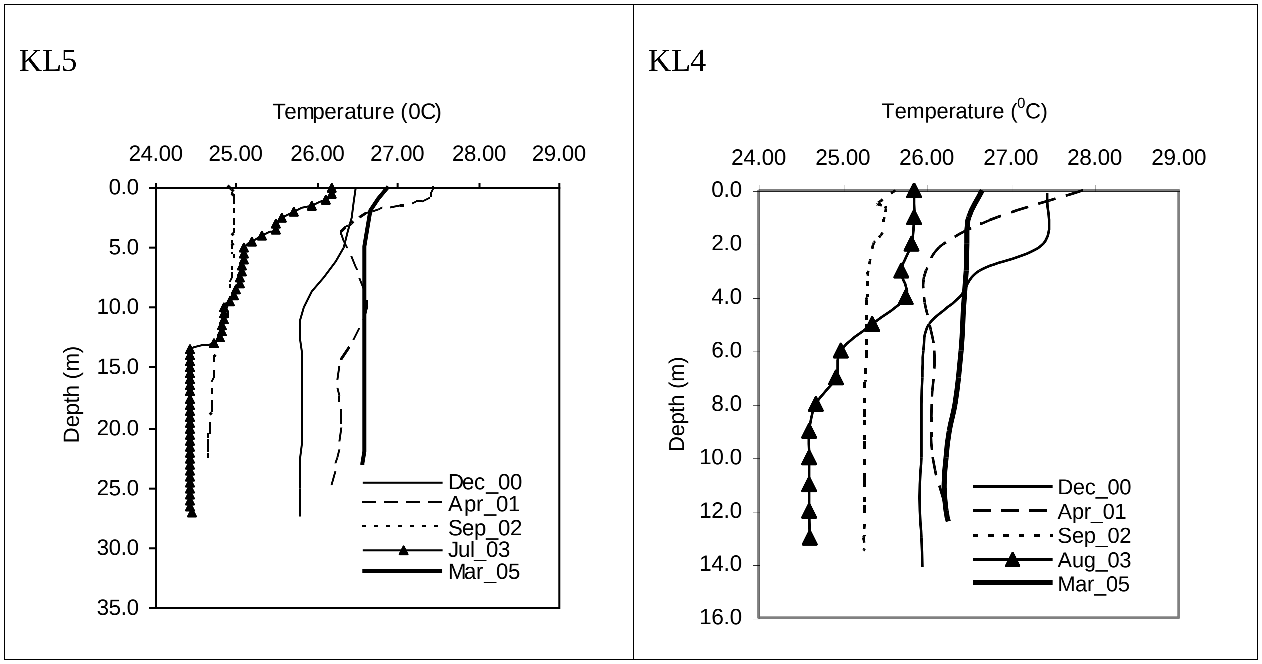

FIG. 11. Comparison of thermal structure at Rusinga Channel (KL5, left panel) showing the diurnal and seasonal thermoclines and shallow bays (KL4, right panel) showing only the diurnal thermocline forming above 5 m depth. Note the different depth scales.

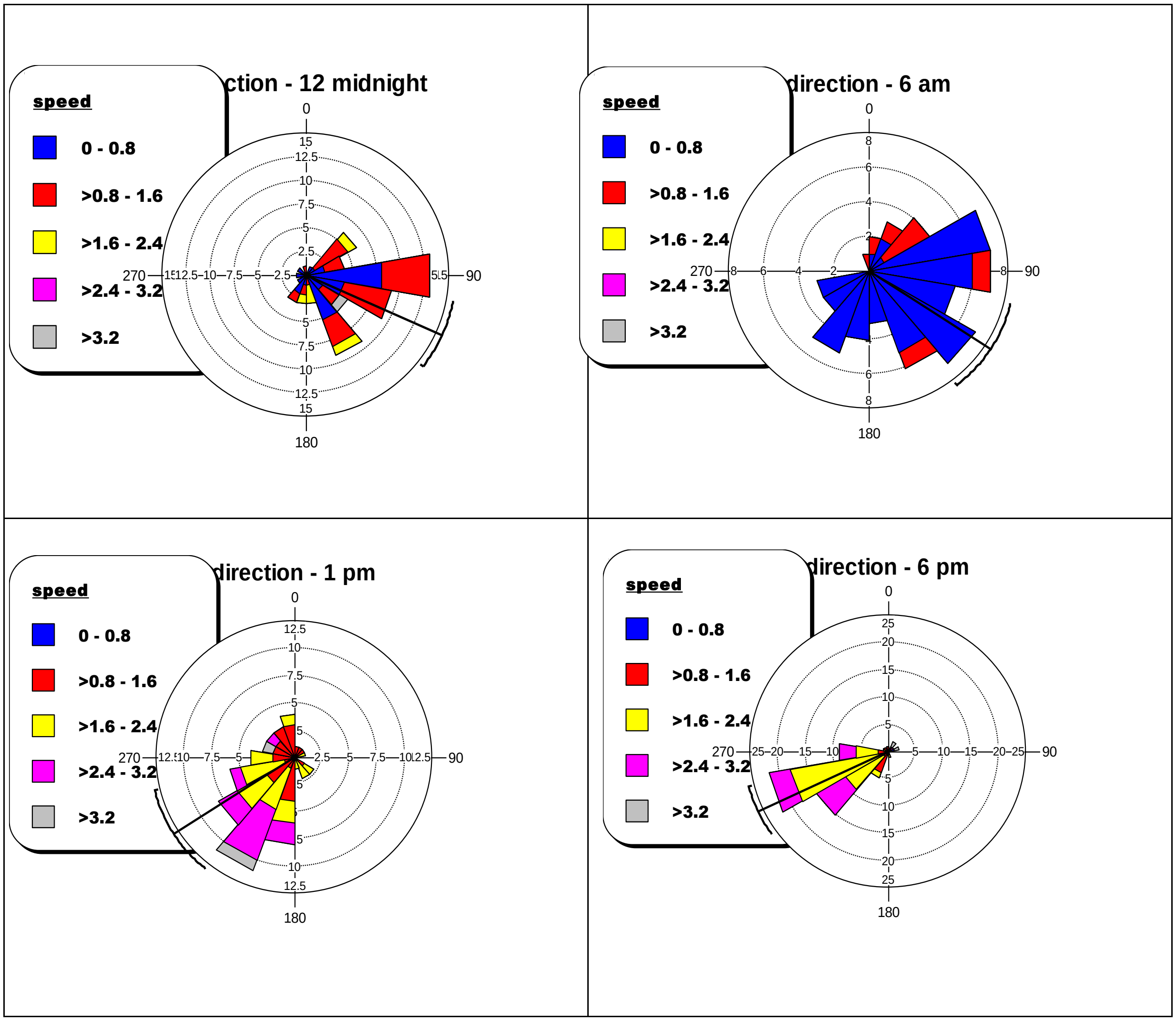

FIG. 12a. Selected wind roses at Yala showing the diurnal variations in the local wind regime illustrating the well known lake breezes from the west during the day and land breezes from the east at night.

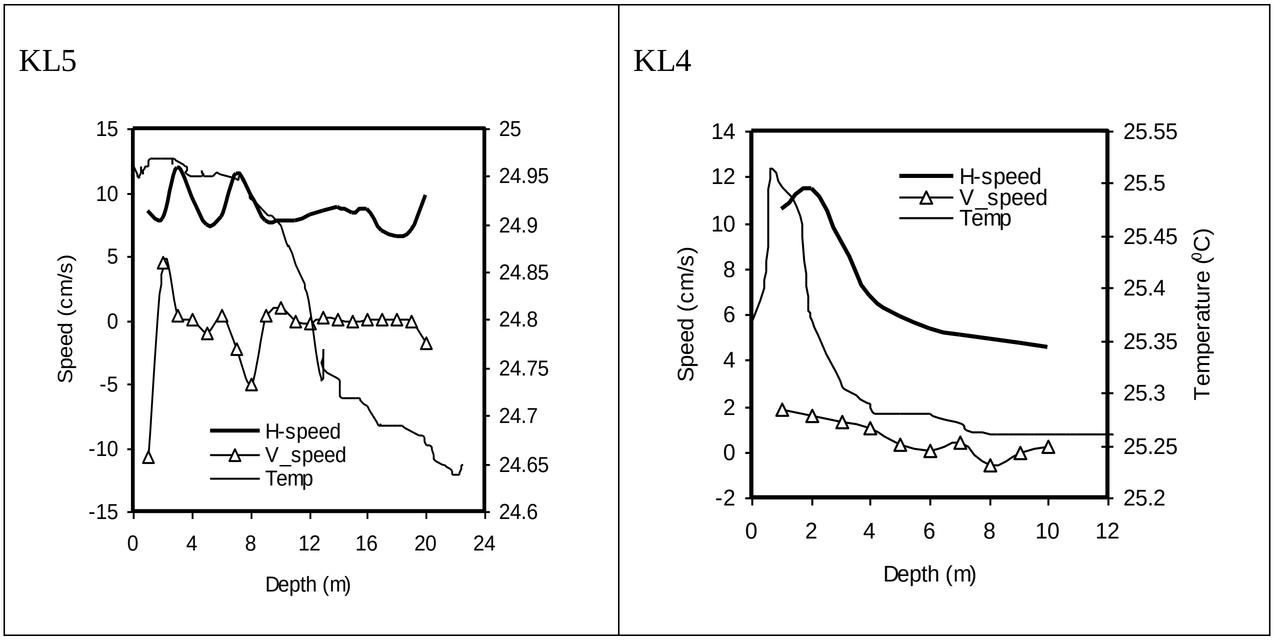

FIG. 12b. Comparison of vertical (V speed) and horizontal (H speed) mixing, and stratification at Rusinga Channel (KL5, left panel) and shallow station at western end of Winam Gulf (KL4, right panel). Note different scales. Negative speed indicates current in the opposite direction.

The upper layers at both stations (<12 m depth) had high oxygen levels of more than 6 mg/L. In contrast, the bottom oxygen concentrations of less than 4mg/L observed at Rusinga Channel were below the bottom concentrations at the shallow stations.

Vertical mixing in the gulf is particularly important in returning nutrients regenerated in deeper water back to the photic zone and occurs on daily basis at the shallower (less than 12 m) areas when diurnal stratification breaks down at night. This daily breakdown leads to efficient nutrient recycling and aeration within the shallow gulfs that is essential to maintaining high algal abundances.

Horizontal mixing

The evidence of horizontal mixing in Winam Gulf is best discussed by focusing on the interchange between the gulf and the open lake. The interchange between Winam Gulf and the open lake was studied by undertaking longitudinal CTD (conductivity, temperature and depth) observations along the Rusinga Channel (Fig. 13). The figure shows isotherms in the gulf sloping downwards which implies that the waters in the channel are heated to higher temperatures when compared to waters of the open lake at the same depths. The cooler, denser open lake waters will tend to replace the bottom waters in the gulf and therefore the hotter surface gulf waters will in return move west into the open lake to balance the pressure gradient. However due to the effect of the land breeze from the west during the day the reverse movement of the surface waters is resisted creating a temporary water build-up in the bay which depends on the strength of the winds and insolation. During the night these processes are reversed and as a result mixing of the waters of the gulf with the open lake is very limited.

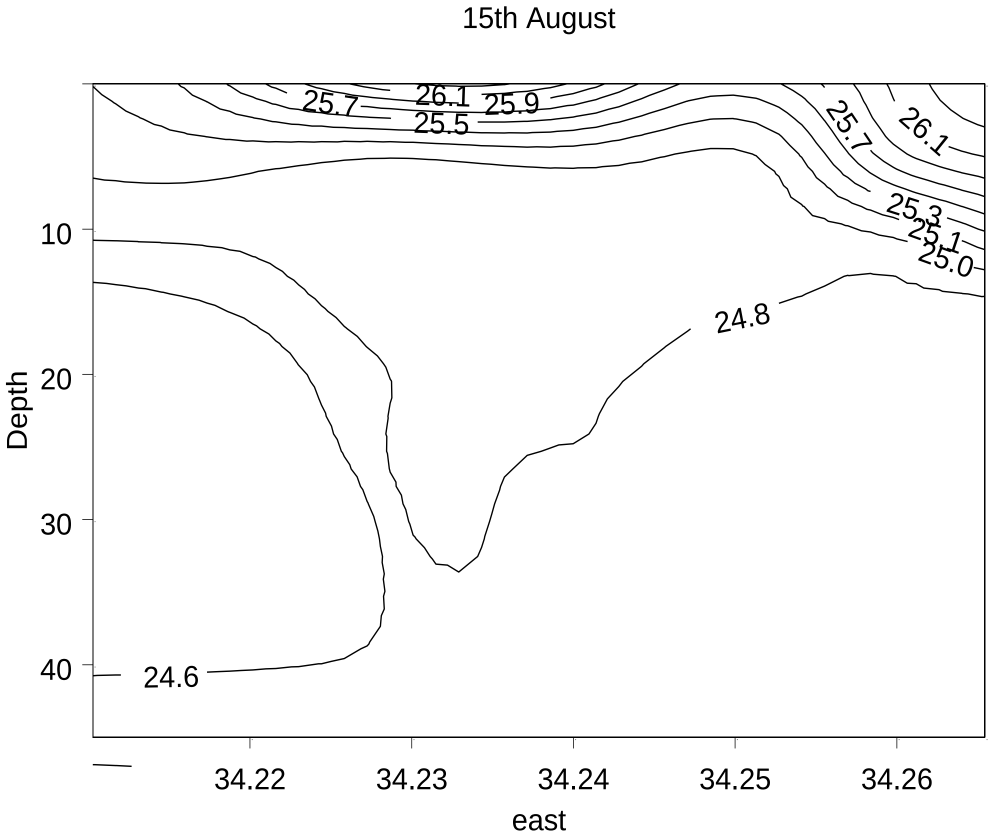

FIG. 13. Isotherms (degrees C)versus depth (m) along a transect between Winam Gulf (to the right on the figure) and Open Lake Victoria (to the left; x-axis are degrees of longitude) along Rusinga Channel on 15 Aug. 2004. Downward sloping isotherms at 34.26 indicate that cooler water should flow under warmer gulf waters.

Current measurements in Ruzinga channel and the gulf registered the velocity of 6.8 cm/s and 8.5 cm/s largely limited to the upper layer (epilimnion). This suggests that water movement in the gulf is dominantly restricted to vertical Langmuir circulations within the mixed layer.

The conditions at the Rusinga Channel effectively restrict interchange between the Gulf and the open lake. At other gulfs and embayments on Lake Victoria similar hydrodynamic processes will be in affect but there net result will vary with coastal topography, lake bathymetry and orientation of the embayments to prevailing winds. The net result for Winam Gulf is to create a relatively isolated water mass that takes on its own physical, chemical and biological characteristics (Chapters 5 and 6) and causes retention within the Gulf of much of the nutrients, sediments and BOD added to the gulf.

LVEMP Model (Hydrodynamic-Quality DELFT3D)

Proper lake management cannot be achieved only by surveillance water quality monitoring of current condition or inferred trends. Simulation modeling of possible causes of change, effects of interventions and meteorological processes is required to support decisions made by those responsible for the lake. The main processes determining the fate and transport of pollutant which are mixing (dispersion) and flow (advection) were studied. These are modelled/simulated using the hydrodynamic module which is based on the generic DELFT3D-FLOW simulation package. This is a three dimensional hydrostatic pressure flow and transport model, which includes horizontal and vertical heat transport based on meteorological inputs and river flows. The calculated flow and temperature fields are input to a water quality model that includes biological processing of nutrients and sedimentation.

Currently, the only wind data which could be used in the model are the global winds for 1998 which were delivered by consultants together with the framework model. The global winds are those at a high altitude above the lake, though it is now clear that they differ greatly from those at the lake surface because of the surface interaction through land-lake breezes. At the lake surface the winds are generally light and irregular and greatly affected by the diurnal onshore-offshore cycle all around the lake perimeter. The model was run for the periods where the global winds are predominant for the months August-September. The model output agrees quite well with the measured currents during the month of September. The water velocities at the surface vary from 2 to 10 cm/s.

Conclusions

Examination of the temperature profiles, wind patterns, Secchi depths and oxygen profiles with hydrodynamic model output lead to the following conclusions:

- Coordinated observations overall of Lake Victoria have confirmed that phases 2 and 3 of the annual thermal and stratification cycle as defined by Talling (196) for the northeastern part of the lake. Phase 2 is the development of the deep (40 m) thermocline in the period February to May, and phase 3 is the total vertical mixing that occurs in July-August. Phase 1 (September-December) is less obvious, i.e. the gradual warming of the water column is weak, and almost total mixing occurs in December-January at some stations. All three phases are less obvious on the western side of the lake.

- The western part of Lake Victoria is much more influenced by the wind forces and therefore experiences more frequent mixing and cooling patterns. The eastern part of the Lake is much more influenced by persistent thermal stratification, and therefore vertical mixing is mainly by seasonal temperature dependent density currents. The implications are that the potential for nutrient transfer, sediment re-suspension is higher in the western part of the lake, which yields favourable conditions high oxygen demanding fish species.

- Due weaker mixing action and resulting stratification, the eastern part of the lake experiences higher water temperatures throughout the year. Because phytoplankton populations are light limited the stratification in the north east favours the maintenance of higher phytoplankton populations as the depth of mixing is restricted. Inshore shallow areas of the lake also will have the highest algal abundances for the same reason. Consequently the potential for fish kills is higherst in the northeastern sector during upwelling events and in shallow, protected inshore regions where high algal biomass can cause excessive oxygen consumption.

- The northern shores of the Lake Victoria experience shallow critical oxygen levels especially inside the archipelago of islands off the Uganda coast and in the vicinity of Rivers Sio, Bukora and Katonga and also around Entebbe. The archipelago of islands restricts horizontal and vertical mixing and allow large algal abundances to build up.

- Wind and its interaction with available fetch, coastal topography and bathymetry is the major force that determines the overall lake circulation, except in the gulfs where the effects of topography and land-lake breezes are amplified.

- Proper lake management can not be achieved only by surveillance water quality monitoring but also requires simulation/modeling of possible interventions and meteorological processes affecting the lake. Thus there is a continuing need for training in modeling especially hydrodynamic and quality modeling.

Recommendations

- Observations of temperatures and currents should be made on a continuous basis at selected locations to understand the forces that drive the generation of and govern the decay of the variable flows between embayments and the central lake. This is critical for highly urbanized bays with significant point sources of loading such as Murchison Bay, Kisumu Bay and Mwanza Gulf.

- More emphasis should be made towards the implementation of the hydrodynamics model available so that management issues can be investigated and potential solutions discussed.

- A detailed bathymetric survey is required for the project to develop proper model development and calibrations and investigation of lake residence time. The current hydrographic chart is well out of date and cannot be used for inshore areas where significant local changes due to sedimentation and river delta extension has occurred

- Data at a temporal and spatial high resolution need to be collected at identified locations to understand the contribution of seiches (internal waves) to nutrient mixing and its contricution to nutrient recycling within the lake.

- The Kagera River and events within its catchment have strong impacts on the northern lake shores because of the hydrodynamic processes of the lake. International action with neighboring Rwanda and Burundi that share the catchment will be necessary to relieve impacts of catchment change along the Uganda coast.

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CHAPTER 5

Lake Victoria: The Changing Lake

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ABSTRACT. *Water quality monitoring activities were carried out on physical-chemical parameters, water chemistry and biotic indices at selected littoral and pelagic stations along north-south and east-west transects over an annual cycle between 2000 and 2005. The activities were aimed at collecting baseline information and data for use to define the current lake conditions and make a water quality assessment of the lake in relation to nutrient/ pollutant loadings as a basis for future monitoring surveys. As much as possible current conditions of the lake were compared to past observations where field sites coincided with those of historical studies.*

Littoral stations (0-20m) showed higher temperatures, pH, turbidities and electrical conductivity while Secchi depths and dissolved oxygen were lower compared to pelagic ones. Deeper pelagic sites experience thermal stratification, leading to strong differences between surface and deep water layers especially in terms of temperature and dissolved oxygen except for June through August during which the lake achieves complete mixing in all stations. On average, littoral stations have higher total nitrogen, chlorophyll, organic matter as well as total particulate carbon. Phytoplankton production and biomass in shallow inshore sites is light-limited due to self shading and the latter can therefore sustain higher algal biomasses because of limited mixing depths. Nitrogen often limits algal growth except for Cyanobacteria that can fix atmospheric nitrogen to meet their N limitations. The higher algal biomass accounts for the higher TN concentrations, chlorophyll and organic matter at littoral sites. During thermal stratification, TP and SRP concentrations are comparable in littoral and pelagic sites while during and just after mixing, both fractions of P are higher in the littoral areas.

Continuous excess SRP and the ability of Cyanobacteria to fix atmospheric nitrogen create nutrient saturated conditions that result in light limitation for algal growth. Annual rainfall is characterised by two peaks in the stratification seasons 2 and 3 and appears to be the main source of nutrient enrichment in the lake, particularly TP. Decomposition of organic matter during the stratification period results into release of TP and Si into deeper waters where they build up to much greater concentration than in surface waters. TN reaches annual minimum during the deep mixing period because of N-poor deep waters. Chlorophyll concentrations also reach their annual minimum at this time as deep mixing imposes strong light limitation on algal growth and nitrogen fixation especially in pelagic areas.

Comparisons with historical records show that the lake today is warmer than in the 1960s but with lower oxygen and pH in the deeper waters. Thus deep water respiration rates, oxygen consumption and CO_2 *are higher in the 2000s largely attributed to the eutrophication of the lake. Oxygen depletion in deeper waters during thermal stratification has led to loss of habitat for fish and other biota. Chlorophyll levels, phosphorus concentrations and electrical conductivity in both littoral and pelagic stations have increased compared to records of the 1960s. On the other hand nitrogen concentrations around marginal bays and gulfs have not shown a marked increase compared to historical records of the 1960s and 1970s. Dissolved silicon in the pelagic areas has decreased 5-20 times compared to historical records as eutrophication has increased Si demand by diatoms relative to rather constant supply from the catchment. In line with increased algal turbidities, Secchi depths have decreased at least two-fold since the 1960s. The need for lake wide regular water quality surveys and basin developments in support of appropriate management interventions can not be overemphasized at present in order to determine whether the lake is continuing along the same trends over time documented in this report.*

INTRODUCTION

Environmental monitoring is defined as “long-term, standardized measurement, observation, evaluation and reporting of the aquatic environment in order to define status and trends” (Chapman 1996). Monitoring of Lake Victoria is important as it is aimed to provide baseline data that is required for better and informed lake management. The current conditions can also be compared with previous studies to establish trends and can be used in the future to evaluate the utility of management actions to maintain the lake’s water quality.

Lake Victoria is very important for its whole basin, downstream riparian communities and even national areas beyond the catchment boundaries for providing freshwater for domestic, agricultural and industrial use, transport, recreation, tourism, fisheries and biodiversity conservation. However, since the early 1960s the lake water quality has increasingly deteriorated. The changes were driven by population increase in the catchment areas and associated economic activities (Hecky 1993). Sedimentary evidence suggest nutrient input to the lake has increased approximately two-fold in the past century (Chapter 7 of this report) and nutrient (N and P) levels in the lake are reported to have risen markedly throughout the lake. Stimulated by these and other nutrients, there has been reported a five-fold increase in algal abundance and a shift in algal composition towards domination by blue-green algae (Cyanobacteria), increased water turbidity, reduced water transparency, increased deoxygenated deep water, increased sickness for humans and animals drawing water from the lake, clogging of water intake filters, and increased chemical drinking water treatment costs for urban centers. Besides spatial displacement of the deep water fish and invertebrate species, the deoxygenation of the lake's bottom waters now poses a constant threat, even in shallower portions of the lake, as periodic upwelling of hypoxic water causes massive fish kills (Ochumba and Kibaara, 1989).

The limnological and chemical status of the lake has been impacted by the poor farming practices that lead to nutrient-bearing sediments release into rivers that drain into the lake, increasing inputs of fertilizers from plantations and farms in the catchment, outfalls from municipal waste treatment plants as well as deforestation and biomass burning that release phosphorus and nitrogen into the air. Major pollutants from these sources have been identified. These especially include phosphorus and nitrogen that are responsible for the limnological and water quality changes that have taken place in the lake. Loads of phosphorus and nitrogen into the lake from municipal, industrial, non-point sources and from atmospheric deposition have been estimated (Chapter 7) and the incremental anthropogenic loads over natural loads run into thousands of tons annually (LVEMP 2002). The excessive addition of nutrients to water bodies from anthropogenic sources and the resulting changes in water quality are global phenomena (Chapman, 1996). Management and reduction of these anthropogenic sources will be necessary to allow the riparian communities of the lake to maintain their beneficial uses of the lake waters and resources.

The lake monitoring programme was designed to evaluate the spatial and temporal variability of the various water quality problems, to enable comparison of these data with earlier water quality data and to provide a comprehensive lake-wide baseline against which future changes in the lake and management of the lake can be evaluated. The specific objectives of lake monitoring programme were to obtain data for determination of the present state of the lake water quality and ecosystem; to analyze the relative importance of the biological processes and limiting factors in the eutrophication of the lake and calibration of the Lake Victoria Water Quality Framework Model. In the longer term, the monitoring program is essential to determining if current and future uses of the lake's resources are sustainable.

Monitoring Design and Operation

The study area is comprised of two main zones of the lake namely the open waters herein referred to as pelagic zone (P) and the nearshore areas herein referred to as the littoral zone (L). This classification is based on the lake depths and distance from the shoreline. Under this classification the littoral zone is that area that is less than 5 km from the shoreline and/or where water depth is less than 20 m; conversely the pelagic zone is that area that is 5 km and beyond from the shoreline and/or where water depth is greater than 20 m.

On the basis of the lake's large surface area, classification, sheltering effects, climatic conditions and the preliminary hydraulic conditions established by earlier research, the monitoring design established 29 littoral and 28 pelagic stations. Each of the pelagic stations was located in such a way that it lay on a transect joining the Tanzanian, Ugandan or Kenyan stations of the harmonised monitoring network. This was meant to enable comparison of physico-limnological profiles, the water chemistry and biotic indices along and across the lake in space and time. This program was designed to define the variations from north to south and east to west over the annual cycle. In the monitoring design, the naming convention for the stations is given as follows:

First letter: Country: K=Kenya U=Uganda T=Tanzania
Second letter: L = Littoral (inshore). P = Pelagic (offshore).

It was planned that a relatively limited number of key stations should be visited on monthly/quarterly cruises and that all the required samples could be collected on one cruise. The study area and sampling locations are shown in (Fig. 1).

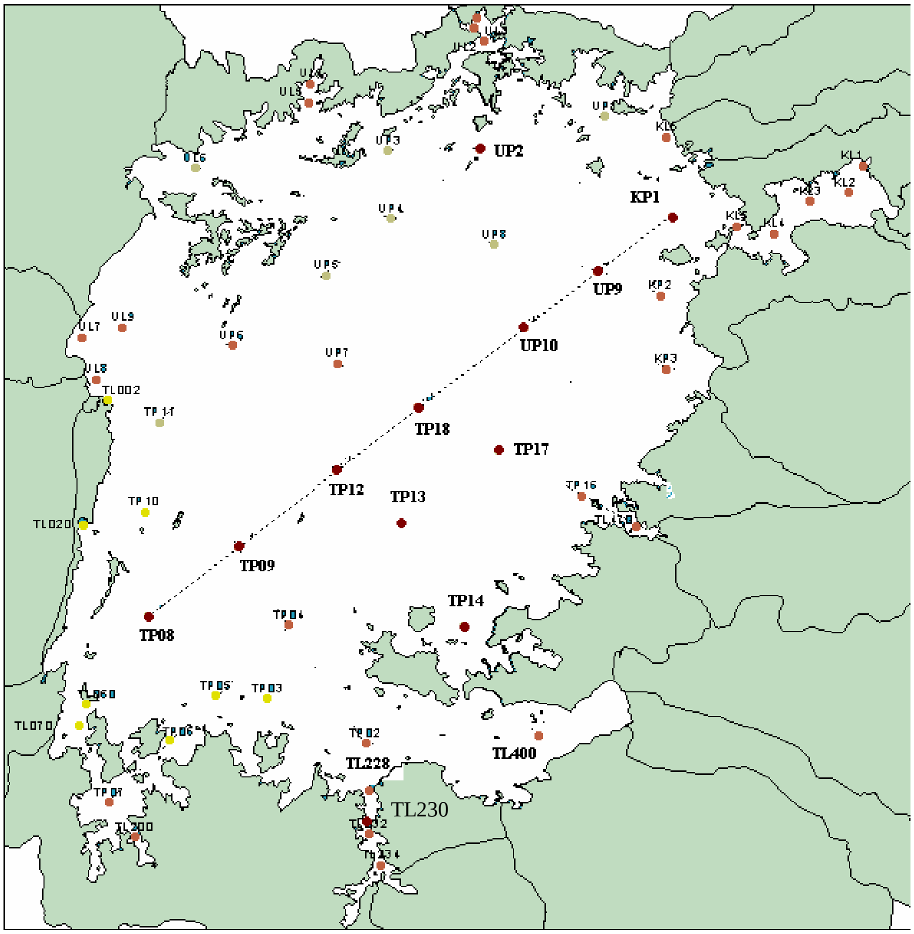

FIG. 1. Location map of the study area showing location of littoral and pelagic sampling sites in Lake Victoria.

The field measurements and samples were taken according to objectives determined at the onset of the project. Data were principally collected at the selected geographical locations in the lake, described by the longitudes and latitude of the sampling and further characterized by the depth at which the sample was taken. The field monitoring operations included *in situ* measurements, sampling of water, biota and particulate matter, sample pre-treatment and conservation, sample labelling and transport. Monitoring data was also characterized and recorded with regard to time at which the sample was taken or the *in situ* measurement made.

Sampling and observation frequency

Monitoring was done monthly for littoral and near-shore pelagic stations and quarterly for the deeper pelagic stations on the Tanzanian and Ugandan waters. Although logistical constraints reduced the frequency of sampling somewhat from that desired, samples were taken in all seasons of the annual cycle. Monitoring program extended over 6 years from 2000 to 2005.

Monitoring Research Vessels

The research vessels RV TAFIRI II, RV IBIS, and RV FWANI were used in Tanzania, Uganda and Kenya waters respectively.

In-situ measurements and sample collection

At each sampling site recording of position was done using a GPS instrument. Other determinations included depth, wind speed, wind direction, air temperature, wave height, wave direction and wave period. *In-situ* measurements of Secchi depth and recording of profiles for temperature, dissolved oxygen, conductivity, pH, light and current speeds and directions were also determined. Water column depth and temperature, dissolved oxygen (DO) using Hydrolab and/or Seabird (CTD) instruments, and light profiles were used to determine the appropriate depths for collection of samples for phytoplankton and zooplankton.

Samples were collected at the following depths:

1. 0.5 m below surface
2. Secchi depth or 10% surface light
3. 2.3 x Secchi depth or 1% surface light
4. Start of DO- or temperature gradient
5. 1 m below start of gradient
6. 1 m above bottom
7. 0.5 m above bottom
8. Every 5 - 20 m between (3) and (4)

Water samples were filtered through glass fibre filters (1µm) for determination of total particulate nitrogen (TPN), total particulate phosphorus (TPP) and total particulate carbon (TPC). Water samples for chlorophyll-a determination were filtered through membrane filters (0.45 µm pore size) and for total biogenic silica (PBSi) 0.2µm membrane filters were used. The filters and filtrate were stored by freezing to 4^0C or below.

Phytoplankton samples for determination of abundance (and calculation of biomass) and species composition were collected with a 5 litre Schindler trap at the surface (0.5m), at Secchi depth of 2.3 times Secchi depth and 5m intervals up to 1m above the bottom in deep waters. The samples were fixed with 1% acid Lugol's iodine solution (APHA, 1995 and 1998). Few drops of formalin (4%) were added to the samples to keep them longer in case of delay in analysis or if samples were desired for archiving. The samples were kept in darkened containers to avoid photolysis of the iodine. Primary production experiments were conducted by incubating for about two hours a set of light and dark bottles filled with lake water from the monitoring stations. This was done by immersing the bottles secured to a retrievable device into the same water column where the samples were collected. A comparison of dissolved oxygen concentrations in the light and dark samples was then done. The difference in dissolved oxygen concentration was used to calculate the photosynthetic rate as a measure of primary production.

Both the Schindler trap and vertical net hauls were used to collect zooplankton samples. Schindler samples were collected at different depths and sieved through 60 µm mesh. The nets consisted of 100 µm mesh size with a mouth diameter of 25 cm. The samples were preserved in 5% formalin for examination later in the laboratory. Zooplankton average densities were derived from triplicate counts taking into consideration the sample volume (S), sub-sample volume (s) and the volume of water filtered along the water column. The densities were expressed in numbers per litre. Benthos samples were taken with Ekman and Ponar grab samplers for quantification and sediment traps were deployed and retrieved according to standard procedures (APHA, 1995).The microbiology of pelagic, littoral and urban lake waters was determined with respect to coliform organisms. Water samples were collected using sterile glass bottles (autoclaved for 15 minutes at 15 lb/in^2 at 121^0C) (APHA 1995).

Laboratory Activities

In the laboratory, samples were allowed to attain room temperature and divided into appropriate aliquots for use in the analysis of nutrients using spectrophotometric methods as outlined in Wetzel and Likens (1991) and APHA (1995, 1998). Phosphate-phosphorus was analyzed as Soluble Reactive Phosphate (SRP) using Ascorbic acid method; nitrate-nitrogen using cadmium reduction and diazoic complex method and silica (DRSi) using the heteropoly blue method. Samples for analysis of total and dissolved organic nutrients were digested and analyzed as outlined in APHA (1995, 1998). Total phosphorus (TP) and dissolved organic phosphorus (DOP) were analyzed as PO_4-P whereas total nitrogen (TN), and dissolved organic nitrogen (DON) were analyzed as NO_3-N. For the analysis of particulate biogenic silica (PBSi), the filtered content was digested using wet alkaline method (2 ml of 0.5 M NaOH added and heated in an oven for 15 minutes at 85^oC) to release the bound silica. The digest was then analyzed as silica (SiO_2-Si). Chlorophyll-*a* pigment was extracted in the laboratory using 90% ethanol and analyzed using spectrophotometric methods as recommended in Wetzel and Likens (1991). For the analysis of total suspended solids (TSS), appropriate sample volume was filtered through a pre-weighed glass fiber filter paper (nominal pore size 0.45 µm), the filter paper with the content dried in an oven for 24h at 105 °C and weighed to calculate the TSS.

Phytoplankton samples were shaken and sub-samples of 1-2ml were introduced in Utermol sedimentation/counting chambers (Utermol 1958) and phytoplankton was allowed to settle for at least three hours. Phytoplankton cells were identified to the species level wherever possible, and counted by the Utermohl method using LEICA DMlL inverted microscope equipped with phase contrast and bright field illumination as needed. Standard literature, including algal taxonomy keys, was used for identification of species. Biovolumes of phytoplankton was estimated using the formula given by APHA (1995) to estimate total algal biomass. Triplicate counts of zooplankton were made and the zooplankton identified to possible taxonomic levels. Samples for benthos and water microbiology were examined in the laboratory using methods recommended in APHA (1995).

Data Quality Control

Comparability of data among national laboratories and national programs was undertaken by using a common protocol for analytical quality assurance amongst the three laboratories located in Kisumu, Entebbe and Mwanza participating in the lake monitoring programme. Quality control also included inter-laboratory comparison schemes and consistency of calibration of instruments. More information on laboratory quality assurance activities are given in Chapter 2 on capacity building.

Data Storage, Treatment and Reporting

Data were stored in digital format in databases to facilitate statistical analysis, trend determinations and presentation and dissemination of results. These databases will increase in value as monitoring data are acquired over time and trends over time can be confirmed or identified.

Data Interpretation

Following the implementation of the monitoring activities the next step was data interpretation. This involved comparison of water quality data between stations, analysis of water quality trends, and development of cause-effect relationships between water quality and environmental data, and judgments of the adequacy of water quality for various uses. Publication and dissemination of water quality reports to relevant authorities, the public and the scientific community was undertaken through workshops, seminars and international peer-reviewed journals.

RESULTS AND DISCUSSION

The number of cruises, *in-situ* measurements and samples undertaken in Kenya, Tanzania and Uganda are shown in Table 1. The monitoring program is the longest and most extensive program of observation ever accomplished on Lake Victoria. Previous studies were either spatially confined to one or two stations or single transects across the lake. This program has allowed appreciation for the first time of the spatial variability within the lake including the persistence of quite different physical (see Chapter 4) and water quality conditions over time in different regions of the lake. In Table 1, the number of cruises and their distribution through the different hydrodynamic periods of the lake (Table 2) is given. The biological data acquired from these cruises on composition of phytoplankton, zooplankton and zoo-benthos will be discussed in Chapter 6 in this volume. From the full suite of analyses and measurements made during 2000-2005, only those that illustrate important spatial patterns and are comparable with earlier research to establish trends are reported in this chapter.

TABLE 1. Summary of the monitoring cruises carried out from 2000-2005.

	Kenya			**Uganda**			**Tanzania**		
Hydrodynamic phase	No. of cruises	No. of profiles	No. of samples	No. of cruises	No. of profiles	No. of samples	No. of cruises	No. of profiles	No. of samples
Stable deep thermocline	4	2380	238	6	1260	169	5	1146	1279
Beginning of destratification	9	1800	180	4	840	350	2	436	596
Complete mixing	5	860	86	2	420	294	3	818	956
Warming-stratification establishment	4	2470	247	4	840	438	8	1914	2114
TOTAL	22	3188	814	16	3360	1251	18	4314	4947

Temporal and Spatial Patterns in Lake Victoria

The results of the determinations of the various variables monitored are summarized in Tables 3 and 4. Hydrodynamic seasons were found to affect many water quality parameters throughout the lake, e.g. temperature, Secchi depth and turbidity (Table 3). Within littoral stations around the lake and within pelagic stations during the individual seasons, there were not found to be any remarkable spatial differences, and so these data were averaged within the different seasons (Table 3). The physical and chemical water quality properties indicated some strong differences between the littoral and pelagic stations across the lake and between surface pelagic stations and deep water stations (Tables 3 and 4).

In terms of physical parameters, littoral stations differed from pelagic (0-20 m) stations in having higher temperatures, higher pH, higher turbidities and lower Secchi depths in all seasons as well as higher electrical conductivity (EC). The EC values indicate possibly higher chemical concentrations of most major constituents (e.g. bicarbonate alkalinity in Table 4) at littoral stations which are more influenced by land runoff (especially the marginal gulfs) than the open waters where dilute rainfall dominates the hydrologic inputs. The lower Secchi depths, higher pH, and higher turbidities (Table 3) are generated by the higher algal abundances that occur in littoral stations compared to the offshore. Deep (>20 m) pelagic waters have lower oxygen and pH than shallower pelagic waters because their lower temperatures lead to stratification and isolation of the deep waters from the surface waters through much of the year. The differences between upper and deeper pelagic waters are minimized in the season 3 when the lake mixes and stratification breaks down (Table 3). Littoral stations generally only stratify on a diurnal basis (Chapter 4) and so there is little or no differentiation with depth. Solar irradiation cannot penetrate to the deep pelagic waters which are cut off from the oxygen equilibration with the atmosphere for most of the year. Without light for photosynthesis, only respiratory processes are active and these lower the oxygen concentrations and pH in the deep water (Fig. 2) as biota consume oxygen and regenerate carbon dioxide from organic matter decomposition.

The nutrient concentrations and other water quality parameters are affected by, and in some cases create, the physical differences described above. Littoral stations, on average, have consistently higher total nitrogen (TN), chlorophyll, and organic matter (loss on ignition, LOI, also total particulate carbon, TPC) concentrations than pelagic stations. Mugidde (1993) demonstrated that phytoplankton production and biomass was light limited due to self shading, and therefore shallower littoral stations with shallower mixing depths can sustain larger biomasses. Lehman and Branstrator (1993; 1995) demonstrated that nitrogen often limited algal growth except for the Cyanobacteria that can fix atmospheric nitrogen to meet their N requirements. Mugidde *et al.* (2003) demonstrated that N fixation was also light limited in the lake and highest rates of N fixation occur in shallower, littoral areas of the lake allowing high biomasses of Cyanobacteria to grow (Kling *et al.* 2001). The higher biomasses of algae, particularly of N fixing Cyanobacteria, account for the higher TN concentrations as well as the higher chlorophyll and organic matter concentrations at littoral stations. In contrast, dissolved Si concentrations are lower at littoral stations as the improved light environment and availability of regenerated fixed nitrogen allows diatoms to grow better than at pelagic stations. Particulate Biogenic Silica (PBSi) a measure of diatom abundance is higher at littorals stations, especially in season 2, except season 4 when the concentrations at littoral and pelagic stations are similar. During the stratified period, seasons 1 and 2, total phosphorus (TP) and phosphate (SRP) concentrations are similar among littoral and pelagic stations while during and just after mixing, seasons 3 and 4, both P fractions are higher in littoral regions. However, in all seasons the SRP concentrations are high relative to concentrations that would be expected to limit algal growth, i.e. <1 μg/L. The continuous excess of SRP and the ability of Cyanobacteria to fix atmospheric nitrogen create nutrient saturated conditions that result in light limiting algal growth (See Chapter 6). However, diatoms require silicon for their growth and the higher algal growth rates in littoral areas results in lower biogenic Si concentrations in these areas compared to pelagic portions of the lake.

There are two rainy seasons in the Lake Victoria catchment caused by the migration of the ITCZ over the lake. The long rains fall in season 2 and the short rains in season 4. Of all the parameters in Table 5.4 only TP responds synchronously in both littoral and pelagic stations with maximum values in seaons 2 and 4 relative to seasons 1 and 3. Nitrate also responds in the pelagic in these seasons 2 and 4 but not in the littoral.

If land runoff through the rivers were the primary source of these compounds, then littoral stations should respond more strongly as they receive the river inputs directly. The co-occurrence of TP maxima in pelagic and littoral stations in seasons 2 and 4 suggests that direct rainfall is more likely to be the source of the increased TP. This is also suggested for nitrate which is also enriched in rainfall (see Chapter 7). However, the algal demand for nitrogen is higher in the littoral regions because of the higher algal biomass, and this high demand may rapidly consume added nitrogen.

Season 3, the period of lake destratification and complete mixing, has strong affects on the pelagic surface waters as they become mixed with the deeper waters that have been isolated through seasons 1 and 2. During the seasons of full or partial stratification (1, 2, and 4), the deep water has lower oxygen and pH because of decomposition of settling organic matter. These decomposition processes release TP and Si into the deep waters where they accumulate and reach higher concentrations compared to surface waters until mixing in season 3. In contrast, TN is similar or lower in pelagic deep water compared to surface waters in the fully stratified seasons 1 and 2 as the low oxygen conditions lead to denitrification of deep waters (see Chapter 6 in this volume). Season 3, the period of complete mixing of the water column increases the oxygen concentrations in deep water and increases Si concentrations in surface waters to their annual maximum. However, nitrogen (TN and nitrate) reach their annual minimum in season 3 because of the mixing with nitrogen-poor deep waters. Chlorophyll concentrations are also at their annual minimum during this period because deep mixing imposes very strong light limitation on algal growth and nitrogen fixation (Mugidde *et al.* 2003).

Comparison with Historical Data

Historical data and data generated by Lake Victoria Environmental Management Project (LVEMP) can be compared for some locations on the lake (Fig. 2). The greatest amount of historical data is for the Bugaia station (UP2) studied by Talling (1965, 1966) and Hecky *et al.* (1994). At this station the structure and characteristics of the water column for the different seasons can be compared. For example, comparison of profiles during season 4 of 1960 and 2000 (Fig. 3) shows the lake to be comparably warm in 2000 but with much lower oxygen and lower pH in deeper waters below the thermocline in 2000. This suggests that deep water respiration rates are higher in 2000 and the consumption of oxygen and production of CO_2 (causing lower pH's) is accelerated. The higher algal productivity as a result of the eutrophication of the lake (see Chapter 6) accounts for this higher oxygen demand from settling organic matter. Hecky *et al.* (1994) and Gophen *et al.* (1995) have also previously documented these changes for the northeastern pelagic sector of the lake.

Chlorophyll a

Chlorophyll a levels in both the littoral and pelagic environments of the lake have increased in comparison to Talling's (1965) measurements and other historic observations. This also agrees with other research carried out before Lake Victoria Environmental Management Project (e.g. Hecky 1993; Gophen *et al.* 1995; Table 5).

Phosphorus

Phosphorus concentration in the littoral and pelagic environments of the lake has considerably increased over the years with concentrations being higher in the pelagic environment compared to 1960s values (Table 5). Concentrations of TP appear to be approximately twice as high as in 1960.

TABLE 2. The four hydrodynamic phases found in Lake Victoria.

	Months	**Water column stability**
Phase 1	January-March	Stable deep thermocline
Phase 2	April-May	Beginning of destratification
Phase 3	June-August	Complete mixing
Phase 4	September-December	Warming-stratification establishment

TABLE 3. Average physical conditions in Lake Victoria in different hydrodynamic seasons between 2000-2005 .

Parameters	**Season 1**	**Season 2**	**Season 3**	**Season 4**
Littoral waters				
Temp. °C	26.37	25.58	24.16	25.31
DO mg/l	6.01	6.58	7.08	6.42
EC µS/cm	116.19	109.69	123.29	117.71
pH	8.45	8.26	8.08	8.53
Secchi m	1.49	1.15	1.23	1.16
Turbidity NTU	13.24	22.96	16.38	6.36
Pelagic (<20 m)				
Temp. °C	25.39	25.18	24.63	24.88
DO mg/l	6.64	6.64	6.80	7.00
EC µS/cm	92.82	97.72	91.53	92.87
pH	8.08	7.26	7.59	8.43
Secchi m	3.39	2.69	3.08	2.95
Turbidity NTU	7.64	8.88	2.38	2.25
Pelagic deep water (>20m)				
Temp. °C	24.8	24.8	24.4	24.4
DO mg/l	4.3	4.9	5.7	4.2
EC µS/cm	94.1	91.4	90.8	94.5
pH	7.8	7.3	7.4	7.7
Turbidity NTU	15.2	9.0	3.7	1.3

TABLE 4. Average chemical conditions in Lake Victoria in different hydrodynamic seasons between 2000-2005.

Parameters	Season 1	Season 2	Season 3	Season 4
Littoral waters				
TN mg/l	1.286	1.721	0.992	0.901
NO3 mg/l	0.033	0.085	0.081	0.063
TP mg/l	0.103	0.172	0.156	0.194
PO4-P mg/l	0.061	0.057	0.077	0.089
PBSi mg/l	0.432	0.541	0.266	0.187
Si mg/l	2.615	3.066	2.152	2.638
ALK mg/l	52.328	49.420	48.123	52.268
CHL mg/l	0.040	0.02	0.026	0.033
Pelagic <20 m				
TN mg/l	0.730	1.594	0.525	0.616
NO3 mg/l	0.041	0.052	0.009	0.051
TP mg/l	0.115	0.174	0.108	0.136
PO4-P mg/l	0.072	0.058	0.069	0.072
PBSi mg/l	0.278	0.267	0.209	0.216
Si mg/l	0.670	0.721	1.271	0.707
ALK mg/l	45.428	47.224	45.955	48.857
CHL mg/l	0.013	0.09	0.010	0.007
Pelagic deep water >20m)				
TN mg/l	0.736	1.389	0.525	0.947
NO3 mg/l	0.074	0.067	0.009	0.102
TP mg/l	0.148	0.214	0.108	0.203
PO4-P mg/l	0.078	0.066	0.069	0.093
PBSi mg/l	0.283	0.213	0.209	0.146
Si mg/l	1.385	1.692	1.271	0.999
ALK mg/l	47.288	47.183	45.955	48.708
CHL mg/l	0.008	0.004	0.009	0.004

Nitrogen

Talling (1965, 1966) did not analyze TN concentrations, only nitrate (NO_3). The concentration of nitrate in the lake was increased in comparison with Talling's data especially below the euphotic zone. However, nitrate concentrations relative to phosphate concentrations remain low because of denitrification processes that have been enhanced by increased hypoxia and anoxia in the deeper water (Hecky et al. 1996). This could be due to several factors. The processes of denitrification and nitrification through nitrogen fixation of atmospheric nitrogen have both increased their rates but have offset each other reducing any proportional increase in nitrate over time. However, soluble reactive phosphorus has increased over time and the ratio nitrate to SRP remains low in surface water as also noted by Talling (1966).

Silica

Silica concentration in the partially enclosed embayment has not had dramatic change in comparison with 1960s and 1970s levels. This is especially true in marginal gulfs that are strongly influenced by river inputs and high turbidities that can limit algal growth. In these restricted environments with reduced circulation with the open lake, Si concentrations are maintained by riverine input of Si. However, dissolved silica concentration in the pelagic environment of the lake has decreased 5-20 fold compared to

1960s and 1970s levels as eutrophication has strongly increased Si demand by diatoms relative to rather constant supply from the catchment.

Secchi

Secchi has been decreasing and present values indicate a two fold decrease compared to measurements made before LVEMP (Worthington, 1930). The consequence of low secchi in the lake has been a drastic reduction in water transparency compared to the 1960 when the lake’s water was more transparent and conducive to a broad range of aquatic life. These increases are consistent with the increase in chlorophyll concentrations.

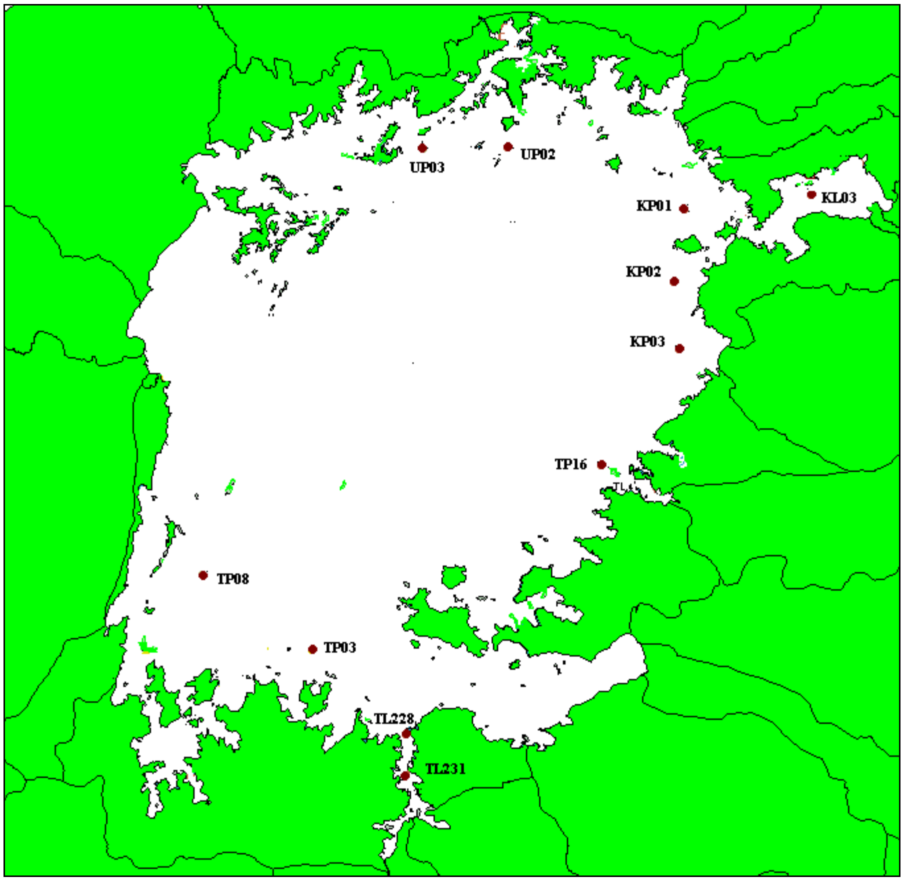

FIG. 2. Location of LVEMP monitoring stations located close to historical stations as detailed in Table 5.

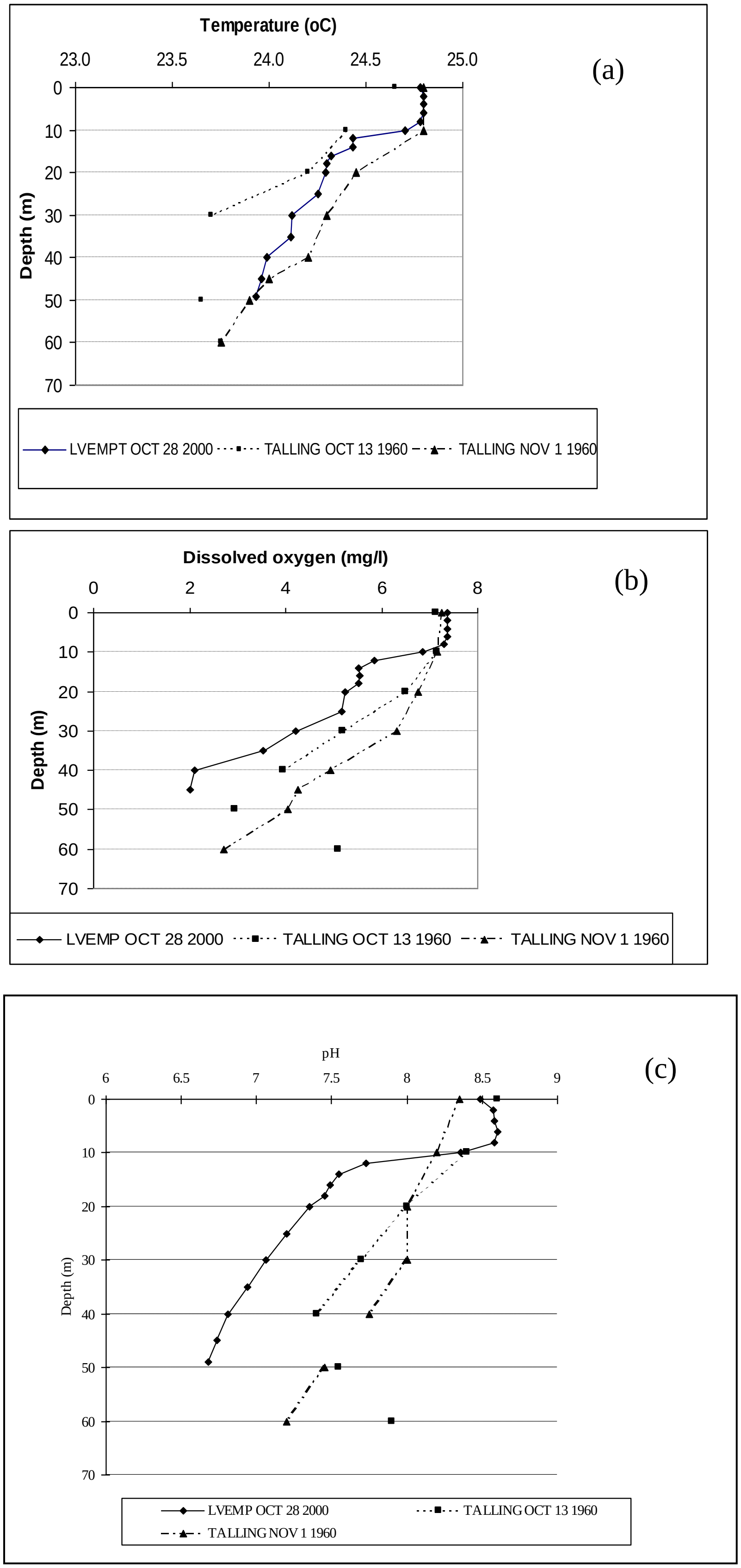

FIG. 3. Comparison of temperature (a), dissolved oxygen (b) and pH (c) profiles for Lake Victoria during the beginning of stratification (October-November) in 2000 with Talling's profiles of 1960.

The high electrical conductivity observed in littoral waters is largely the result of stations in the confined gulfs were mixing with the open lake is restricted and where riverine inflows affect the conductivities due to soluble salts (dissolved solids) that are carried by rivers coming in from the catchment, which has diverse geological structure. The pelagic waters are more influenced by rain water with low conductivity that dilutes the rivers. Comparison with data gathered before LVEMP show that electrical conductivity of water in pelagic and littoral waters has risen somewhat over the years likely as a response to a changing precipitation: evaporation balance over the lake.

CONCLUSIONS-SIGNIFICANT CHANGES

The data that has been generated during LVEMP show significant ecosystem changes that include:

- Presence of high levels of nutrients in the lake;
- Occurrence of frequent algal blooms enhanced by high nutrient levels in the lake
- Algal biomass increase as evidenced by high chlorophyll a levels and primary productivity;
- Increased turbidity resulting from land inflows and biological activity within the lake;
- Reduced water transparency as a result of increased turbidity in the water
- Depletion of oxygen levels with severe cases (anoxic conditions) in pelagic bottom waters;
- Reduced silicon levels as demand by Si requiring algae such as diatoms has exceeded the re-supply of Si from the catchment;
- Rise in P concentrations has been driven by multiple changes in the catchment that have led to increased P loading including deforestation, biomass burning, soil erosion, urbanization, increasing fertilizer;
- Deteriorating oxygen conditions and visibility in the lake has led to loss of fish habitat and possibly other beneficial uses of the lake.

RECOMMENDATIONS

- Critical scrutiny of results after several years of operation have shown the need for dedicated water quality studies of basin developments in support of impact assessment, local trend analysis and need for management interventions to prevent further degradation of the lake.
- The aim in LVEMP II should be to facilitate continued monitoring in support of management interventions to reduce pollution loading and to evaluate trends over time in the whole lake. Regional facilitation of sharing, comparing and interpreting results must also have priority in to insure coordinated actions to address common problems.

TABLE 5. Comparison of LVEMP data (2000-2005) with historical data.

Stn.	**Source**	**TP µg/l**	**PO$_4$-P µg/l**	**SiO$_2$-Si mg/l**	**NO$_3$-N µg/l**	**TN µg/l**	**pH**	**EC µS/cm**	**Temperature °C**	**Chl-a µg/l**	**Secchi m**
KL3	LVEMP	20-113	5-16	2.66-7.138	3-11	892-3090	8.2-9.0	159-165	25.49-26.86	25-35	0.8-1.2
	Talling	67		2.75	29		8.75	145	27.5		
KP1	LVEMP	63-92	3-7	0.04-0.145	1-182	410-860	6.7-8.9	94	24.51-26.84	2-20	1.6-3.6
	Talling	49		2.66					25.9		
KP3	LVEMP	75-92	6-7	0.37-3.63	7-9	440-530	6.4-8.3	94-96	22.59-25.35	3-13	2.8
	Talling	26		2.33					25.9		
Kenya littoral	LVEMP		21				6.7-10	105-181	21.8-28.8	35-40	0.2-2.4
	Mavuti & Litterick 1991		6.8					120-150	24.35	40.7-50.6	0.7-1.8
	Ochumba & Kibaara (1989)						7.42-9.4	85-123			
Kenya pelagic	LVEMP	63-92	3-7				6.1-9.8	98-104	20.88-27.74	10	1.6-4.2
	Gophen et al 1995	70-103	4-73		10-30	440-1160					1.8
	Ochumba & Kibaara (1989)						6-8.85	88.1-102			
	Mavuti & Litterick 1991		15.7						23.6	15.8	
	Worthington 1930										7.8
TL228	LVEMP	74-108	35-83	.45-1.2	14-279		7.2-8.2	91-92.2	24.7-25.5	7-11	1.5-2.8
	Talling	53		2.15							
TP3	LVEMP	77-141	18-33	0.63-0.99	32-64		7-7.6	82.1-82.5	24.8	6-14	3-4
	Talling	33		1.96				96	25.05		
TP8	LVEMP	82-126	20-31	0.22-0.32	5-75		6.77-7.86	89.9-90.7	24.95-25.61	4-9	4
	Talling	33		2.00					24.9		
TP16	LVEMP	87-107	27-39	0.68.1.13	5-79		6.44-6.91	91.1-91.9	25.12-25.18	5-13	3-4
	Talling	47		2.05			8.5	95	25.4		
TL231	LVEMP	102-107	13-54	0.83-0.93	13-119		7.51-9.25	95.8-97	24.15-26.65	16-111	0.9-1.1
	Akiyama et al (1977)		0-122	0.6-2.8	0-18	-	6.9-9.0	-	22.0-26.0	2-8.5	1.1-1.9
UP2	LVEMP	50-160	23-60	0.14 – 0.20	11.9 – 50	25-55	6.76-9.76	92.5 – 92.8	25.9 – 26.0	2.4 – 6.24	2.3–2.7
	Talling	43	5-15	4.05	18				25.1	2-4	
	Hecky (1993)	62-124	12-43	0.1-2.5	11-84	336-448				11-23	1.2
UP3	Talling	45		4	6		8.05		25.1		

Talling = obtained from raw data for 1960-61 and used with permission from Talling.

LVEMP = data collected during LVEMP Phase 1 between 2000 and 2005.

- LVEMP I imposed a steep learning curve on the responsible agencies as capacity for monitoring had to be developed including training of staff to enable them to interpret the results of the monitoring progam and this resulted in delays in bringing forward results. The capacity is now in place and timely interpretations should reduce lag time between observation and forwarding results to no more than 1 year.
- LVEMP data compared to historical records indicate fast changing lake ecology because of increasing human activity in the lake catchment affected also possibly by global weather changes. This calls for regular monitoring surveys in order to keep pace with potential environmental changes. It also requires enhanced capacity in water quality modelling in order to properly identify causation of observed changes and to guide further management action by evaluating different scenarios of remedial intervention.

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APPENDIX 1. Lake Monitoring stations- coordinates and maximum depth.

STATIONS	LONGITUDE	LATITUDE	AV. MAXIMUM DEPTH (m)	NUMBER OF TIMES VISITED (n)
KP 1	33° 59’ 40’’ E	00°18’ 48’’ S	47.0	22
KP 2	33° 57’ 3’’ E	00° 36’ 56’’ S	56.0	22
KP 3	34° 03’ 49’’ E	00° 54’ 18’’ S	33.0	18
KL 1	34° 43’ 14’’ E	00° 07’ 15’’ S	3.5	22
KL 2	34° 39’ 46’’ E	00° 13’ 25’’ S	3.0	22
KL 3	34° 31’ 11’’ E	00° 15’ 21’’ S	5.5	22
KL 4	34° 22’ 43’’ E	00°22’ 48’’ S	12.0	22
KL 5	34° 14’ 17’’ E	00° 20’ 58’’ S	23.0	22
KL 6	33° 58’ 23’’E	00° 00’ 42’’ S	14.0	22
UL1	33°15' 23" E	00°26’ 60" N	7.5	16
UL2	33°14' 52" E	00°24’ 10" N	18.0	16
UL3	33°17' 00" E	00°20’ 56" N	23.0	16
UL4	32°37' 05" E	00°11’ 02" N	12.2	11
UL5	32°37' 01" E	00°07’ 01" N	12.0	11
UL6	32°11’06 " E	00°07’ 01" S	9.0	4
UL7	31°45' 05" E	00°46’ 02" S	9.0	6
UL8	31°48' 08" E	00°55’ 05" S	11.0	6
UL9	31°54' 06" E	00°44’ 01" S	16.0	4
UP1	33°44' 02" E	00°04’ 00" N	27.0	4
UP2	33°16' 08" E	00°04’ 08" S	68.0	16
UP3	32°55' 03" E	00°03’ 04" S	47.0	8
UP4	32°55' 05" E	00°19’ 10" S	55.0	8
UP5	32°41' 06" E	00°32’ 04" S	51.0	16
UP6	32°19' 03" E	00°47’ 56" S	47.0	16
UP7	32°43 '05" E	00°52’ 02" S	60.0	16
UP8	33°19' 02" E	00°25’ 01" S	67.0	10
UP9	33°42' 04" E	00°31’ 02" S	67.0	10
UP10	33°26' 00" E	00°44’ 01" S	69.0	16
TL-002	31º 51' 30" E	01º 00' 40" S	9.4	6
TL-020	31º 46' 02" E	01º 28' 51" S	11.0	6
TL-060	31º 52' 59" E	02º 06' 39" S	7.0	5
TL-070	31º 44' 54" E	02º 14' 43" S	11.5	6
TL-100	31º 51' 32" E	02º 32' 05" S	11.0	6
TL-200	31º 59' 29" E	02º 42' 19" S	4.6	5
TL228	32º 50' 58" E	02º 29' 26" S	17.5	14
TL-230	32º 52' 06" E	02º 35' 26" S	9.5	15
TL-231	32º 51' 12" E	02º 37' 04" S	8.0	13
TL-232	32º 50' 22" E	02º 39' 26" S	5.5	14
TL-233	32º 52' 06" E	02º 42' 42" S	4.8	12
TL-234	32º 53' 51" E	02º 46' 26" S	4.8	14
TL-400	33º 16' 16" E	02º 18' 37" S	21.5	6
TL-470	33º 43' 31" E	01º 30' 43" S	3.5	6
TP-02	32º 50' 18" E	02º 18' 36" S	43.1	14
TP-03	32º 27' 53" E	02º 08' 27" S	52.4	7
TP-04	32º 46' 51" E	01º 51' 39" S	60.0	10
TP-05	32º 16' 11" E	02º 07' 44" S	50.2	7
TP-06	32º 05' 42" E	02º 17' 59" S	27.0	7
TP-08	32º 07' 12" E	01º 49' 36" S	50	8
TP-09	32º 21' 07" E	01º 33' 54" S	59	13
TP-10	31º 59' 58" E	01º 25' 51" S	41.7	6
TP-11	32º 03' 31" E	01º 05' 46" S	38.0	7
TP-12	32º 43' 24" E	01º 16' 56" S	68.6	11
TP-13	32º 12' 00" E	01º 51' 52" S	70.0	1
TP-14	32º 12' 34" E	01º 51' 57" S	43.6	6
TP-16	33º 39' 12" E	01º 22' 17" S	48	6
TP-17	33º 20' 16" E	01º 12' 11" S	70.5	4
TP-18	33º 05'18’’ E	01º 08' 36" S	68.5	9

CHAPTER 6

Eutrophication of the Lake Victoria Ecosystem

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ABSTRACT. *Between 2000 and 2005 water quality and limnological studies were carried out in Lake Victoria in order to establish the eutrophication effects on ecosystem health. Comparison between littoral and pelagic areas of the lake showed marked spatial and temporal differences between and within the zones.*

Nitrate nitrogen (NO_3-N) and phosphate phosphorus (PO_4-P) concentrations ranged between 16.2 - 87.9 µg/l and 39.6 - 92 µg/l respectively and were both higher in the northeast. Silica (SiO_2-Si) concentrations ranged between 0.525 and 0.902 mg/l and the values were higher in the northeast and southwest compared to mid-lake stations. Nyanza Gulf had lower PO_4-P concentrations (16.2 to 21.1µg/l) than the Mwanza and Napoleon Gulfs (54.8 to 68.7µg/l) but registered higher SiO_2-Si concentrations (4.5 to 5.2 mg/l) than the other two gulfs. NO_3-N concentration in the gulfs ranged between 25 and 93 µg/l with Napoleon Gulf having higher values than the other two gulfs. Total phosphorus (TP) in the pelagic waters ranged between 0.078 and 0.10 mg/l and total nitrogen (TN) ranged between 0.53 and 0.83 mg/l. The TN:TP ratio (<20) in the main lake indicated that phytoplankton growth in the lake may be nitrogen-deficient; a situation favoring dominance of nitrogen fixing Cyanobacteria. This low TN:TP ratio is probably associated with the increased phosphorus loading and selective nitrogen loss through denitrification aqs well as enhanced recycling of P associated with increased anoxic conditions in the deep pelagic waters. Comparison with Talling's 1961 values, SiO_2-Si concentrations in the lake have generally decreased by a factor of 3 and up to 8 at the Talling's historical station of Bugaia (UP2). Chlorophyll a concentrations in the pelagic areas ranged between 3.6 and 11.7 µg/l and were generally higher in the littoral than to the pelagic *areas. The phytoplankton community was dominated by Cyanobacteria (>50%) especially the species Microcystis, Anabaena and Cylindrospermopsis in both the littoral and pelagic waters. Relatively high diatom biomass was recorded in the pelagic compared to the littoral areas, but Aulacoseira (Melosira), the formally dominant diatom species was rarely encountered. Compared to previous records, the invertebrate community composition has remained relatively stable despite drastic changes in water quality and fish stocks, but changes in abundance were evident. Zooplankton densities were generally higher in the littoral than pelagic zones. The abundance of Caridina nilotica, lake fly larvae, and other invertebrates have increased in the lake with the decline of haplochromine stocks. Comparison of present zooplankton density estimates with previous records indicates no marked differences in abundance patterns over the past 15 years suggesting a stable and dependable resource to sustain water quality and fishery-related functions. The OECD indicators of trophic status indicate that the pelagic waters range from mesotrophic to eutrophic and the littoral zones are hypertrophic.*

In order to stem further deterioration of lake water quality, management of phosphorus loading into the lake should be given urgent priority.

INTRODUCTION

Eutrophication is an alteration of the production cycle of the lake ecosystem due to enrichment by nutrients (particularly nitrogen and phosphorus). It leads to excessive growth of algae or macrophytes affecting seriously the water quality (e.g. low oxygen content, high turbidity, toxic algae, release of toxic gases from the sediments such as hydrogen sulphide etc). These changes favour the most robust algal and animal species whilst the more sensitive ones may disappear, and the changes interfere with various beneficial uses of water.

Until about mid twentieth century, eutrophication had not been recognized as a pollution problem world wide. Since then, eutrophic conditions have happened in many parts of the world including Lake Victoria (Hecky 1993). More aquatic scientists now have the insight to recognize that human activity including urbanization, deforestation, intense cultivation, animal husbandry, introduction of exotic fish species and overfishing, can accelerate the rate of nutrient inputs and cycling, resulting in changes in the physical, chemical and biological properties of a large water body such as Lake Victoria (Bugenyi and Balirwa 1989, Ogutu-Ohwayo 1990, Hecky 1993, Hecky *et al* 1994, 1996, Lipiatou et al. 1996, Mugidde 1993). Increasing human population and all their associated activities have accelerated the rate of delivery of nutrients and caused eutrophication of Lake Victoria (Chapter 7 Nutrient Loading; Hecky 1993; Lipiatou *et.al*, 1996; Verschuren 2002).

During the last 4 decades, Lake Victoria has undergone major water quality and biological changes. The introduction in the 1950s and early 1960s of the exotic Nile Perch (*Lates niloticus*) and Nile tilapia (*Oreochromis niloticus*) has led to dramatic loss of many native cichlid species (Witte et al 1992). The phytoplankton species composition in the lake has changed from one dominated by large diatoms, mainly *Melosira* and *Stephanodiscus* (Talling 1966) to that presently dominated by Cyanobacteria (blue green algae) (Ochumaba and Kibaara 1989; Mugidde 1993; Lung'aiya et al 2000; Kling et al 2001) and primary productivity and chlorophyll have increased 2-fold and 8 to 10-fold respectively (Mugidde 1992, 1993; Chapter 5). Other reported changes to the lake are decline in the euphotic zone depth, more thermally stable water column leading to more persistent hypoxic deep waters, a decrease in soluble reactive silicon (DRSi) and an increase in soluble reactive phosphorus (SRP) and total phosphorus (TP) in the water column (Chapter 5; Hecky 1993; Lehman and Branstrator 1993). However, prior to the LVEMP, the studies that identified these changes were limited in spatial and temporal coverage and the sources of nutrient enrichment were not fully characterised and quantified. Through the emplacement of lake and catchment monitoring programs LVEMP has now provided the essential comprehensive data to appreciate the scale of the eutrophication problem in Lake Victoria and the most important sources of nutrients (Chapter 7)

The changes in the lake ecosystem have threatened the long-term sustainable utilization of lake resources and have attracted local and international concern (World Bank, 1996). In 1997 the three East African riparian countries, Kenya, Tanzania and Ugandan with the assistance of the World Bank and the Global Environmental Facility initiated a program to study and understand the nature, causes and magnitude of these changes in order to put in place appropriate intervention measures to enhance sustainable utilization of lake resources for socio-economic development of the basin. During the past five years, scientists from the three east African countries have undertaken extensive lake-wide water quality studies in order to establish the current water quality status, identify and quantify changes in the lake, and predict possible future water quality changes in relation to the human activities in the catchment. This chapter reports on the extent of eutrophication in Lake Victoria, and its effects on the aquatic biological resources.

Materials and Methods

In-situ measurements of oxygen, temperature and transparency (Secchi depth) were taken and samples for analysis of nutrients, invertebrates, and phytoplankton biomass and species composition were collected from the harmonized lake wide monitoring network (Figure 1) between August 2000 and April 2005. A detailed description of the study area, the criteria for selection of stations and the sampling and analytical methods are presented in chapter 5.

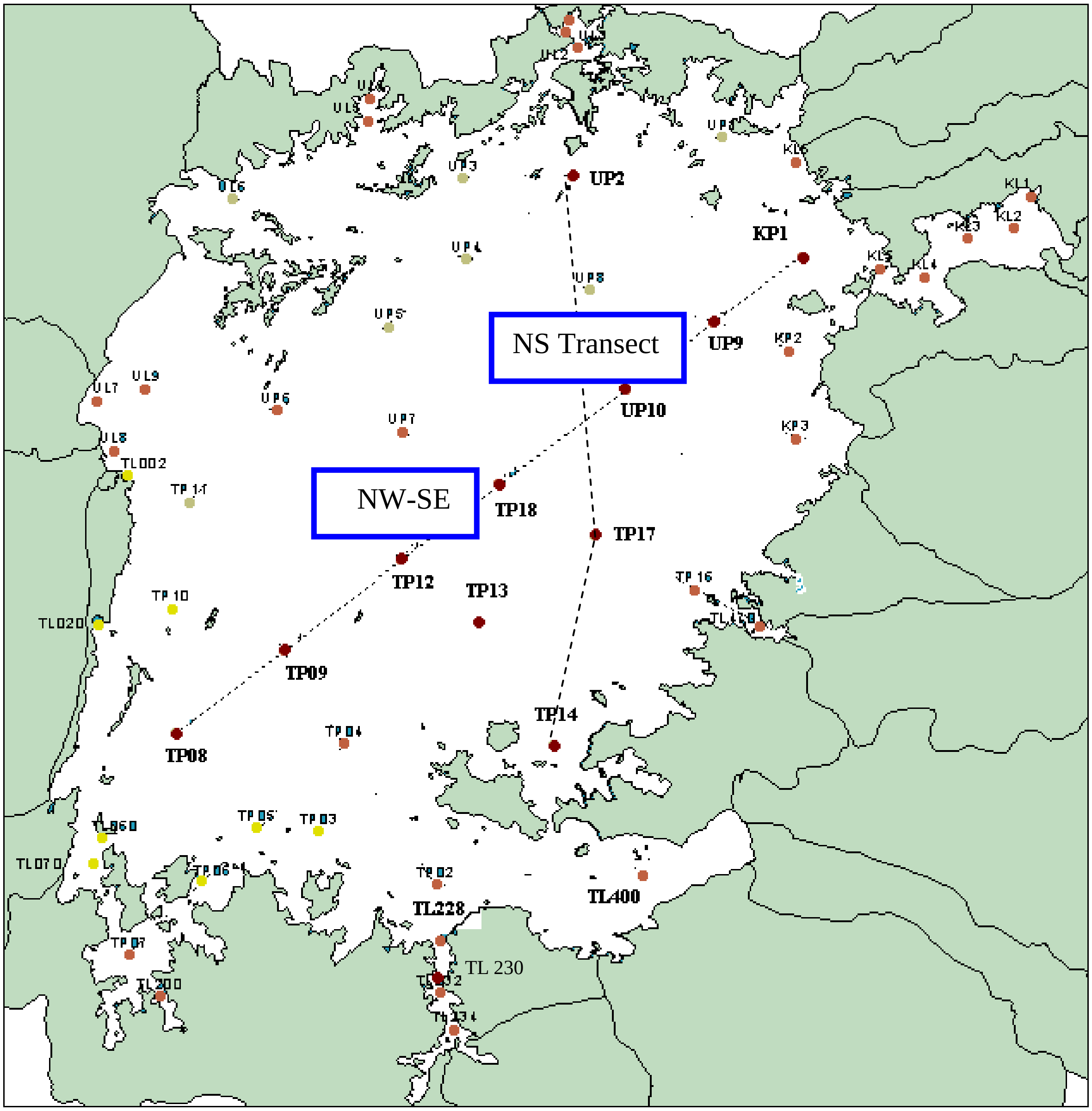

FIG. 1. ***Map of Lake Victoria showing the harmonized in-lake monitoring network and the northeast-southwest and north-south transects***.

RESULTS

Nutrients

Soluble nutrient concentrations along the northeast-southwest (NE-SW) transect (Fig. 1) are presented in Figure 2. Nitrate nitrogen (NO_3-N) and phosphate phosphorus (PO_4-P also referred to as soluble reactive phosphorus, SRP) concentrations ranged between 16.2 - 87.9 µg/l and 39.6 - 92 µg/l respectively and were both higher in the northeast. Dissolved reactive silicon (SiO_2-Si) concentrations along the transect ranged between 0.525 and 0.902 mg/l and the values were higher in the northeast and southwest part of the lake compared to mid-lake stations.

SiO_2-Si concentration showed a gradual decrease along the south-north transect (TP14, TP17, UP2 and UL1), from 0.70 to 0.29 mg/l (Fig. 3). UP2, the pelagic station near Bugaia Island, had mean SiO_2-Si, PO_4-P and NO_3-N concentrations of 0.29 mg/l, 128.2 µg/l and 51.4 µg/l respectively. Dissolved nutrients varied between the three gulfs of Mwanza, Napoleon and Nyanza (Fig. 2b). Nyanza Gulf had lower PO_4-P concentration (16.2 to 21.1 µg/l) than the Mwanza and Napoleon Gulfs (54.8 to 68.7 µg/l) but had higher SiO2-Si concentration range (4.5 to 5.2 mg/l) than the other two gulfs. NO3-N concentration in the gulfs ranged between 25 and 93 µg/l with Napoleon Gulf having higher values than the other two gulfs while also having very low SiO_2-Si.

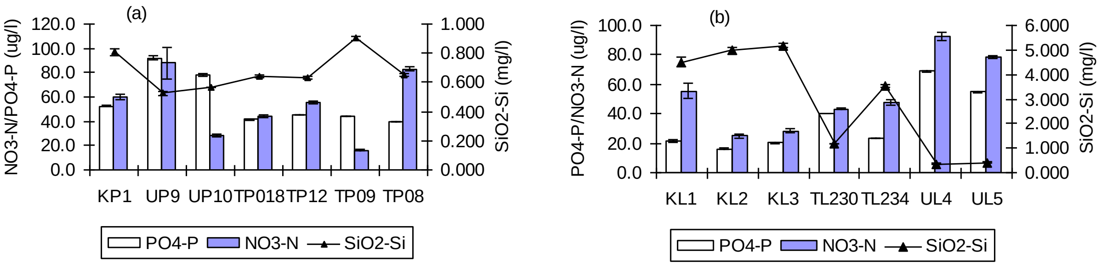

FIG. 2. Average dissolved nutrient concentrations (a) along the northeast-southwest transect in Fig.1 and (b) within the major gulfs, Winam (KL1, KL2), Mwanza (TL230,TL234) and Napoleon (UL4, UL5). Standard deviations for parameters are indicated.

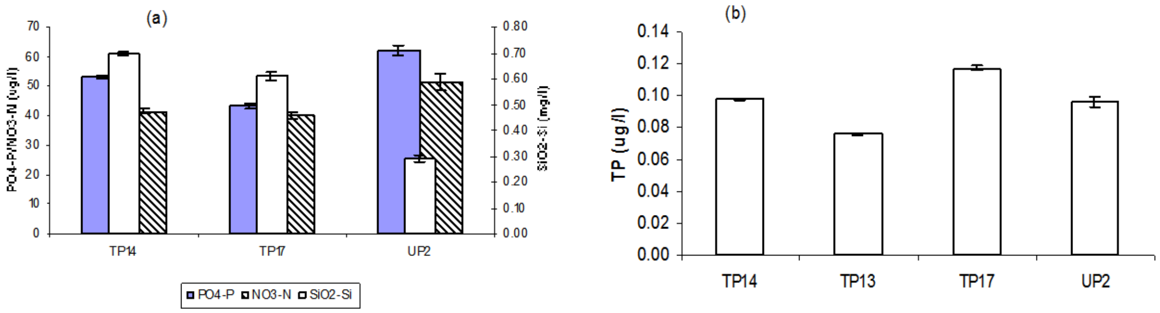

FIG. 3. Average concentration of (a) dissolved nutrients and (b) Total Phosphorus (TP) along the North-South Transect of Figure 1.

Along the north-south transect, total phosphorus (TP) ranged between 80 and 120 µg/l and along the northeast-southwest transect from 78 and 100 µg/l (TP14 and UP2 respectively) (Fig. 3b and 4a). TP values in the three gulfs (Mwanza, Napoleon and Nyanza) ranged between 52 and 100 µg/l with Nyanza Gulf having the lowest average concentration values and Mwanza Gulf having the highest average concentration values

(Fig. 4b). Total nitrogen ranged between 53 and 83 µg/l along the NE-SW transect with TP18, located in the middle of the lake, having the lowest average value.

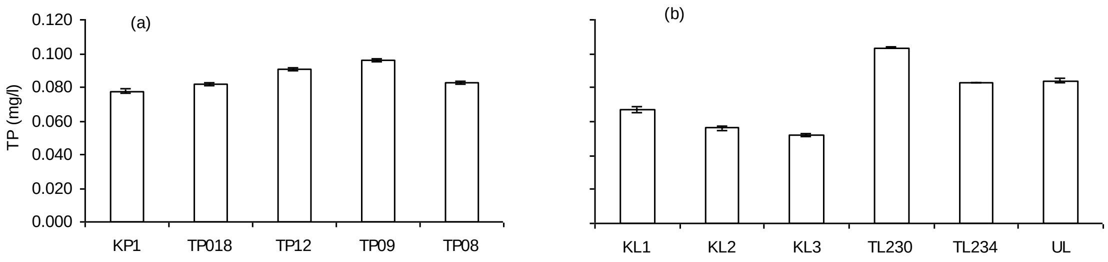

FIG. 4. Total phosphorus concentrations along the (a) open pelagic lake zone and (b) in Mwanza, Napoleon and Nyanza Gulfs.

The mean TN:TP ratio (molar) in the pelagic open lake along NE-SW transect (Fig. 5a) differ from the ratios in the Mwanza and Nyanza Gulfs (Fig. 5b). The ratios show that in Mwanza Gulf either N or P can become limiting to algal growth whereas in the Nyanza Gulf P is limiting based on values in Guildford and Hecky (2000). On average, in the open pelagic lake zone, nitrogen is tending strongly to N deficiency.

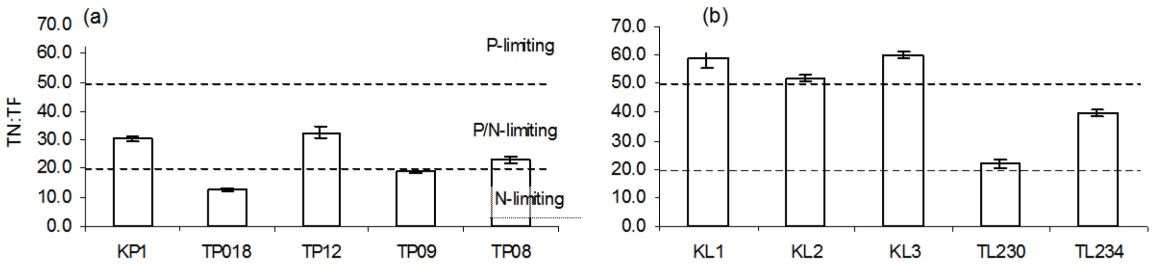

FIG. 5 Mean TN:TP ratios for open pelagic stations (a) and Mwanza and Nyanza Gulfs (b). (Areas between the stippled lines indicate the zones where either nitrogen or phosphorus become limiting to phytoplankton growth).

Phytoplankton Biomass and Species composition

Chlorophyll *a* concentrations were generally higher in the littoral areas (and Gulfs) than in the pelagic open waters (Fig. 6a and 6b). Along the NE-SW transect (Fig. 6a) the concentrations ranged between 3.6 to 11.7 µg/l and were higher on both ends of the transect, with UP10 in the middle of the lake having the lowest average concentration value (Figure 6a). The station UP2 had an average concentration of 3.2 µg/l. Water transparency (Secchi depth) in the lake, ranged between 0.4 and 7.5m. Secchi depth values were higher in the open lake stations (2 to 7.5m) compared to littoral stations (0.4 to 1.8). The graphical relationship between chlorophyll and Secchi depth is presented in Figure 7. Algal biomass (chlorophyll) controls light penetration over much of Lake Victoria with the exception of turbid Winam Gulf where resuspended mineral sediments affect light penetration (Gikuma-Njuru and Hecky 2005).

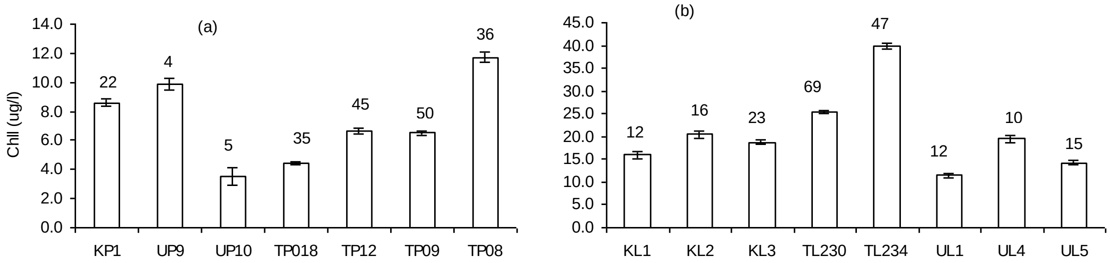

FIG. 6. Mean Chlorophyll a concentrations in the (a) open pelagic lake zone and (b) Mwanza, Napoleon and Nyanza Gulfs. Note difference in vertical scale between (a) and (b); number of samples (n) contributing to the mean are shown above the bars

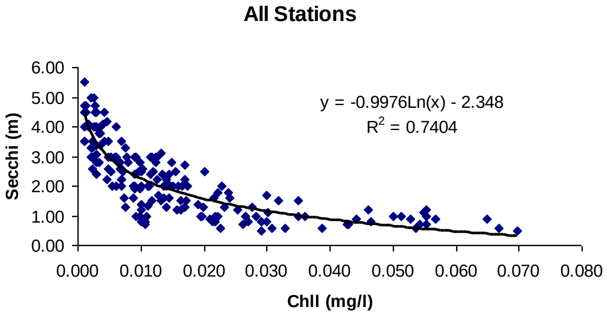

FIG. 7. Relationship between chlorophyll a and transparency (Secchi depth) in Lake Victoria for both littoral and pelagic zones.

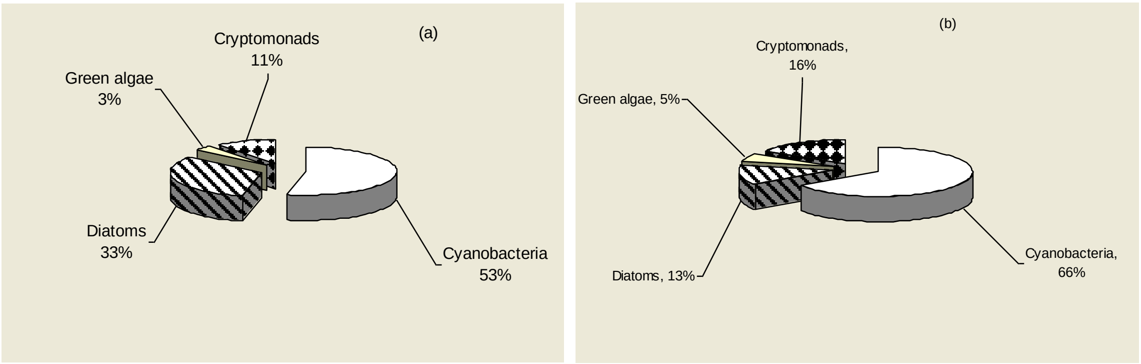

FIG. 8. Relative biomass of major phytoplankton groups in (a) Open pelagic waters and (b) in littoral areas in Lake Victoria.

The phytoplankton community in the lake was dominated by Cyanobacteria (>50%) both in the littoral and pelagic waters (Fig. 8), followed by diatoms. *Microcystis*, *Anabaena* and *Cylindrospermopsis* were the most common Cyanobacteria in the lake, whereas *Nitzchia* was the most common diatom. Higher Diatom biomass was recorded in the pelagic than in the littoral stations. *Aulacoseira* (*Melosira)*, the formally dominant diatom species (Talling 1966; Akiyama *et al* 1977) were rarely encountered in the present study. Green algae were the most diverse group in species followed by blue green algae.

Invertebrates

Species composition and distribution

Copepods, cladocerans, Rotifera, Diptera and Mollusca comprised the invertebrate community. Rotifera, Bivalvia and Gastropoda were the most diverse groups, containing several genera and numerous species. Each of the broad groups contained species that exhibited lakewide distribution while other species of the groups were rarely encountered.

Abundance

The invertebrate community was numerically dominated by copepods among the zooplankton, dipteran larvae and molluscs. Zooplankton densities indicated generally higher concentrations in the littoral compared to pelagic zones (for example Fig. 9). Cladocerans characteristically occurred at low abundance throughout the lake with their highest numbers recorded in the very shallow waters near Kisumu (KL1).

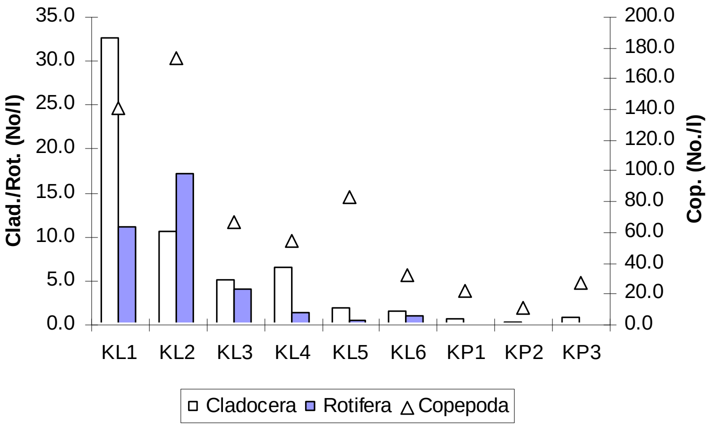

FIG. 9. Mean abundance estimates of zooplankton taxonomic groups at littoral (KL) and pelagic (KP) stations in Kenya including Winam Gulf (KL1to KL5) in Lake Victoria 2000-2005. Key: Cop.= copepoda, Clad.= Cladocera, Rot.= Rotifera.

Vertical distribution and abundance of zooplankton

Day time vertical distribution patterns in the littoral areas showed generally well dispersed zooplankton distributions over the entire water column (Fig. 10a).

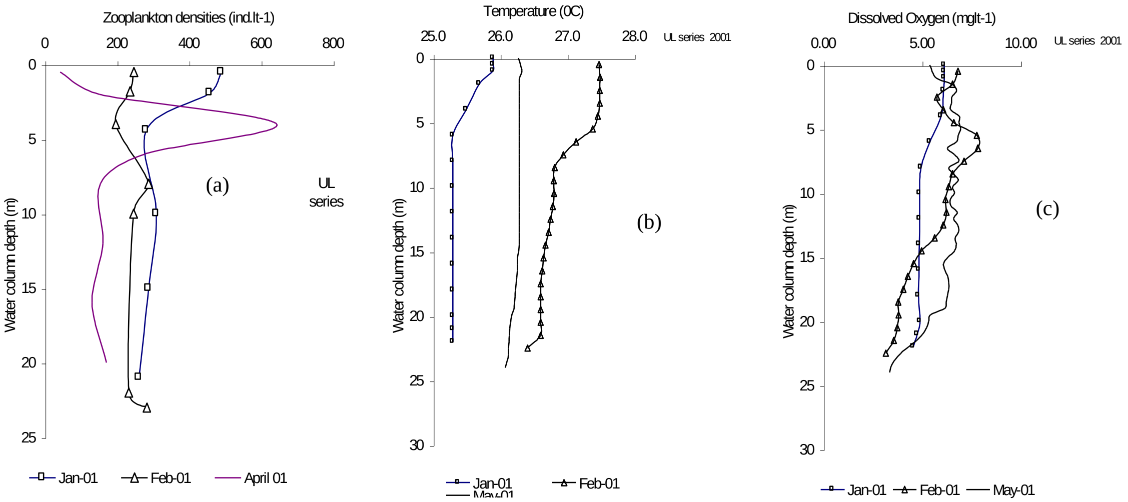

FIG. 10. Vertical profiles of zooplankton densities (a), temperature (b) and dissolved oxygen (c) at selected littoral sites, Lake Victoria 2001.

The corresponding environmental profiles also showed even distribution of temperature and dissolved oxygen throughout the water column at these littoral stations (Fig. 10). Zooplankton biomass data from TL 230 confirmed that in the littoral zones zooplankton occurred throughout the water column (Fig. 11).

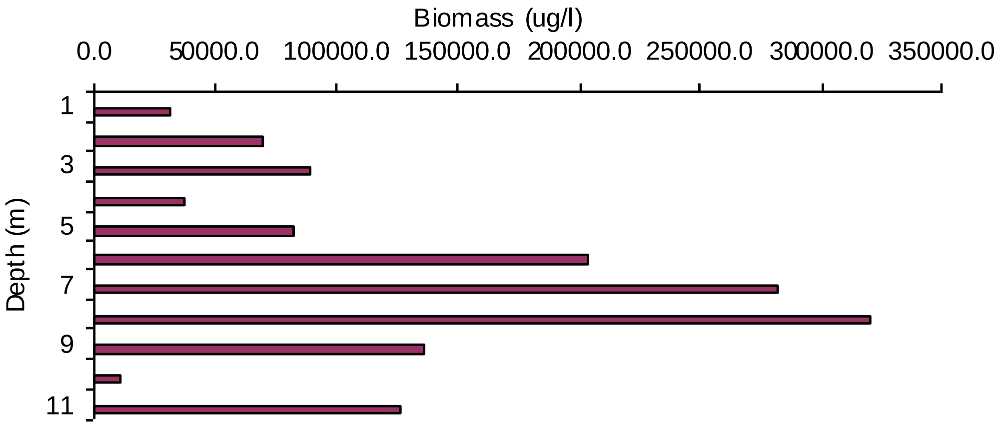

FIG. 11. Day time vertical distribution of zooplankton biomass at station TL 230, Lake Victoria, December 2000.

The vertical distribution of zooplankton at deeper open pelagic stations (UP2, UP7 and UP10) during thermal stratification showed concentration of organisms in surface and mid-waters with few or no organisms in the bottom water layers (Fig. 12).

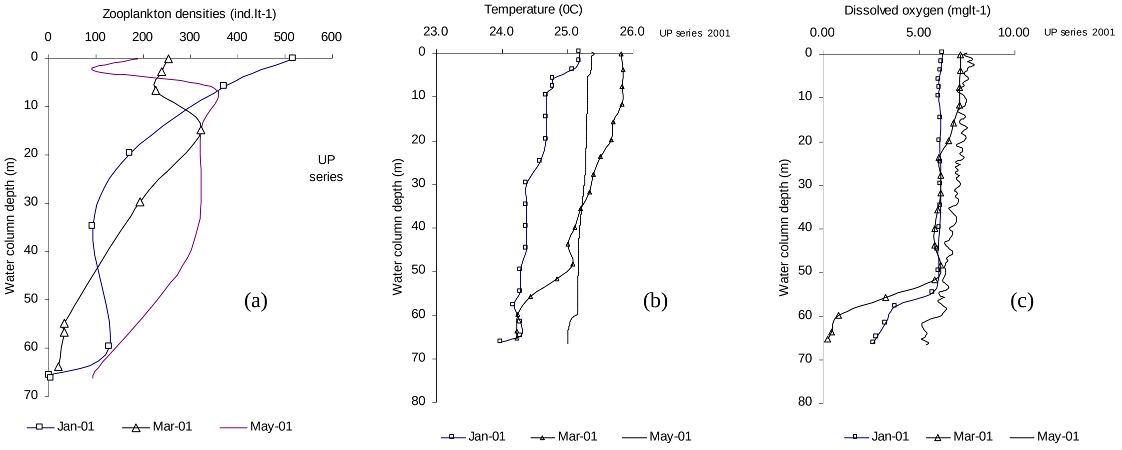

FIG. 12. Vertical profiles of zooplankton densities, temperature and dissolved oxygen at selected pelagic sites, Lake Victoria 2001.

Corresponding oxygen and temperature profiles indicated pronounced development of thermoclines and oxyclines between 50 and 70 metre depths below which the water mass was characterized by low dissolved oxygen, even < 1.0mgO_2 L^{-1} in March 2001. Also phytoplankton primary productivity, which is grazed by the zooplankton as their food resource, is restricted to the upper 15m by penetration of light for photosynthesis (Mugidde 1993), and the availability of rapidly growing phytoplankton in the upper part of the water column accounts for the higher abundance of zooplankton in the upper water column.

DISCUSSION

Nutrient Indicators

Compared to Tallling values for SiO_2-Si concentrations of 1961, concentrations in the lake as a whole (excluding the semi-closed inshore areas) have decreased by a factor of 3, although at his primary station south of Bugaia Island (UP2), SiO_2-Si concentration has decreased by a factor of 8. PO_4-P concentration in the open pelagic waters has increased 4 to 8-fold compared to values measured by Talling in 1961. This draw down of SiO_2-Si, an essential element for diatoms, is due to eutrophication effects of high P loads into Lake Victoria. Similar depletion of dissolved SiO_2-Si also occurred during the P driven eutrophication of the Laurentian Great Lakes in North America where P loading reduction programs have led to a reversal of the eutrophication and a restoration of SiO_2-Si concentrations (Barbiero *et al*. 2002). TP concentration has shown a marked increase (4-fold), from 20 to 47 µg/l as measured by Talling in 1961, to the present 78 to 140 µg/l. The TN:TP ratio (molar) in the main lake (<20) indicate that phytoplankton growth in the lake is nitrogen deficient (Guildford & Hecky 2000). This favors the dominance of nitrogen fixing Cyanobacteria which is in line with high nitrogen fixation rates in lake reported by other researchers (Mugidde *et al* 2003). This low TN:TP ratio is associated with the increased phosphorus loading into the lake and selective loss of nitrogen through denitrification and enhanced recycling of P which is associated with increased anoxic conditions in the deep pelagic waters (Hecky 1993, Hecky *et al* 1996, LVEMP 2002).

Bio-indicators

The observed species composition of the Victoria invertebrates is consistent with the previous studies (Worthington 1931; Macdonald 1956; Rzoska 1957; Akiyama *et al*. 1977; Okedi 1990; Mavuti and Litterick 1991; Mbahinzireki 1994; Mwebaza-Ndawula 1994; Waya 2001; Waya and Mwambungu 2004; Waya 2004). This observation suggests that the community composition has remained relatively stable despite drastic changes in water quality and fish species composition save for a single cladoceran , *Simocephalus vetullus* recorded by Rzoska (1957) which has not been reported in recent studies. Bridgeman (2001) has also reported drastic decline of the cladoceran species, *Bosmina longirostris,* and chydorids from sediment core analysis. A cladoceran species, *Daphnia barbata* hitherto unrecorded in the lake has recently been reported in samples from the Nyanza Gulf. Mwebaza-Ndawula (1994) reported changes in relative abundance of the broad taxonomic groups from dominance of calanoid to cyclopoid copepods and the reduction of cladocera abundance, formerly >30% to the present 5-7%. Such changes appear to reflect ecosystem responses to the changing water quality and consumer communities.

The abundance of *Caridina nilotica*, lake fly larvae, and other invertebrates have increased in the lake with the decline of haplochromine stocks (Witte *et al* 1992). *Caridina* is now considered a keystone species for the Nile perch while the lake flies are not well utilized based on food web isotope studies (Campbell *et al* 2003). *Rastrineobola argentea* is a small zooplanktvorous fish that is most abundant in inshore areas and feeds on zooplankton. Comparison of present zooplankton density estimates with previous studies (Mavuti and Litterick 1991, Branstrator *et al.* 1996, Mwebaza-Ndawula 1998; Waya 2001) indicates no marked differences in abundance patterns over the past 15 years. This suggests a stable and dependable food resource and a sustainable zooplankton community as prey for fishes. The zooplankton community is a critical component of the diet of all larval and small juvenile fishes. However the current zooplankton community does not effectively graze the filamentous and colonial Cyanobacteria that now dominate the phytoplankton community (Lehman and Branstrattor 1993), and condequently phytoplankton biomass accumulates to high concentrations that can cause self-shading and impose light limitation restricting further algal growth (Mugidde 1993). The stability of the current invertebrate community is largely dependent on the superabundant cyclopoid copepods, the prawn, *Caridina nilotica,* dipteran larvae and mollusks which occur widely in the lake and constitute key forage items for a number of juvenile and adult fishes, and especially the major fisheries (Corbet 1961; Ogutu-Ohwayo 1990; Mwebaza-Ndawula 1998). These abundant prey species are considered to be critical in the recovery of lost haplochromines and other fishes. These invertebrate prey species were formerly heavily used by the trophically specialized haplochromines that had specific adaptations for exploiting these prey. The loss of the haplochromines relieved predation pressure on these invertebrates and that together with increased energy flow because of eutrophication has created a strong prey base that sustains the high productivity of juvenile Nile perch.

The occurrence of hypolimnetic anoxia at the thermally stratified deepwater areas (i.e. UP, KP and TP stations) has reduced habitable space as shown in the displacement of zooplankton (Fig. 12) from deep water. Among the invertebrates, *Caridina nilotica* has become a keystone species because it is resilient to low oxygen conditions (Branstrator *et al* 1996). The ability of these organisms to find refuge from fish predation by temporarily occupying hypoxic waters ensures that reproductive populations and growth potential is maintained. Recent work by Sekiranda (2005) shows progressive impoverishment of benthic and fish communities in three Ugandan bays (Murchison, Fielding and Hannington) with water quality ranging from non-polluted, nascent pollution to highly polluted conditions based on intensity of settlement and agriculture within the bays. Thus, increasing agricultural land use and the associate increased loading of sediments and nutrient is an emerging threat to invertebrates and other lake biota especially in confined embayments that restrict dispersion of the incoming loads. Occurrence of relatively high abundance of well known hypoxia-tolerant biological indicators such as larvae of the lake flies (chironomids and chaoborids), *Caridina nilotica* and rotifers in the lake is a signal of deteriorating water quality conditions although these are useful food organisms for juvenile fish. However, Ogutu-Ohwayo (1999) has documented the decline in condition of Nile perch after the depletion of the haplochromines, and Balirwa *et al* (2003) have suggested that restoration of haplochromines could lead to higher growth rates of adult Nile perch and increased yields to the fishery.

The reductions in Secchi depth are a general indicator of the loss of transparency and a reduction in the depth of the euphotic zone. Phytoplankton primary production is restricted to the euphotic zone and has become light limited because of self-shading (Mugidde 1993). The narrowing of the euphotic zone as algal biomass accumulates in a nutrient saturated system also contributes to the increase in maximum phytoplankton biomass concentrations. However, depth integrated primary production does not increase with increasing biomass in light limited systems for which chlorophyll controls light penetration. Silsbe (2004) has recently shown that as chlorophyll concentration increases above 20 μg/L integral gross primary production plateaus at a maximum value of approximately 20 g $O_2/m^2/d$. The consequence of this is that currently high chlorophyll concentrations in inshore areas can be reduced without reducing the primary productivity of the ecosystem. The currently high phytoplankton biomasses also shade out benthic algal growth which was an important component of the diet of algivorous littoral haplochromines and also supported other littoral invertebrate food webs upon which carnivorous haplochromines depended. In other species rich African Great Lakes such as Lake Malawi, benthic algal productions sustains a number of invertebrate and fish species (Bootsma et al. 1996). The loss of the littoral benthic productivity likely contributed to the loss of these specialized feeding groups as littoral benthic algal production declined.

Biodiversity Declines

Eutrophication often leads to changes in relative abundance of species as some are favored by changes in productivity while others suffer as the habitat degrades. Seehausen *et al.* (1997) concluded that the eutrophication of Lake Victoria has contributed to the decline of the endemic species flock of haplochromines because of reduced visibility (declining Secchi depths) and loss of chromaticity (color) in transmitted light. They demonstrate that species richness under present lake conditions is a function of light transmissivity at all wavelengths. The reduction of Secchi depth from historic conditions would therefore cause deterioration of haplochromine mate selection which is based on visual cues and lead to more hybridization of these closely related species. As well as loss of visibility affecting mate selection, Seehausen *et al.* (2003) further conclude that loss of visibility and color visualization will lead to increased competition among predators and favor Nile perch over endemic predators. Haplochromines have eyes that are sensitive to a broad spectral range and are effective predators in highly transparent water while Nile perch have visual capacities to adapted to low light and low color environments. Certainly the Nile perch through its direct predation effects contributed to the decline of the endemic haplochromine populations, but the eutrophication contributed to the loss of biodiversity because its effects on visibility in the system and created conditions in which Nile perch where competitively favored over native species. Restoration of haplochromine stocks and a diversified fishery will require both management of eutrophication as well as management of Nile perch stocks.

Process Indicators

The lake was found to stratify between February and April with weak stratification occurring between September and November. The lake fully mixes between June and August and partially in December to January, although inter-annual variation to these patterns has been observed. This is consistent with past observations in Lake Victoria (Talling 1965, 1966, 1969 and Mugidde 2001). Generally, Lake Victoria is now warmer and more stable than in the 1960s (Hecky 1993, Hecky et al. 1994, Lehman *et al.* 1998). Minimum water temperatures during the mixing period in June-July are 0.5 ^{o}C warmer in the 2000 to 2004 than they were in the 1960s. High water temperature due to stronger thermal stratification affects water chemistry in a number of ways. Elevated temperatures accelerate chemical reactions and microbial processes such as denitrification –nitrification (Seitzinger 1988), thus affecting nutrient cycling and availability as well as algal biomass development and oxygen availability. More stable thermal stratification makes the lake less able to mix effectively and promotes low oxygen conditions in deep waters while surface waters remain well oxygenated due to replenishment in day light by high algal photosynthetic activity and wind effected oxygenation. The stronger and more persistent thermal stratification aggravates the increased oxygen demand resulting from increased organic matter from primary production. Hypoxia also favors regeneration of soluble reactive phosphate and produces a positive feedback to maintain even higher phosphate concentrations and leads to a positive feedback and increased internal loading of phosphorus.

System Changes

Compared to values reported by Talling (1966), chlorophyll a concentration in the open pelagic waters of Lake Victoria has increased 2-3 fold. However the station near Bugaia Island (Talling's sampling station), had concentrations ranging between 1.92 and 3.84 µg/l), which are within the range reported by Talling (1966). But chlorophyll concentrations at Bugaia were apparently higher in the early to mid-1990's (Mugidde 1993; Mugidde et al 2003) when chlorophyll concentrations (mean 13.5 µg/l) were more similar to those found at other pelagic stations (Fig. 5a) in the LVEMP period of observation.

Worthington (1930) reported higher transparency values (6.0 to 8.0m) in the pelagic area compared to current values, but in the gulfs the current values are more comparable to those reported by Worthington. This decrease of water transparency in the pelagic waters is the result of increased phytoplankton biomass reported above as observed by other researchers (Mugidde, 1993; Kling et al 2001) as chlorophyll concentrations and Secchi depths are highly correlated.

Phytoplankton primary productivity was in the range 8 to 50 g O_2 m^{-2} d^{-1}, with the mean average of 18.3 g O_2 m^{-2} d^{-1} that was approximately twice higher than the values recorded in the 1960s (Mugidde 1992, 1993; Talling 1966). Overall, the algal photosynthetic efficiency is now lower as indicated by average productivity per unit biomass of 18.1 mg O_2 mg $chl^{-1}h^{-1}$ in the 1990s compared to 25 mg O_2 mg $chl^{-1}h^{-1}$ in the

1960s. This high algal primary productivity supports remarkable levels of secondary production including fish production in Lake Victoria. Currently the phytoplankton are light limited so any increase in nutrients will not lead to an increase in production although phytoplankton biomass can reach higher concentrations depending on hydrodynamic conditions. Conversely a reduction in nutrients can reduce algal biomass without affecting annual primary production significantly until chlorophyll values drop below 20 µg/L.

The very fertile conditions can support elevated algal wet biomass in the range 5 to 250 mg l^{-1} which has risen by a factor of 4 to 5 since the 1960s (Kling *et al.* 2001). High P concentrations and resulting high N-demand favour dominance of nitrogen fixing Cyanobacteria (blue-green algae), primarily speces of *Cylindrospermopsis*, *Anabaena* and *Microcystis*. Overall, there is seasonal succession in species composition of algae with increasing dominance of N-fixing blue-green algae during the early stratified period followed by non-fixers which benefit from the recycled fixed nitrogen later in the stratified period and during the deepest mixing period in June-July.

The shift in dominance from the historical algal communities dominated by diatoms such as *Aulacoseira* (formerly *Melosira*)and green algae to Cyanobacteria is in response to increased P laoding into Lake Victoria (Hecky 1993; Lipiatou *et al*. 1996; Verschuren *et al*. 2002) and increasing N-demand by phytoplanktom (Mugidde *et al*. 2003). The shift in diatom dominance away from *Aulacosiera* which formed the main food of the native commercially important tilapiine *Oreochromis esculentus* and its reduction might have affected stocks of this species. The decline in *Aulacoseira* and shift to more thinly silicified *Nitzschia* spp. is a consequence of the falling SiO_2-Si concentrations in the lake.

TABLE 1. OECD boundary values for fixed trophic classification system (extracted from Mason (1997).

Trophic	*TP*	*mean Chl*	*max Chl*	*mean Secchi*	*minimum*
Ultraoligotrophic	<4.0	<1.0	<2.5	>12.0	>6
Oligotrophic	<10.0	<2.5	<8.0	>6.0	>3.0
Mesotrophic	10-35	2.5-8	8-25	6-3	3-1.5
Eutrophic	35-100	8-25	25-75	3-1.5	1.5-0.7
Hypertrophic	>100	>25	>75	<1.5	<0.7

Explanation of terms:
TP = mean in-lake total phosphorus concentration (ug/l);
mean Chl = mean annual chlorophyll a concentration in surface waters (ug/l);
maximum Chl = peak annual chlorophyll a concentration in surface waters;
mean secchi = mean annual Secchi depth transparency (m)

TABLE 2. Trophic status in pelagic and littoral waters in the lake as indicated by different indicators.

	TP	***mean Chl***	***max Chl***	***mean Secchi***	***min Secchi***
Pelagic zone	100	10	40	3	1.2
	Hypertrophic	Eutrophic		Eutrophic	
Littoral zone	156	39	128	1.3	0.3
	Hypertrophic	Hypertrophic		Hypertrophic	

Trophic classification of Lake Victoria can be done using the OECD trophic classification system for lakes (Table 1) in order to appreciate how Lake Victoria compares to other global lakes. The littoral zone was found to be hypertrophic with respect to all the trophic state indicators whereas the pelagic open zone was hypertrophic with respect to TP but eutrophic with respect to other indicators (Table 2). However, considering water transparency (Secchi depth) as an indicator, some stations near the middle part of the lake (eg TP 10, with Secchi depth up to 7.5m), can be considered mesotrophic. The high TP concentrations in the lake can be as a result of enhanced external and internal phosphorus loading in to the lake coupled with less phosphorus demand by phytoplankton due to light limitation in the lake (Mugidde *et al* 2003). By comparison with the OECD the trophic status of the open pelagic waters has changed from mesotrophic (with respect to TP, chlorophyll and Secchi as reported by Worthington (1930) and Talling (1966)) to presently eutrophic status while littoral waters have changed from mesotrophic-eutrophic to hypertrophic.

Relation to fisheries

The occurrence of hypolimnetic anoxia, especially in the deep open waters, during periods of thermal stratification may result in displacement of demersal fishes and other bottom dwelling biota vertically into mid-waters and/or laterally into shallower areas. This phenomenon commonly leads to disappearance of fish from established fishing grounds such as is the case around Goziba (Nabuyongo) islands in Tanzania during February-March (as reported by local fishermen) and because of the loss of habitable space. This condition was associated with migration of fishermen from the Goziba islands to the islands of Ukerewe, Bumbire and Kerebe due to scarcity of fish in the traditional fishing area during March 2004. Under critical conditions hypoxia in the lake can result in fish kills (Ochumba 1990) when upwelling conditions occur.

Some species of cyanobacteria such as *Microcystis, Cylindrospermopsis* and *Anabaena* that commonly occur in the lake today can produce toxins that have deleterious impacts on aquatic biodiversity and other biota including humans (Hummert et al 2001; Krienitz *et al.* 2002). Phytotoxins have been reported in some inshore areas in Nyanza and Mwanza Gulf (Krienitz *et al.* 2002) and pose a risk to aquatic biota, food web functioning and potability of lake waters. Algal biomass has increased disproportionately to the increase in productivity indicating that the transfer of energy from primary producers to grazers is now less efficient than it was or could be. Decreased visibility in the system and loss of fish biodiversity may also have affected the transfer of energy between prey and predator in food chain. Low light conditions thus created also affects visual feeding and may also be associated with observed high hybridisation among tilapiine fishes (Balirwa *et al.* 2005) and contributed to loss of species diversity.

The increased nutrient concentrations, has made the lake vulnerable to invasive weeds such as the water hyacinth which at its peak during the mid and late 1990s covered large areas of sheltered bays and gulfs, leading to increased light attenuation, low dissolved oxygen concentrations and loss of fish habitats. The reported increased biomass of *Caridina niloticus* and lake flies as a result of increased eutrophication and change of food web has provided the food-base for the expansion of *Lates niloticus* and *Rastreonobola argentia* populations, which now have great economic importance to the region, but they are also indicators of deteriorating water quality.

CONCLUSIONS

1. Nutrient and phytoplankton data has confirmed earlier reports on water quality and ecosystem changes in Lake Victoria. These include increased phosphorus levels, reduced silica concentration in the water, increased phytoplankton biomass, higher primary productivity and major changes in species composition.
2. Increased phosphorus enrichment from external sources may further enhance phytoplankton biomass in inshore areas and lead to further dominance by N fixing and other Cyanobacteria, many of which are potentially toxic.
3. N fixation is an important process that makes atmospheric nitrogen available to meet the requirements of N deficient Cyanobacteria. This process accounts for 50-80% of total external nutrient loading and cannot be controlled except through reducing phosphorus loading and availability.
4. The integral phytoplankton primary productivity has increased approximately a factor of two from historic rates but the primary productivity of the system is now light limited. Further nutrient enrichment will not supply more energy from phytoplankton and will increase the risk of intense algal blooms and the invasion by floating macrophytes that are not limited by light.
5. The current ecosystem conditions are a threat to sustainable utilization of lake resources including the fishery because 1) they impose deep water anoxia limiting habitable volume for higher organisms, 2) limit fish biodiversity, 3) create the potential for algal toxins to affect food webs and human consumers and 4) favor resurgence or invasion by water hyacinth and other floating macrophytes,

6. The wide distribution and high abundance of copepods, dipteran larvae, molluscs and *Caridina nilotica* have adjusted to the new conditions and can provide a sustainable and resilient food web, but they do not control algal abundances through direct grazing and, in turn, may be inefficiently used by fish compared to former conditions. Restoring visibility in the system by reducing algal biomass would have benefits for food web efficiency, fish biodiversity and potentially growth rates of mature Nile perch if haplochromines were restored as prey of the perch.

RECOMMENDATIONS

- Integrated management of nutrient loading (mainly phosphorus) into the lake should be implemented catchment-wide to reduce over time the algal biomasses in the lake and restore aspects of the former condition of the lake especially reduced Cyanobacteria and improved visibility.
- Regular lake monitoring is a necessary part of an early warning mechanism to avert further decline in lake ecosystem health and inform the management on the impact of catchment management on the lake ecosystem.
- Together with stakeholders, responsible agencies should establish achievable water quality objectives to guide the multiple-use management of the Lake Victoria ecosystem.

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CHAPTER 7

Nutrient Loading

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ABSTRACT. *It is now recognized by most of the scientific community that Lake Victoria is enriched with nutrients. There are, however, conflicting reports on the magnitude of nutrients received from different sources and the dynamics of nutrients in the Lake. Studies were carried out to determine the lake nutrient balance and suggest strategies for sustainable utilization of the resources. Lake nutrient balance is essential for understanding primary productivity and ecosystem function and for planning nutrient management strategies.*

The current findings identify major point and non point sources of nutrients and estimate the rates of sedimentation into Lake Victoria. The determination of pollution loads from point sources was limited to the Biochemical Oxygen Demand (BOD5), Total-Nitrogen (TN), and Total-Phosphorus (TP). For the non-point pollution sources emphasis was given to TN, TP and TSS, the loads from rivers and atmospheric deposition have been calculated, both due to their relevance as quality indicators and their contribution to eutrophication of the Lake. For the purpose of determining the nutrient balance of the lake, the sedimentation rates in the lake have also been calculated both fluxes per unit area and total lake bottom accumulation.

Municipal effluent load was higher than industrial one, but they both represent a threat to the community downstream the discharge point and the littoral zone of the lake. Atmospheric deposition was the overall dominant source contributing about 39,978 and 167,650 tons of TP and TN respectively to the lake annually. The riverine loads are estimated at 9,270 of TP and 38,828 tons/y of TN respectively, and represented in both cases 80% of the total non-point load. Point sources are estimated to contribute about 4.3 of TN and 1.9 tons/year of TP. The cores dated and analyzed show dry weight accumulation rates of 100 $g.m^{-2}y^{-1}$ *to 300* $g.m^{-2}y^{-1}$*. Linear regression indicates sedimentation rates of 0.5 to 1 mm per year. Furthermore, highest rates of permanent sediment accumulation occur in the deepest areas of the lake. However, the study indicates that rate of nutrients regeneration is 90% for C and N and 60% for P. It is therefore recommended that pollution loading into the Lake be controlled by reducing point sourcing and providing tertiary treatments for removal of*

P, use of phosphorus free detergents, cleaner production technologies, and addressing non-point sources by improved land management. An initial goal of reducing the anthropogenic phosphorus loading to the lake by 30% would reverse the current upward trend and achieve water quality conditions that occurred in the 1980's when fish production was at its maximum. Trans-boundary efforts may be required to control atmospheric deposition into water bodies.

INTRODUCTION

Well-documented changes have occurred to the water quality in Lake Victoria and its ecosystem over the past five decades *(Ref)*. Among them, the most widespread and currently most serious is eutrophication (Chapter 6). It is now evident that Lake Victoria has received increased loadings of some plant nutrients from the catchments due to population growth and associated land-use changes as well as industrial and urban development. The increased additions of nitrogen (N) and especially phosphorus (P) have saturated the lake's biological capacity to absorb these, and have caused the lake's N-fixation rates and P concentrations to rise to the extent that algal growth is now light limited. The main sources of nutrients to the lake can be defined as point and non-point sources. The point sources have traceable and quantifiable origin, mainly from industrial establishment, municipal effluent, shoreline settlements and urban runoff. On the other hand non-point pollution sources generally originate from land run off, wet and dry atmospheric precipitation, and ground water which transfer nutrients, mobilized by broadly distributed human activities, into rivers and directly to the lake. Ground water inputs are considered minor based on water budget studies (McCann, 1972, Rwegoshora *et al*, (2004) and are not further considered in this chapter.

Of the materials delivered to the lake via rivers and the atmosphere, only relatively small amounts of these nutrients are flushed out of the Nile due to minor portion of the total water budget leaving the lake at Jinja. Most of the dissolved and particulate nutrient material entering the lake is processed by biological organisms within the lake and eventually sedimented as detritus, processed into gaseous forms e.g. bacterial denitrification which produces nitrogen gas, or simply settles to the bottom of the lake e.g. mineral sediments. Hence knowledge of sedimentation rates and patterns is necessary to fully account for the materials brought to the lake. Sedimentation studies are critical in calculation of the nutrient mass budget, determining the fate of added nutrients (volatilization or sedimentation) and estimation of internal and external loading of nutrients.

Although it is now recognized by most of the scientific community that the lake is enriched with nutrients, there are conflicting reports on the magnitude of nutrients received from different sources and the dynamics of nutrients in the Lake (LVEMP 2002) Therefore the objectives of this chapter are to identify and quantify sources of the nutrient loading which are essential for understanding primary productivity, determining algal community composition and resulting ecosystem function. If there is agreement that nutrient loading is excessive and should be reduced then the information on loadings will be critical to determining nutrient management strategies.

Point Sources

Point sources are, in principle, the easiest sources to estimate and the easiest to control. The nutrient loads from point sources enter receiving waters at defined and relatively confined outfalls that can be sampled and, if necessary, treated. Because these outfalls are collected from areas having large populations and intensive water use, these point sources can be important components of the total loading to some lakes. In North American Great Lakes, the reduction of P at point sources accomplished major reductions in total loading and recovered the lakes' from eutrophication (Barbiero *et al.* 2002). Because point source discharges are often dominated by products of human waste and agro-processing industries, they have high oxygen demand that can affect the oxygen status of receiving water and their suitability for sustaining higher life forms. Oxygen conditions can also affect the availability of N and P with hypoxia favoring release of P from mineral matter and loss of N by denitrification. The technological aspect of point sources also identifies them as a clear increment over natural nutrient loading; and therefore, directly attributed to anthropogenic (caused by humans) nutrient loading.

Methods of Estimating Loads

The determination of pollution loads from point sources was limited to the following parameters: Biochemical Oxygen Demand (BOD_5), Total-Nitrogen (TN), and Total-Phosphorus (TP) because of their relevance as quality indicators and their contribution to eutrophication of the Lake. Along with these key parameters, pH, conductivity, Chemical Oxygen Demand (COD), Alkalinity, Chloride, Dissolved Oxygen (DO), Faecal Coliforms (FC), TSS (total suspended solids), and heavy metals were often analyzed and available in the national water quality reports. Two criteria were used for selection of point sources for the assessment. Only towns with more 10,000 inhabitants have been included, defining smaller towns as rural settlements. For the selection of industries, only those referred to as "wet" industries (using water in the production) were considered. Various methods have been used to quantify the industrial and municipal effluents depending on data availability. These include direct measurement, standard figures for municipal loads, industrial loads based on production figures and approximate (expert) estimates.

For the direct measurement, standard procedures (APHA 1998) were used to sample and analyze the wastewater from the industries and municipalities. Different methods were applied to measure velocities of the discharges depending on the various situations. These included current meter, concentration, bucket, and float methods. By establishing the wetted cross sectional area, discharges were calculated as they are the products of velocity and wetted cross sectional area. The loads, that are products of concentration and discharge, were then calculated.

Based on the above calculation methods, basic loads (weighted averages) for each of the point sources were calculated. Basic loads are defined as the actual wastewater pollution generated at the individual point source, i.e. from towns and industries. Based on the disposal methods used the reduction of the basic wastewater loads before reaching the Lake was assessed. The resulting load indicates the best estimate of the pollutants reaching Lake Victoria.

Ranking of Municipal Point Sources for Lake Victoria

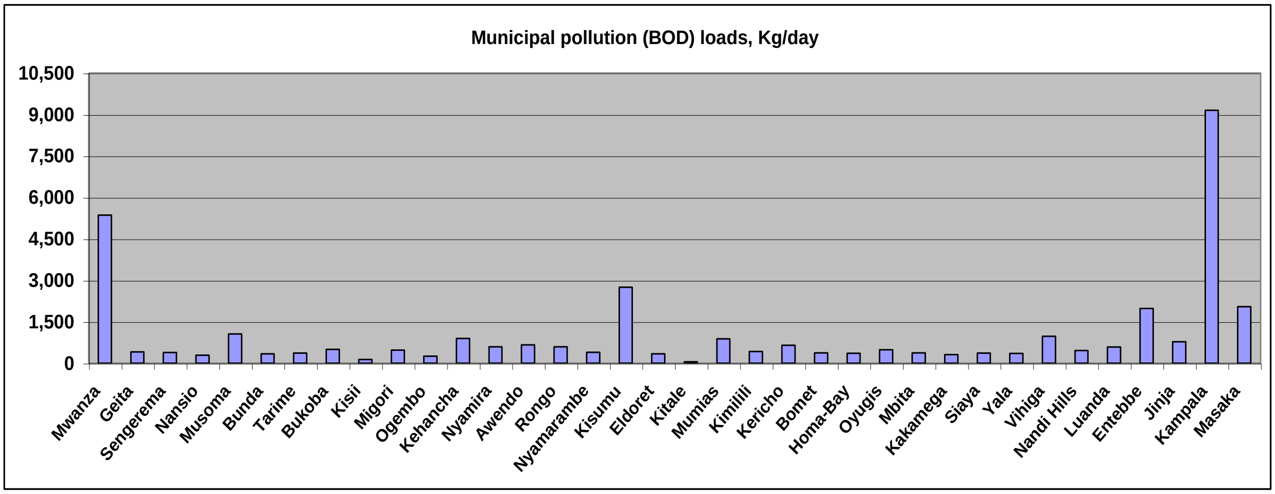

FIG. 1. Mean daily BOD loads for all major urban centres in the Victoria basin.

Considering only BOD, the loads of all the urban centers are shown on Fig. 1. The highest values are observed at Kampala, Mwanza, Kisumu, Masaka and Entebbe in a descending order. A relative values were apparent for TN and TP.

Total country industrial and municipal loads in terms of BOD are given in Fig. 2. Municipal loads for BOD dominate over the industrial loads. Furthermore it shows that Kenya leads in municipal pollution loading followed by Uganda, while Kenya and Tanzania contribute industrial loads of the same magnitude. In Kenya and Uganda some industries are connected to the municipal sewer, hence they are captured as municipal loads. Cane sugar processing, soft drinks manufacturing, fish processing, vegetable oil processing, breweries and distillery industries are the major categories of polluters to the lake in a descending order (see Appendix 1 which gives mean daily TN,TP, BOD data for all municipal and industrial sources). The data in Appendix 1 were used to estimate total loads to Lake Victoria from all municipal and industrial sources.

Critical Areas

Critical "hot spots" of the region are the major urban centers along the shoreline of the Lake Victoria namely Entebbe, Kampala, Kisumu, Mwanza and Musoma. Apart from Entebbe, which discharges into an open shoreline, these centers discharge their waste into sheltered bays and gulfs, i.e. Murchison Bay, Winam Gulf, Mwanza Gulf and Mara bay. These gulfs and bay have relatively restricted exchange with the larger lake and thus dilution and absorption of these loads is restricted and their impact on the larger lake thereby reduced. Mwanza Gulf receives the entire load from the Nyashishi catchment around Mwanza with loadings of BOD 9,091 TN 1,528, TP 520 Kg/day, while Murchison Bay receives 60% of the pollution generated by Kampala City (LVEMP 2002) which is BOD 11,376, TN 2,556, and TP 1,764 Kg/day. Likewise Winam Gulf receives pollution loads from various municipalities which total BOD 7,641, TN 2,481, and TP 582 Kg/day. Unfortunately, urban wetlands which could further filter and reduce some of the loads from these centers have been encroached on to allow urban farming, settlements and industries. This loss of absorptive capacity in the wetland aggravates the growing loads that are proportional to the serviced populations in these centers. The entry of these loads to these confined gulfs and bays reduces the effective load to the open lake but aggravates conditions in the embayment. Higher concentrations of nutrients may result near outfalls, and highest nutrient concentrations and algal biomasses are found in these locations. Similarly these areas were, and are, growth centers for water hyacinth because of the abundance of dissolved nutrients, the floating plants ready access to sunlight for photosynthesis, and the shelter from strong winds and waves.

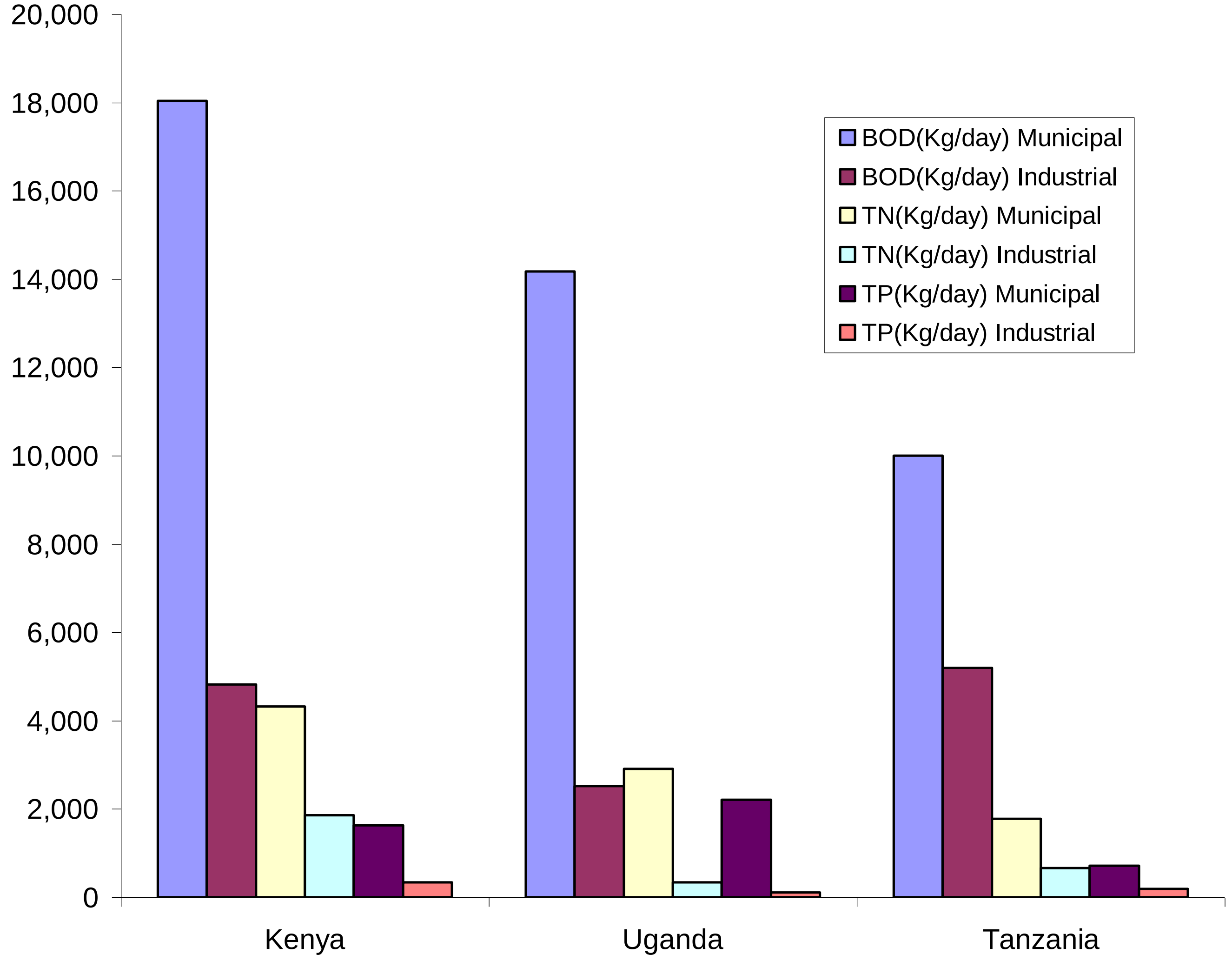

FIG. 2. Mean daily industrial and municipal loads by country.

Emergent Issues

Shoreline Settlements (*Fishing Villages/Fish landing sites, Beach Resorts, Ports and Piers)*

Shoreline settlements in Tanzania and Uganda have pit latrine coverage of less than 20% (Mnyanga, 2002; LVEMP 2002). In many places the "in-law taboo", high construction costs and lack of awareness forces people to defecate in the bush (free range) or directly in the lake. Garbage collection is also poor in that less than 40% of garbage is collected in these settlements (LVEMP 2002). Fish cleaning waste and liquid and solid waste from eating areas, market and households end up in the lake. Sanitary conditions are very poor, and the lake water quality along the settlements is poor with faecal coliforms (indicators of recent faecal pollution), in the range of 50 to 1000 counts per 100 ml. A few households have toilets, but they are nicknamed "choo cha daktari" meaning doctor's toilet, which is toilet shown when health inspectors go around inspecting the situation of health and sanitation in household. This has resulted in high prevalence of water-borne and other water related diseases like cholera, bilharzia, scabies, diarrhoea, cough and malaria.

Strategies being implemented to improve the dire situation in fishing villages include:

- Public awareness on ways of improving sanitation such as use of *ECOSAN* toilets. To this end, micro-projects were initiated to address the issue of lack of toilets *e.g.* in Dimo (Masaka district) and Musonzi (Kalangala district) *ECOSAN* toilets were constructed as pilots for other fishing villages to copy. Their sustainability is to be ensured by beach management units (BMUs).
- Reduction of solid waste volume (which is mainly of biodegradable matter) by encouraging domestic composting.
- Formation of self-help groups to improve their organizational capability and prosperity.
- Promotion of private sector participation in waste management is also taking place.

Urban Run-off (Nakivubo Channel, Mirongo River, Kisat River)

Almost all the urban run-off from Kampala City that ends up in Lake Victoria is led through Nakivubo channel into the Inner Murchison bay. Likewise in Kenya, the discharges from the malfunctioning conventional wastewater treatment plant at Kisumu are led into the Winam Gulf through the Kisat stream which has turned black due to pollution. However, in Tanzania, the situation has changed drastically after the rehabilitation of the Mwanza sewerage system which used to discharge raw sewage into Mirongo River. Mirongo River which traverses Mwanza City. The Mirongo was operated as a storm water drain for about 12 years (1991-2003) and formerly received the bypassed sewage and conveyed raw sewage from the Municipal Sewerage system into the Kirumba Bay (Mnyanga 2002). After rehabilitation of the sewage plant, faecal coliforms dropped dramatically in the Mirongo River (Fig. 3). This improvement in Mirongo water quality is a positive example of how pollution control can improve conditions in the Victoria. All three of these municipal waste discharges are entering the same waters that are source waters for water treatment plants (WTPs). Studies at Kampala have highlighted the risk that these waste discharges pose to the large populations reliant on these WTPs as well as other people who take their drinking water directly from the lake without treatment. Not only is there a health risk if treatment fails at WTPS but the cost of treatment are increased by the excess algal growths that occur in these confined embayments including the growth of Cyanobacteria (blue green algae) which can produce algal toxins thereby amplifying the risks to consumers.

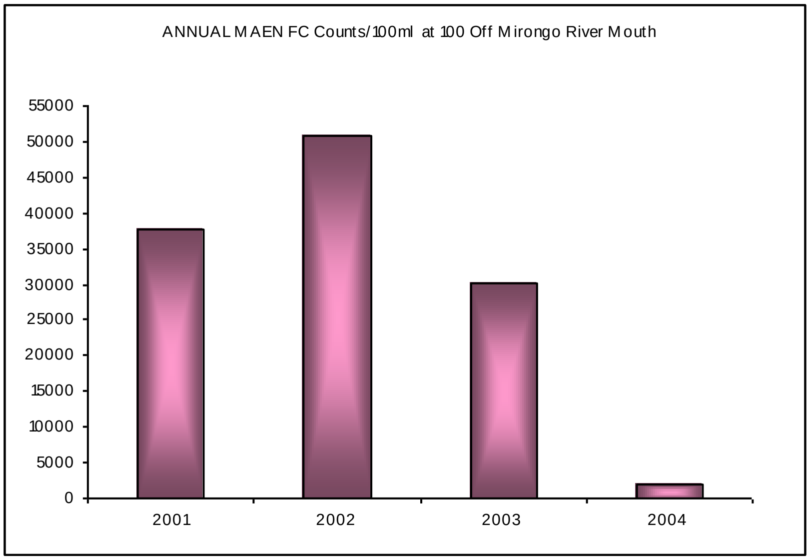

FIG. 3. Annual Mean FC Counts 100m off mouth of the Mirongo River in Mwanza Gulf.

Currently the technology at these sewage treatment plants does not include tertiary treatment to remove inorganic nutrients released by degradation of organic material within the sewage treatment process. Tertiary treatment by chemical means would provide immediate benefits to improving water quality in receiving waters. Similarly protection of wetlands that also can provide tertiary treatment should be a priority. The construction of increased capacity for Nakivubo channel threatens to overload the Nakivubo wetland that currently provides beneficial treatment of discharges from the former channel. Integrated ecosystem management is required in these major urban areas to protect the beneficial uses of the aquatic resources in these embayments.

Phosphorus Free Detergents

In addition to other remedial measures (e.g. Cleaner Production and ‘end-of-pipe’ treatment in industries) to reduce pollution in Municipal and Industrial wastes, governments of the three riparian countries should consider imposing regulations limiting or eliminating phosphorus from detergents sold for use within the Lake Victoria basin. After reduction of phosphorus from point sources, the relative role of phosphorus from diffuse sources will increase. This means that measures against diffuse sources may become necessary if improvement of water quality cannot be achieved by further elimination of phosphorus point sources. Phosphate detergents contribute to both point and non-point source loading. Economical alternatives to phosphate detergents were readily substituted in North America.

Sanitary Facilities in Water Vessels

Sanitary facilities are supposed to be incorporated in all marine vessels. The facilities are meant to hold the wastewater until the vessel anchors. At the pier, the wastewater should be discharged into a sewerage system for treatment. This however is not the case with vessels cruising in Lake Victoria including those by local fishermen, passenger and cargo ships and even research vessels. The scenario is similar in Kenya, Uganda and Tanzania. Where the law says something on this, the enforcement is very poor. The magnitude of this pollution source has not yet been quantified.

Scale of Investments Required

In Uganda, the National Water and Sewerage Corporation contracted a Consultant, and produced a Sewerage and Sanitation Master Plan for Kampala which stipulates the need to install satellite sewage treatment plants according to the topographic set up of the city, instead of pumping and collection of all the sewage into the existing Bugolobi Sewage Treatment Plant, and eventual discharge into the Inner Murchison Bay. Likewise, in Tanzania the Ministry of Water and Livestock Development through the Mwanza Urban Water Supply and Sewerage Authority (MWAUWASA) and with the assistance from the EU cleaned and expanded sewer lines for 5.6 Km and rehabilitated the Waste Stabilization Ponds at Butuja and the pump house at Gandhi Hall in Mwanza. The impact on the water quality of the Lake is illustrated by Figure 3. Two new sewerage systems to have treatment plants at Igoma and Butimba are to be constructed soon under another EU Project with an objective of having a sewer length of 243.7 Km and connecting 200,300 people by the year 2025. The Kenyan Government having recognized the waste from Kisumu conventional waste treatment plant (Kisat) as a danger to Lake Victoria, and its surrounding environment, has come up with short and long term programmes to rehabilitate the plant and the Waste Stabilization Ponds. The Lake Victoria South Water Service Board on behalf of the Government and with assistance from French Government is undertaking the project. A consultant is on board undertaking the preliminary designs. These positive steps must proceed and receive adequate funding and sustainable cost recovery to ensure maintenance and operation of the improved facilities. Tertiary treatment at the STPs should be part of all projects to begin to reduce the excessive nutrient loading and related eutrophication of Lake Victoria. Wetland protection and encouraging use of natural and constructed wetlands to provide tertiary treatment to smaller municipalities and industries is a low cost strategy that builds on the sustainable capacity of wetlands to improve receiving water quality in Lake Victoria.

CONCLUSIONS

Pollution hotspots consist of major urban centers and industries, most of which discharge their effluence into sheltered bays. This affects water quality and beneficial use by the riparian communities most immediately in those embayments and contribute to the nutrient loading of the entire lake. Fishing villages do not have sanitation infrastructure, and have direct use and influence on lake waters. Marine transport remains a poorly defined source of BOD, nutrients and possibly other contaminants.

Increasing urbanization of the lake basin population will continue and will make municipal and industrial point sources increasingly important to the local receiving waters as well as the lake as whole. Technology exists to address this problem, but investment and application of appropriate technologies are not keeping pace with the growing populations.

Waste management as well as provision of safe drinking water are intimately linked in coastal cities and towns and require integrated ecosystem management to insure safe water for all.

RECOMMENDATIONS

- Although baseline data is adequate, continued monitoring will be necessary to determine trends and rates of change.
- There is need for development of clear standards and consistent enforcement for municipal and industrial point sources around the basin.
- Upgrade existing treatment facilities and add tertiary removal of phosphorus while increasing the sewerage system to include most of the urban populations.
- Public education and sensitization should be emphasized in order to reduce point source loading and public awareness of the risks of non-treatment of wastes.
- Promotion of Cleaner Production in the industrial sector should be intensified

NON-POINT SOURCE LOADING

Non-point source loading is the diffuse addition of nutrients and other pollutants mobilized by the activities of humans within the catchment and transported by streams, rivers and the atmosphere to the lake. Riverine loading originates from land areas defined by the heights of land separating catchment and sub-catchment boundaries. Atmospheric loading can originate from within the same defined catchment and sub-catchment areas as the riverine loading. However, the atmospheric loading from the catchment can be added on to by the atmospheric exchange that extends beyond the catchment boundaries. The phenomenon of Long Range Transport of Atmospheric Pollutants (LRTAP) has been well studied in northern temperate areas where transport of pollutants from industrial and intensive agricultural areas has been shown to effect water bodies hundreds to thousands of kilometers away from the emitting area for the pollutants (Hoff et al. 1996). Although much less studied in terms of its importance to lakes in the tropics, atmospheric loadings must be considered for Lake Victoria because 80% of the water inputs to the lake’s water balance come directly from rain on its surface. The remaining 20% of the water input comes from rivers (primarily), coastal streams and direct runoff to the lake. In addition, the atmosphere can supply nutrient inputs through dry deposition which can occur in the absence of rainfall and therefore is separated from the water inputs to the lake. Although the route of transport, river or air, is different and the effective area contributing materials is different (watershed boundaries for the rivers, airsheds for atmospheric loading), the anthropogenic loads carried by these pathways have a common origin which is the land- based human activities. Soil erosion can occur by water or wind. Biomass burning exposes the land to erosion and increases the emission of particulates and gases into the atmosphere. The reduction of those loads will require land management practices intended to minimize non-point source loadings.

Methods

Non-point pollution into Lake Victoria is of basically two forms: river borne from catchments and atmospheric deposition directly onto the lake surface. The river borne catchment loads were estimated for the major rivers draining each of the lake's sub-catchments. Emphasis was placed on having simultaneous water quality and flow measurements, allowing calculation of transports of the pollutants through the river systems and in particular, the discharges into the lake. Samples for atmospheric deposition were collected from island and lakeshore stations at Bukasa Island, Entebbe, Lolui Island, Bukoba, Kadenge and Kisumu representing the different rainfall zones of Lake Victoria, (Figure 4). The water samples were analyzed for the following nutrients NH_4-N, NO_2^-N, NO_3^-N, TN (total nitrogen), PO_4-P, and TP (total phosphorus and soluble reactive silica using standard water quality analytical methods (APHA, 1998).

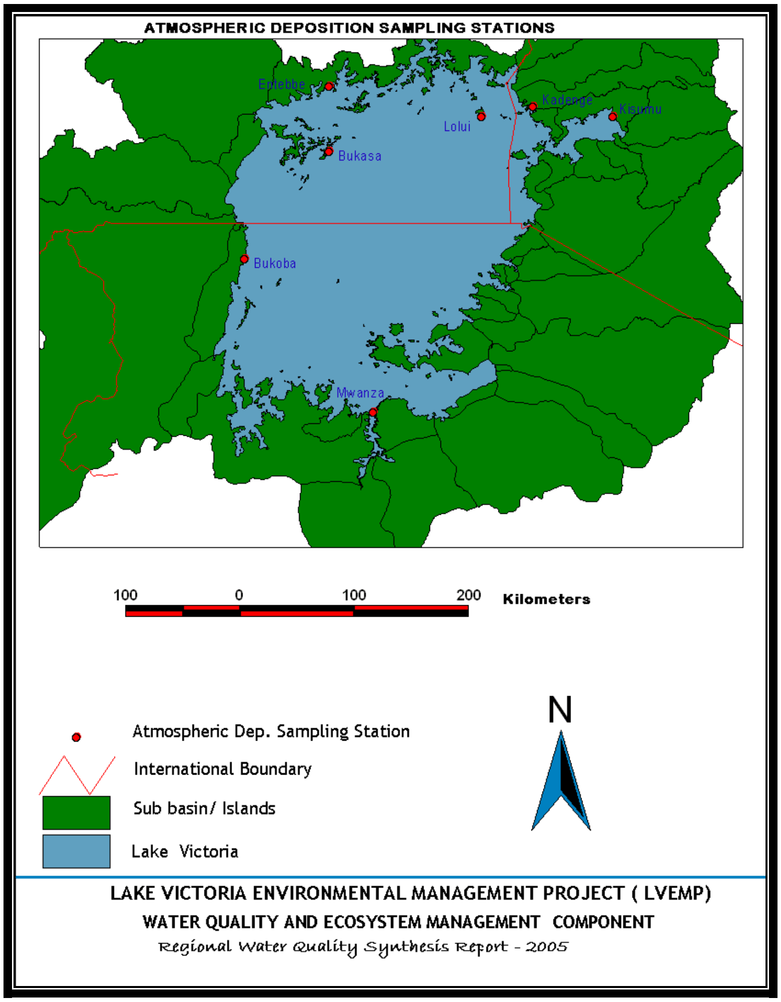

FIG. 4 Map showing sampling stations for atmospheric deposition.

Only TP and TN are presented here for the non-point loads with TSS results also given for the rivers. To normalize the concentrations of nutrients for wet atmospheric deposition for each sampling point, and volume weighted mean concentrations have been calculated to account for the tendency of small rain events to have high concentrations while heavy rain events are more dilute because of washing out the atmosphere. The lake was subdivided into ten (10) major rainfall areas and the volume weighted mean concentration (VWMC) was multiplied by annual rainfall for the appropriate area of the lake.

Dry deposition was measured by setting out open pans of water of known surface area and volume, then noting the changes in concentration of nutrients over a 24 hour period. Dry deposition measurements were generally made every two weeks. Daily rates were multiplied by the number of dry days in each sampling interval. Riverine loads were monitored near the mouths of major rivers. Discharge at the time of sampling was multiplied by the concentration of the parameter to give a daily estimate. For annual loads, the VWMC for each river was calculated and applied to the annual discharge estimate for the river to estimate the annual loading. Where sampling points were significantly upstream of the river mouth the estimate of annual loading was adjusted for the catchment area below the sampling point. Direct (non-channelized) runoff was estimated from the area, expected runoff and the VWMC of the nearest river

RESULTS AND DISCUSSION

Atmospheric Loading

The numbers of wet deposition samples collected and analyzed from each station are indicated in Table 1 below for the period 2000-2004.

TABLE 1. Total number of samples of wetfall collected from each station.

Country	Stations	Samples Collected
Tanzania	Mwanza	74
	Bukoba	63
Kenya	Kisumu	25
	Kadenge	13
Uganda	Lolui	86
	Entebbe	177
	Bukasa	157

Wet Deposition

The spatial variations for annual volume weighted mean concentrations TP and TN are shown in Fig. 5. These results indicate that Entebbe had the highest VWMC in both wet TP and TN, while Kisumu had the lowest, possibly attributable to differences in the local climatic conditions and air mass movements. Entebbe receives higher rainfall compared to Kisumu, but this is not likely to account for higher concentrations at Entebbe. Generally, higher rainfall leads to greater washout of aerosols and particles from the atmosphere and lower VWMC. Kisumu being a larger urban area than Entebbe might be expected to be a greater emission source for N and P, but there is always a possibility that a station may be overly affected by an unknown local emission source. However the Entebbe data are similar to the Ugandan islands of Bukasa and Lolui where there are no local urban sources and land use effects are minimized by the small land area on these islands. These results from Uganda also demonstrate that offshore concentrations of TN and TP in the rain can be similar to or higher than concentrations measured at shore-based locations. This supports the extrapolation of shore-based depositional measurements over the lake. In general the northern coast and islands in the northern archipelago have the highest TN and TP VWMCs yet observed on Lake Victoria. Although observations stations are still few, these wet deposition results suggest that there may be a strong influence of air masses from the northwest affecting the TN and TP concentrations in rain over the Ugandan portion of Lake Victoria. More stations and with greater spatial resolution including over the islands will be required to understand the spatial patterns evident in this study.

Concentrations of TN and TP in rainfall recorded during the LVEMP period can be compared to other similar measurements made previously Lake Victoria and on other lakes in East Africa. Tamatamah et al (2005) studied three sites in Tanzania (including Mwanza and Bukoba) reported VWMC for TP of 0.02 to 0.03 mg/L which were comparable to results from Lake Malawi of 0.03 mg/L TP. Langenberg et al. (2003) reported TP values ranging from 0.04 mg/L at Kigoma to 0.1 mg/L near the large city at Bujumbura, both urban locations on Lake Tanganyika. The VWMC's for TP from LVEMP stations range from 0.03 mg/L at Kisumu to 0.23 mg/L at Entebbe higher than previously reported values for Victoria and extending to higher values than have been reported previously in East Africa. Similarly TN VWMC values reported here (0.76-5.7 mg/L, Fig. 3) are higher than reported at Malawi (0.2 mg/L TN). Elevated nitrogen concentrations in rain are often associated with biomass burning and the higher concentrations of TN in the rain around Victoria may be a result of the higher populations around this great African lake compared to the other lakes (Bootsma and Hecky 1993). Higher populations will require more biomass burning for fuel wood and land clearance and maintenance. TP would also be increased because of the production of P-rich ash. However, the difference between the results of Tamatamah (2005) and those presented here would indicate a great degree of inter-annual variability. In part this can result from the distribution of rain events sampled as sampling many smaller events and missing a few large events will also cause the estimate of VWMC's to be higher. More detailed study is required to improve the confidence that can be placed in the concentrations of TN and TP in rainfall.

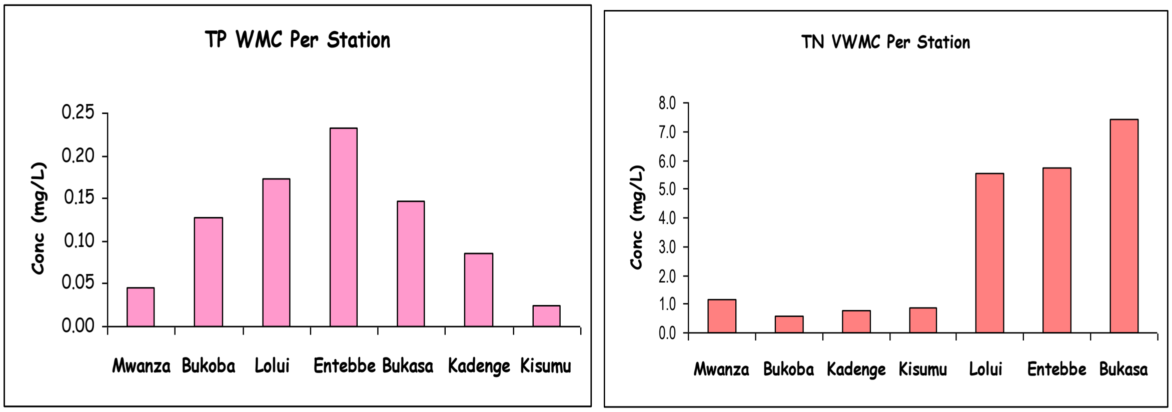

FIG. 5. Annual VWMC of TP (a) and TN (b) from wet atmospheric deposition at all sampled locations.

Dry Deposition

Only two stations, Kisumu and Bukoba, covered a full annual cycle and were used to estimate deposition from dry fall. Based on climatic conditions, the two stations represent the eastern (lower rainfall) and the western (higher rainfall) part of the lake. The mean daily deposition rates at the two stations have been estimated to be 0.26 mg/m^2/day (Kisumu) and 0.54 mg/m^2/day (Bukoba) for TP and for TN 5.45 mg/m^2/day (Kisumu) and 11.3 mg/m^2/day (Bukoba). These estimates were spread over the entire lake to give the estimates at each rainfall box (Chapter 3). The estimates of mean dry deposition rates for TP at Bukoba are somewhat higher than reported by Tamatamah et al. (2005) for Bukoba (0.4 mg/m^2/d). The TP dry deposition rates are also similar to those measured in Malawi, 0.8 mg/m^2/day, while the TN dry deposition rates at Bukoba and Kisumu bracket those in Malawi, mean 7.8 mg/m^2/day (Hecky and Bootsma 1993). Although the rates measured during LVEMP are comparable to those measured in other studies in southern and eastern Africa, two stations are inadequate to give high confidence in the dry deposition estimates. Extrapolation of dry deposition rates to the lake also require estimates of dry days per year and such estimates over the open lake are open to error because of the lack of meteorological observations on the open lake. More studies with greater spatial and temporal resolution are required to evaluate fully not only the loading by dry deposition from the atmosphere but also to determine whether there are regions of high emission either within or outside the Victoria catchment.

Catchment Loads

The terrestrial loads were estimated for all the rivers (Fig. 6) in the basin for three parameters, TN, TP and TSS. A total of 1751 water samples have been collected from all significant catchment rivers during the study period, and the loads calculated as the product of VWMC (Table 2) and annual discharge for each individual river system. The total catchment loadings and yield for TN, TP and TSS are summarized in Table 3.

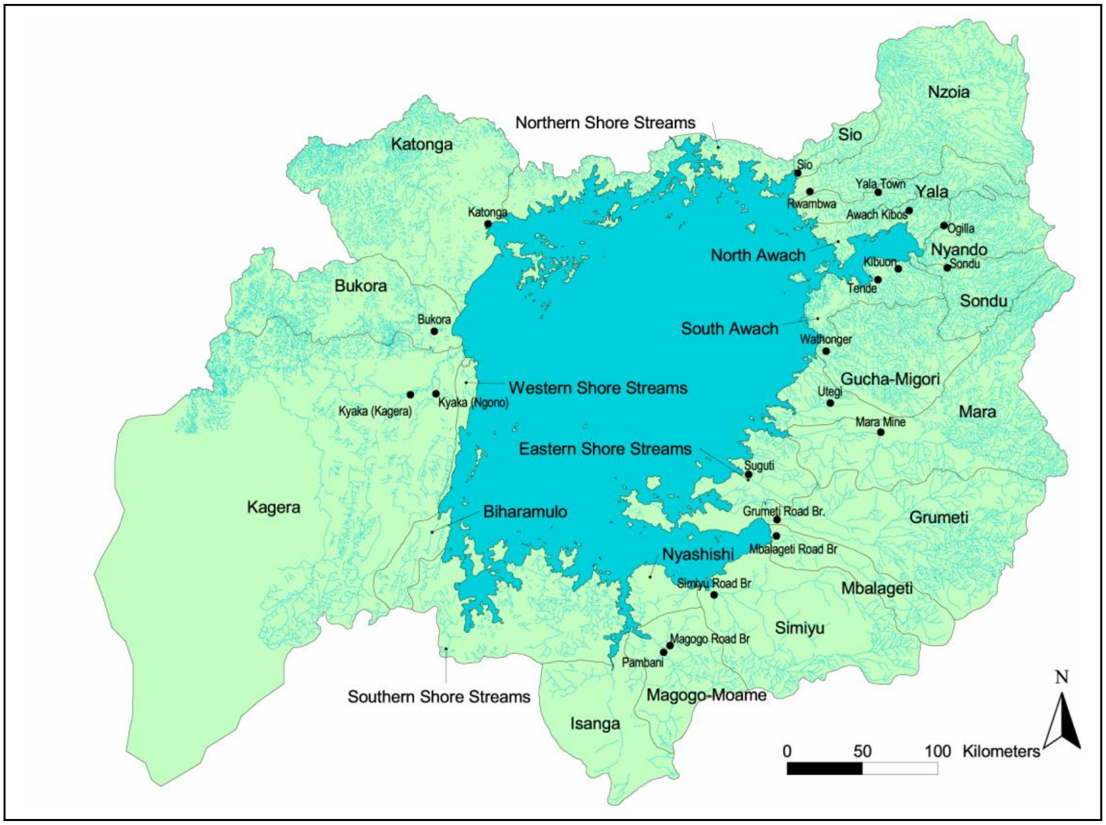

FIG. 6. Distribution of sampling stations in the Lake Victoria Cacthment.

The Nyando River and the Kagera River had the highest TN concentration (Table 3) while the Simiyu and other streams along the eastern coast of Tanzania had the highest TP concentrations. These Tanzanian Rivers also had high VWMC's for TSS. Hecky *et al* (2003) also found a high correlation between TSS and TP as P tends to be bound to particulate matter. Loadings depend not only on the VWMC but also the annual discharge. The Kagera was the largest source of TN and TP followed by the Simiyu. The Simiyu was the largest source of TSS. The Simiyu is highly seasonal (Chapter 3) and is nearly dry in the dry seasons and low annual rainfalls can lead to low loadings while high rainfall can washout accumulated sediments from low flow years. The LVEMP period of observation probably does not capture adequately the possible interannual variability of these rivers, but the semi-arid Tanzanian catchments likely have the highest variability while the Kagera with its large well watered catchment and storage in many wetlands would likely have the lowest interannual variability in flow and loadings of nutrients and sediments. Compared with the preliminary study of LVEMP (2002), it is apparent that the initial study overestimated TN loading to the lake, while underestimating TP loading. The longer period of observation during 2000-2004 has likely increased both the accuracy and the precision of these estimates compared to earlier efforts that relied on fragmentary data or used standard export coefficients derived in other ecosystems to estimate loadings to the lake. The highest loadings of TN and TP are from the Kagera River which also has the largest catchment, and so this large proportion of total loading may be expected. Surprisingly the Simiyu River in Tanzania appears to be the largest contributor of sediments providing as much as the next three largest contributors combined, Kagera, Nzoia and Gucha Migori. This high sediment load of the Simiyu is likely responsible for the high TP load which is second only after the Kagera. Other noteworthy loads of TN and TP come from the Nzoia and the Gucha Migori which are the two largest catchments in Kenya. Ugandan catchments are dominated by wetlands and have very low loads.

TABLE 7. Summary of volume weighted mean concentrations (VWMC's) used to calculate annual loads from total discharge in the rivers over the LVEMP period. (1998-2004).

Rivers	TN	TP	TSS
		mg/L	
Kenya			
Nzoia	1.09	0.12	136.5
Gucha Migori	1.36	0.32	199
Nyando	1.9	0.4	213.9
Yala	1.06	0.09	115.5
Sondu-Miriu	1.22	0.12	94.8
South Awach	1.68	0.18	188.4
North Awach	0.77	0.12	110.6
Sio	0.85	0.13	77.6
Tanzania			
Kagera	1.856	0.253	155.2
Mara	1.251	0.174	223.6
Grumeti	1.251	1.13	437.8
Simiyu	0.125	1.4	437.8
South Shore Streams	0.589	0.222	236.5
Isanga	0.589	0.222	236.5
East Shore Streams	1.251	1.405	437.8
Magogo-Moame	0.589	0.222	236.5
Mbalageti	1.251	1.13	437.8
Biharamulo	1.222	0.242	236.5
Nyashishi	0.588	0.49	236.5
West Shore Streams	1.223	0.242	190.9
Uganda			
Katonga	1.06	0.07	9.1
Bukora	0.76	0.25	129.9

TABLE 3. Catchment Loadings of total nitrogen (TN), total phosphorus (TP) and total suspended solids (TSS) into Lake Victoria by National Rivers.

	Area	**Discharge**	**Mean annual loads**		
River	Km^2	m^3/s	TN t/yr	TP t/yr	TSS t/yr
TANZANIA					
Kagera	59,682	279.4	16,357	2,238	1,281,065
Mara	13,393	41.4	1,646	228	294,186
Grumeti	13,393	12.9	511	464	179,056
Simiyu	11,577	42.9	1,695	1,904	2,075,144
Southern shore streams	8,681	24.6	457	172	183,654
Isanga	6,812	29.7	553	208	222,219
Eastern shore stream	6,644	20.2	797	895	278,891
Magogo	5,207	8.9	166	62	66,688
Mbalageti	3,591	5.2	208	189	73,031
Biharamulo	1,928	18.3	708	140	110,560
Nyashishi	1,565	1.6	318	25	12,383
Western Shore Streams	733	21.3	821	162	128,325
KENYA					
Nzoia	12,842	115.	5,414	844	678,110
Gucha-Migori	6,600	59.1	3,090	842	465,855
Nyando	3,652	18.0	1,615	340	23,144
Yala	3,357	34.9	1,608	136	175,283
Sondu-Miriu	3,508	42.2	1,821	183	145,192
South Awach	3,156	6.0	265	28	29,826
North Awach	1,985	3.8	48	7	6,938
Sio	1,437	11.4	346	53	31,665
UGANDA					
Katonga	15,244	2.3	387	25	3,321
Bukora	8,392	7.0	277	91	47,413.
Total loading into the lake			37,182.0	9,246	6,511,950

Variability in river yields and chemical composition

The river basins have different physiographic characteristics such as altitude, rainfall, basin slope, vegetation cover, soils, and runoff coefficients that impose different yields of nutrients and sediments even under natural conditions. Agricultural use can alter those physical characteristics as well as add nitrogen and phosphorus as fertilizers and accelerate soil erosion. The resulting differences among the catchments in yields and composition of loads can be appreciated from Table 4 which gives the yields per unit area of catchment and the ratios between the TN, TP and TSS yields which normalize the annual loads by the catchment area of the rivers. The Simiyu stands out for its high yield of sediments while the remaining rivers have sediment yields that are comparable to catchments in Malawi that were characterized as lightly to moderately disturbed by agriculture (Hecky et al 2003). The Simiyu and western shore streams of Tanzania had the highest TP yield among the major Victoria catchments. The sediment and TP yields of the Simiyu would place it among the highest disturbed catchments of the Lake Victoria. Simiyu is densely populated in its lower reaches and the flood plain has been occupied for agriculture. Some small streams on the east and west coast of Tanzania draining regions of relatively high population density also had high yields of sediments and TP. The Ugandan rivers and especially the low gradient Katonga River that is choked with papyrus had very low yields of sediments and nutrients. Among the Kenyan rivers the Gucha Migori had highest yields of sediments and TP. The upper catchment of Gucha Migori is hilly, steep, densely populated, with intensive agriculture characterized by simple farming practices; while in the lower reaches the river flows through dry rangelands. The upper catchment of the river is experiencing excessive rates of soil erosion.

The Nyando River in Kenya stands out compositionally for its high yield of TN and TP compared to its sediment yield. This likely reflects the high use of N and P fertilizers within the catchment which is one of the most intensive areas for agriculture in Kenya. The Nyando tributaries arise in the highlands under intensive agriculture that would be expected to have high sediment yields. However, it does have an extensive lowland floodplain that may allow sedimentation of a fraction of its suspended sediment load before it reaches Lake Victoria. The floodplain would not necessarily allow retention of dissolved nutrients and the high ratios of TN and TP to TSS would result at the mouth of the river. The southern Tanzania Rivers starting in the east with the Grumeti and extending up to the Biharamulo catchment have exceptionally low N: P ratios due primarily to low N yields and not exceptionally high TP yields. This area of Tanzania is semi-arid and is characterized by grasslands, open savannas and limited woodlands and extensive animal husbandry. Savanna burning may reduce nitrogen yields by volatilizing nitrogen compounds to the atmosphere. In contrast the total P loads from Tanzanian rivers that include the internationally shared Kagera River, in aggregate provide a total of nearly 6700 tons of TP or nearly approximately 70% of the total riverine load to Victoria. Kenya riverine loads, in contrast, are nitrogen rich. Kenyan catchments arise at higher altitudes that receive more rainfall and have more forests and woodlands in their upper catchments. The higher N loads are likely a result of higher organic productivity in Kenya catchments and their TN: TP ratios are more similar to relatively well forested Malawian catchments (Hecky et al. 2003). Ugandan riverine loads are small in magnitude. Despite being the second largest sub-catchment in the Victoria basin after the Kagera, the Katonga has yields of TN, TP and TSS among the lowest in the basin. The low gradient of the river and the extensive cover of papyrus along and over the river retain the sediments and nutrients delivered to it. The high TN: TSS and TP: TSS in the Katonga illustrate that most of the nutrients yielded from the catchment are in the dissolved phase. The river has a remarkably high TN: TP ratio that may be imposed by the lush and extensive growth of papyrus. Bukora also has several small lakes and wetlands within its catchment that also reduce yields of nutrients and sediments despite relatively high populations and intensive agriculture in the catchment.

TABLE 4. Summary of yields of sediments (TSS), TN and TP and ratios of TN to TP and the nutrients to sediment yields for the national rivers.

River	Area	Discharge	TSS	TN	TP	TN:TSS	TP:TSS	TN:TP
	km^2	M^3/s	t/km^2/y	kg/km^2/y	kg/km^2/y	Kg/ton	kg/ton	w/w
Tanzania								
Kagera	59682	279.5	21.5	274	38	12.8	1.8	7.2
Mara	13393	41.7	22.0	123	17	5.6	0.8	7.2
Grumeti	13363	13.0	13.4	38	35	2.8	2.6	1.1
Simiyu	11577	43.0	179.2	146	164	0.8	0.9	0.9
South Shore Streams	8681	24.6	21.2	53	20	2.5	0.9	2.7
Isanga	6812	29.8	32.6	81	31	2.5	1.0	2.6
East Shore Streams	6644	20.2	42.0	120	135	2.9	3.2	0.9
Magogo-Moame	5207	8.9	12.8	32	12	2.5	0.9	2.7
Mbalageti	3591	5.3	20.3	58	53	2.9	2.6	1.1
Biharamulo	1928	18.4	57.3	367	73	6.4	1.3	5.0
Nyashishi	1565	1.7	7.9	20	16	2.5	2.0	1.3
West Shore Streams	733	21.3	175.1	1121	222	6.4	1.3	5.0
Kenya								
Nzoia	12842	115.3	52.8	422	66	8.0	1.2	6.4
Gucha Migori	6600	59.1	70.6	468	128	6.6	1.8	3.7
Nyando	3652	18.0	6.3	442	93	69.8	14.7	4.8
Yala	3357	35.0	52.2	479	41	9.2	0.8	11.8
Sondu-Miriu	3508	42.2	41.4	519	52	12.5	1.3	9.9
South Awach	3156	6.0	9.5	140	14	14.8	1.5	10.1
North Awach	1985	3.8	3.5	24	4	7.0	1.1	6.4
Sio	1437	11.4	22.0	241	37	11.0	1.7	6.5
Uganda								
Katonga	15244	2.3	0.2	28	2	127.6	8.3	15.4
Bukora	8392	7.0	5.6	41	13	7.3	2.3	3.2

Estimation of Total Non-Point Loads

The estimates of total loads of nitrogen and phosphorus and suspended sediments from the catchments and atmospheric deposition are summarized in Table 5 below. The atmospheric loads dominate, but these estimates are based on relatively few site observations especially for dry deposition where only two stations have been extrapolated. The estimates for total atmospheric deposition of total P in Table 5 are nearly three times higher than estimates made by Tamatamah et al. (2005) in 1999-2000, and the rates are more than twice as high as measured by Bootsma and Hecky (1999) on Lake Malawi. The TN loading rates (2.4 tons/km^2/y) of lake surface are more similar to the atmospheric loading rates of 2.0 kg/km^2/y reported by Bootsma and Hecky (1999) on Lake Malawi, and they are comparable to rates of N deposition experienced in some industrialized regions of the world. The estimates of atmospheric deposition of TP in Table 5 are remarkably high and yield much lower N: P ratios than observed in Malawi. Too little is known about inter-annual variability of atmospheric deposition of nutrients to determine if the TP loading rates of Tamatamah et al. (2005) or those in Table 5 are more representative of atmospheric deposition over Lake Victoria. Even if the lower rates of Tamatamah et al (2005) were assumed, atmospheric deposition of P would still account for 60% of the reduced total annual loading of TP which would be 22,700 tons. So, atmospheric deposition would remain the dominant non-point source of TP to the lake. The atmospheric deposition rates for P reported for Lake Victoria are 10 to 20 times those observed in agricultural and industrial areas in temperate countries, and it is likely that differences in land management practices (especially prevalence of open biomass burning) as well as climatic differences determine these higher rates.

TABLE 5. Estimates of total N, P and Suspended Sediment loads from the catchment and atmosphere.

PARAMETER	CATCHMENT ((tons/Year)	ATMOSPHERIC (tons/Year)	TOTAL LOAD (tons/Year)	PERCENTAGES	
				ATM.	CATCH.
TP	9,247	39,978	49,225	81.2	18.8
TN	38,828	167,650	206,478	81.2	18.8
TSS	6,511,950	-	6,511,950	-	-

TABLE 6. Relative Magnitude of Loading Sources to Lake Victoria.

Pollution Source	**TN (tons/year)**	**%TN**	**TP (tons/year)**	**%TP**
Atmospheric Deposition	167,600	17	39,978	79
Rivers	38,800	4	9,247	18
Biological N-fixation	757,000	78		
Point	4,300	1	1,690	3
TOTAL	967,700	100	50,915	100

Biological Nitrogen Fixation

An additional source of nitrogen loading to Lake Victoria is biological nitrogen fixation by the Cyanobacteria that now are the dominant phytoplankton. The N-fixing Cyanobacteria have risen to prominence because the high concentrations of phosphorus and hypoxic/anoxic deep water have created a nitrogen deficit in the phytoplankton (Chapter 6). The N fixing Cyanobacteria overcome this N deficit by fixing their nitrogen requirements. Mugidde et al. (2003) have measured light dependent biological N fixation in Lake Victoria, and current rates are light limited due to self shading by algal biomass. Annual biological N fixation rates range from 0.6 g N/m^2/y in deeply mixed offshore stations in the central lake to 14 g N/m^2/y in shallower inshore areas, less than 20 m depth, with a mean annual rate for the whole lake estimated to be 11 g N/m^2/y. For the whole lake, biological N fixation can provide an estimated 757,000 tons (Table 6). Nitrogen fixation therefore accounts for nearly 80% of the annual loading of nitrogen to Lake Victoria, and this nitrogen fixation is driven by the availability of excess soluble reactive phosphorus and the elevated phosphorus loading rates.

Total Nutrient Loadings

The total phosphorus loading is dominated by direct atmospheric deposition on the lake surface with atmospheric loading of P accounting for 60 to 80% of total annual P loading depending on whether the low or high estimates of atmospheric P loading are used. Nitrogen loading is dominated by biological N fixation with atmospheric loading of N being the second most important source. Municipal and industrial loadings only account for a small portion of the total annual loading of N or P. However, these localized point sources, in the immediate vicinity of coastal urban areas and settlements and the associated biological pollution represented by faecal coliforms and potential pathogens, create unacceptable health risks and intense algal blooms when they are released into confined embayments such as Kisumu Bay or Inner Murchison Bay. Therefore these point sources have first priority for reduction. Similarly, the loads from the catchment, entering at river mouths, can also have severe local impact local gulfs, bays and some near-shore areas. For the expansive open lake however the atmosphere sources dominates the nutrient loading for both N and P. The high N loading rates are dependent on biological N fixation that is driven by the excess availability of P. To reduce the P loading to Lake Victoria back to natural rates, it will be necessary to reduce atmospheric P deposition and catchment P loading. Because point source loadings are a small fraction of loading at the whole lake scale, efforts to improve land management will be necessary to reduce the non-point sources and thereby whole lake loadings.

CONCLUSION

The current non-point loadings whether from the atmosphere or rivers represent major losses of soils and nutrients from the agro-ecosystems and are symptomatic of degrading soil fertility in the catchment. The trend is unsustainable without nutrient replenishment in agricultural lands, and fertilizer supplements will aggravate nutrient loading if soil erosion remains uncontrolled. There is an urgent need to modify land use practices to enhance nutrient and soil retention on the land. Atmospheric deposition dominates the non-point loadings with some of the highest rates of deposition known globally. Biomass burning is currently an integral part of agricultural practice as it is used to clear land, release nutrients from crop debris and grasslands, control pests as well as serving manifold domestic uses for heating and cooking. Although not widely appreciated as vector for nutrient loss, biomass burning does mobilize nutrients into the atmosphere and has likely been a major source of increased nutrient loading to Lake Victoria. Improved land management will be necessary to reduce the current loadings, but it will also preserve soil fertility by retaining nutrient on the land.

RECOMMENDATIONS

Aggressive action and investment is required to eliminate the public health risks and local eutrophication caused by point sources. This is the highest priority to restore beneficial uses of Lake Victoria for urban populations and rural coastal settlements including fishing villages.

Best land management practices should be implemented to control soil erosion, improve soil quality and reduce soil and nutrients losses to rivers, atmosphere and eventually the lake. Benefits will accrue to the farmers and agricultural productivity as well as to lake and river water quality, but benefits to the lake in reducing eutrophication will take longer to achieve than addressing point sources.

Some catchments such as the Nyando, Gucha Migori and Simiyu should be targets for remedial action as they stand out from other rivers in their yields of nutrients and sediments.

The Kagera as the largest river and largest single catchment nutrient source in the basin can have the largest effects on the lake of all the rivers. Catchment degradation is certainly affecting the river but extensive wetlands in Rwanda may still be buffering the effects as its yields and composition are not exceptional among the basin’s rivers. However, given the magnitude of flows and current loads in this large catchment, its maintenance should be a high priority and a focus of regional and international action.

A regional atmospheric deposition network with more stations and standardized methodologies is necessary to improve loading estimates for the lake. These deposition studies should include a broader range of analyses so that sources for the measured deposition can be identified. Until such information is available it is impossible to determine where the major source regions are for this deposition and what processes (e.g. savanna burning, tropical forest burning, urban domestic burning) are mobilizing the nutrients into the atmosphere.

SEDIMENTATION IN LAKE VICTORIA

Sedimentation is the settling of particulate matter through the water and its accumulation on the bottom of the lake. Because of currents and associated turbulence especially during annual destratification and mixing, sediments that settle to the bottom can be resuspended and resettled several times before arriving at a depth below which turbulence is too weak to affect resuspension. When sediments can no longer be resuspended, they accumulate at those deeper locations and become permanently buried. Consequently although sediments are settling from the water all over the lake and generally in proportion to the abundance of particulate matter in the water, areas of permanent burial are restricted to the deeper parts of the basin. Nutrients taken up by biological processes will settle as part of the biogenic detritus, but these nutrients which are associated with biogenic sediments can also be remineralized back into solution if consumed and digested by organisms or can be released by microbial action. This regeneration from particulate form back into solution is referred to as internal nutrient loading. Internal loading can be estimated by comparing the settling rates of particulate nutrients with the rate of permanent burial. The difference between the downward settling flux of nutrients and their permanent burial rate on the whole lake provides an estimate of the internal loading of the nutrients. Some nutrients can be regenerated as a gas, for example, organic carbon can be metabolized to carbon dioxide or methane gas and lost from the system. Nitrogen compounds can also be reduced to nitrogen gas. Regeneration, therefore, does not necessarily mean that nutrients become bioavailable and contribute to internal loading. However, elements such as phosphorus and silicon do not have gaseous phases in the biogeochemical cycle and estimates of their internal loading are more direct.

Nutrients once loaded into the lake can only leave by three pathways; 1) sedimentation, 2) loss at the outflow, 3) as a gas back to the atmosphere. For elements that do not have a gaseous phase, the balance between external loading and the outputs through outflow and permanent burial should balance, unless the concentration of the nutrient in the lake is increasing or decreasing as a response to an imbalance between gains and losses. Therefore, estimation of loss to sediment, loss to outflow or change in amount in the lake can provide an independent check on the external nutrient loading estimates by examining the balance of inputs and outputs. Sufficient information has been generated through LVEMP studies and collaborative research with international investigators to attempt a full nutrient budget for phosphorus for the first time for Lake Victoria. A key component in that nutrient budget is sedimentation.

Methods

Duplicate sediment traps with diameters from 4.5 cm to 8.4 cm and an aspect ratio >5 were mounted on an anchored rope kept vertical with a subsurface buoy and connected to a marking buoy. Three sets of traps were placed at each station:

- At the end of the photic zone (2.3 x secchi depth)
- 2 m above the sediment
- One set in between the two.

After 1 - 2 days of exposure the traps were retrieved and the trapped particles were sub sampled and collected on GF-C glass fibre filters (pore size 1 µm) to be analyzed for filterable total suspended solids (TSS), particulate phosphorus (P), particulate (N) and particulate carbon (C), and also collected on Nucleopore membrane filter (pore size 0.45 µm) to be analyzed for biogenic silicon (PBSi) that is produced primarily by diatoms, an algal group that produces a silica shell. The settling fluxes can then be calculated in mg/m^2/d based on the trap area and exposure time.

Two undisturbed sediment cores (5 - 10 cm diameter, 20-30 cm length) taken by a gravity corer or sub sampled from a dredge were sectioned into depth slices for analysis. These slices of the cores from known depths were taken for age determination by radiometric dating as well as to estimate sediment accumulation rates. These cores have been analyzed for total phosphorus, total carbon, total nitrogen, biogenic silicon and for microfossil contents.

RESULTS AND DISCUSSION

Sedimentation Rates

Estimates of settling flux of carbon, nitrogen, phosphorus and biogenic silicon were made at pelagic and littoral water quality monitoring stations (Chapter 5). There were 27 pelagic stations in Lake Victoria (10 in Uganda, 14 in Tanzania and 3 in Kenya). However, the actual deployments and retrieval of sediment traps at these stations were much less than what had been planned due to a number of reasons including loss of sediment traps due to vandalism. Hence the total number of total successful deployments was 235. Sedimentation traps were deployed at a total of 29 littoral stations in

Lake Victoria (9 in Uganda, 14 in Tanzania and 6 in Kenya) where sediment traps were deployed. The total number of successful deployments was 301 at littoral stations. Sediment flux values were calculated for each country for both pelagic and littoral stations. The results are presented in tables 7 and 8.

TABLE 7. Littoral Stations - Mean areal rates of sedimentation from the water column at all stations sampled in each country. Total particulate P (TPP), total particulate N (TPN, not done for Tanzanian samples), total biogenic Si (TBSi) and total particulate C (TPC).

Country	Sediment rates (mg/m^2/d)			
	TPP	TPN	TBSi	TPC
Kenya	5.0	61.3	465.1	4966
Tanzania	6.8	-	20.0	422
Uganda	5.9	78.6	20.2	777

TABLE 8. Pelagic Stations - Mean areal rates of sedimentation from the water column at all stations sampled in each country.

Country	Sedimentation rates (mg/m^2/d)			
	TPP	TPN	TBSi	TPC
Kenya	2.2	60.7	381.1	1495
Tanzania	3.6	-	7.9	295
Uganda	1.4	41.0	7.4	284

The results for the littoral stations from the three countries are similar for TPP and TPN. However for TBSi and TPC, the values from Kenya are significantly higher than the other two countries. The Kenya littoral samples are from Winam Gulf with one station off the Yala River. Shallow Winam Gulf is affected by resuspension that may affect detrital carbon and diatom frustules more than TPC and TPN which may be efficiently regenerated into dissolved forms of the nutrients. The higher rate of TBSi and TPC sedimentation may also demonstrate the strong influence of the many inflowing rivers on the suspended material in Winam Gulf. The mean sedimentation rates for littoral and pelagic areas are quite comparable for Uganda and Tanzania which sample most of open Lake Victoria's area. The sedimentation rates for TPP and TPC are higher for littoral areas than pelagic areas. This reflects the higher productivity and higher algal biomasses in the littoral areas (Chapters 5 and 6).

Elemental Composition

On average the settling materials had relatively high TPC: TP and TPN: TPP ratios indicating that organic matter dominated at both littoral and pelagic stations (Table 10). There were substantial differences among the settling material in Kenya waters and those of the other two countries. Winam Gulf dominates the littoral samples in Kenya and it is relatively rich in TBSi and TPC compared to TPP (Table 10). Settling materials from Tanzania and Uganda littoral areas are more similar with the southern littoral areas in Tanzania having lower TPC: TPP ratios indicating relative enrichment in phosphorus. The TBSi:TPP ratios demonstrate that the settling material is poor in particulate Si in both Ugandan and Tanzanian littoral waters.

Pelagic stations are deeper, and the collected material has to settle through a longer water column that can allow biological processing to have more time for nutrient regeneration in the deep waters (Table 9). Pelagic settling material off Kenya remains enriched in C and Si relative to P suggesting that Winam Gulf affects the compositional ratios at these deep KP (Kenya Pelagic) stations that are all relatively close to Winam Gulf's Rusinga Channel, the outlet from the Gulf. However the TPN: TPP ratios of settling materials in Kenyan and in Ugandan pelagic waters are similar as are the water depths at these pelagic stations. The higher TPN: TPP ratios at these pelagic stations compared to littoral samples are the result of preferential regeneration of P from the settling materials during the longer descent to the deeper pelagic traps. The pelagic samples have similarly low TBSi:TPP ratios as the littoral samples from Uganda and Tanzania and indicate Si impoverishment is lake-wide outside of marginal embayments such as Winam Gulf. Silicon depletion has occurred over the past several decades (see Chapters 5 and 6) as a result of nutrient enrichment in TN and TP. The low TBSi:TPP ratios of the open lake littoral and pelagic stations compared to those in Winam Gulf are a result of that Si depletion. Winam Gulf has not had the same depletion in dissolved Si as the open lake stations (Chatper 6) and concentrations are unchanged since earlier times.

TABLE 9 Littoral and Pelagic Stations – Composition ratios of settling materials based on weight/weight comparisons of mean sedimentation rates. Nitrogen not done on Tanzanian samples.

Country	**Littoral**			**Pelagic**		
	TPN:TPP	TPC:TPP	TBSi:TPP	TPN:TPP	TPC:TPP	TBSi:TPP
Kenya	12.1	993	93	29	680	173.0
Tanzania	-	62	3	-	82	2
Uganda	13.3	132	3	29	202	5

Annual Rate of Permanent Burial and Internal Loading

Sediment accumulation values for the entire lake were generalized from several sediment cores from various locations in Ugandan waters including inshore stations and from the deepest part of the lake. The cores dated, and analyzed, show dry weight accumulation rates that range from 100 g m^{-2} y^{-1} to 300 g m^{-2} y^{-1}. In terms of linear rates these are comparable to rates of about 0.5 to 1 mm per year. These rates are comparable to those observed in other great lakes (Kalff 2002); therefore, infilling of

Lake Victoria through sedimentation is not a concern except in the vicinity of deltas where deposition of coarser materials may be accelerating as more sediment is delivered by rivers than occurred historically. The calculation of permanent sediment burial of nutrients as estimated from cores and the area of accumulation of fine sediments is summarized in the Uganda National Water Quality Synthesis Report, and the results given in Table 10 for C, N, P and Si burial rates. The average littoral sedimentation rates from all traps were applied to the total littoral area of the lake (<20m), and the pelagic rates were applied over the area of pelagic deposition (>20 m) in Table 10. The downward flux of settling material, as kilotons/year, exceeds the rate of permanent burial for all the elements except Si. The difference between the downward flux and the rate of burial indicates that there is regeneration from the sedimentation flux, and this difference is an estimate of internal loading to Lake Victoria. Nearly 90% of sedimenting carbon and nitrogen are regenerated and much of this may be lost as gaseous carbon dioxide and nitrogen gas through the microbial processing. About 70% of sedimenting phosphorus is returned to the water column and adds to the water column concentrations as this element does not have a gaseous phase. Silicon is calculated to have a deficit in that the apparent rate of burial exceeds the current sedimentation rate. This is an artifact of the methodology as the burial rate is actually calculated over several years of sediment formation. This negative result indicates that past rates of burial of Si were higher than current rates of burial and sedimentation. This imbalance occurs because the large store of dissolved Si in the lake in the 1960's has been drawn down and deposited in the sediments as often happens during eutrophication of lakes (Chapter 6; Barbiero et al. 2002). Current rates of Si burial are limited to the amount of new dissolved Si entering the lake each year.

Nutrient balance of Lake Victoria

Phosphorus added by atmospheric deposition and rivers should be approximately equal to the amounts being lost to permanent burial, loss at the Nile outflow with any imbalance between those inputs and outputs resulting in a change in concentration. The current knowledge of these fluxes is given in Table 11. There is a positive balance calculated for both N and P. This means our best current estimates of inputs are greater than the known outputs. This is not surprising for nitrogen because a major loss through denitrification has not been included as it is currently unmeasured. The apparent positive balance for nitrogen is in fact an estimate for loss of nitrogen by denitrification. This large loss of nitrogen needs to be confirmed through direct measurement. The phosphorus budget is also out of balance with more inputs than outputs. Because all losses and inputs have been measured the imbalance can only be explained by a significant error in one or all the input or output terms. Because of the size of the imbalance the only single term that could account for the error is the estimate of atmospheric deposition. As noted above this input term was identified to have the most uncertainty because of the few stations contributing to the estimate. If the value of Tamatamah et al (2005) for atmospheric input were used then the imbalance in the P budget would be reduced to -5,000 tons of P from the estimate of 20,750 tons in Table 12. This would be a significant improvement and an exceptionally good balance for such a large lake. It would seem that the current estimate of atmospheric deposition based on the LVEMP measurement is likely too high but even reducing the atmospheric deposition estimate to that of Tamatamah et al. (2005) would still leave atmospheric deposition accounting for 60% of the total inputs of phosphorus.

TABLE 10. Comparison of total annual sedimentation in traps with permanent burial of the nutrients for all of Lake Victoria (excepting Winam Gulf).

	Area	C	N	P	Si
	km^2	kilotons/year			
Littoral Zone <20m	16910	3703	431	36	123
Pelagic Zone >20 m	48800	5173	908	44	133
Total sedimentation	65710	8876	1339	80	256
Permanent Burial >40m	36400	1249	107	24	1036
Internal Loading		7627	1232	55	-780
Per cent return		86	92	69	-305

TABLE 11. Nutrient balance for Lake Victoria. The annual increase in Lake TN is estimated using a TN: TP ratio for the current lake and assuming it applied in 1960.

	TN (t/y)	TP (t/y)
External loading (Table 7.6)	967,700	50,920
Annual Increase in Lake (1960-2000)	30,360	2,760
Permanent Burial	107,000	24,000
Outflow through Nile	56,200	3,410
Balance	774,140	20,750

Long Term Trends

Significant eutrophication effects were detectable as early as the 1940’s based on microfossil analysis of sediment cores (Verschuren et al. 2002). However, the phosphorus content of sediments and the increased deposition of Si began in the 1950’s based on dated cores. Since then the P content of all cores that have been studied has been rising. Mugidde *et al* (Uganda National Water Quality Synthesis Report) also notes that between the early 1990’s and early 2000’s, TP concentrations have continued to rise. In fact the rate of increase in TP in lake water has apparently remained steady at approximately 0.001 mg/L since 1960. This steady increase has been recorded in the sediment cores. The loading rates are still increasing and continued degradation and intensified algal blooms and anoxia can be expected into the future unless actions are taken to reduce the loading rates. If the period from 1900 to 1950 is taken to be a baseline of near natural loading rates prior to increasing in the 1950’s up until the present, then the loading rates recorded in the sediments have raised concentrations of P from 125 mg/g to 200 mg/g in sediment core, an increase of 60%, and the difference can be considered due to human impacts mobilizing P from the catchments.

Natural loading of P is only 60% of the current load and at least 40% is anthropogenic i.e. human-activity induced additional loading. If this increase is applied to current estimates of loading rates then the current anthropogenic load is between 9,000 to 20,000 tons of P depending on whether a high or low estimate is accepted for atmospheric deposition. This estimate assumes that external loading has remained proportional to burial over the period of record. The anthropogenic load would have to be reduced to stop the increasing eutrophication of the lake or to restore Lake Victoria to its natural P loading rates. Point sources, which are clearly anthropogenic (Table 6), account for 10% to 25% of the anthropogenic load and could be readily reduced through investment in modern technologies. If the P loads of the Simiyu and Gucha Migori were reduced to yields similar to their neighboring rivers (Table 4) and all river loads were reduced by 10%, then a further 30 to 15% reduction in anthropgenic loading would be accomplished. However, the greatest scope for reduction may be in reducing atmospheric loads. Accomplishing this reduction may require broader regional action beyond the riparian states, and it would best be targeted after more strategic studies of emission sources for the atmospheric P load were known. The lake itself now has a sizeable reservoir of P that has built up over the last six decades. The current residence time of TP, i.e. the total mass of TP in the lake divided by the rate of input or removal, is on the order of 5-10 years because of the relatively high internal loading so the recovery period for the lake to adjust to a new loading regime will be on the order of 15-20 years depending on how aggressively actions are taken. The lake is deficient in nitrogen and that allows the N-fixing algal species to have a competitive advantage over other algae (Chapter 6). Consequently, nitrogen loading is also dominated by biological fixation of nitrogen (Table 6). Any attempts to try to reduce algal biomasses by controlling nitrogen loadings from the catchment or by atmospheric deposition will be futile. Nitrogen removal would only increase the N deficiency in the system and would be compensated by biological N fixation.

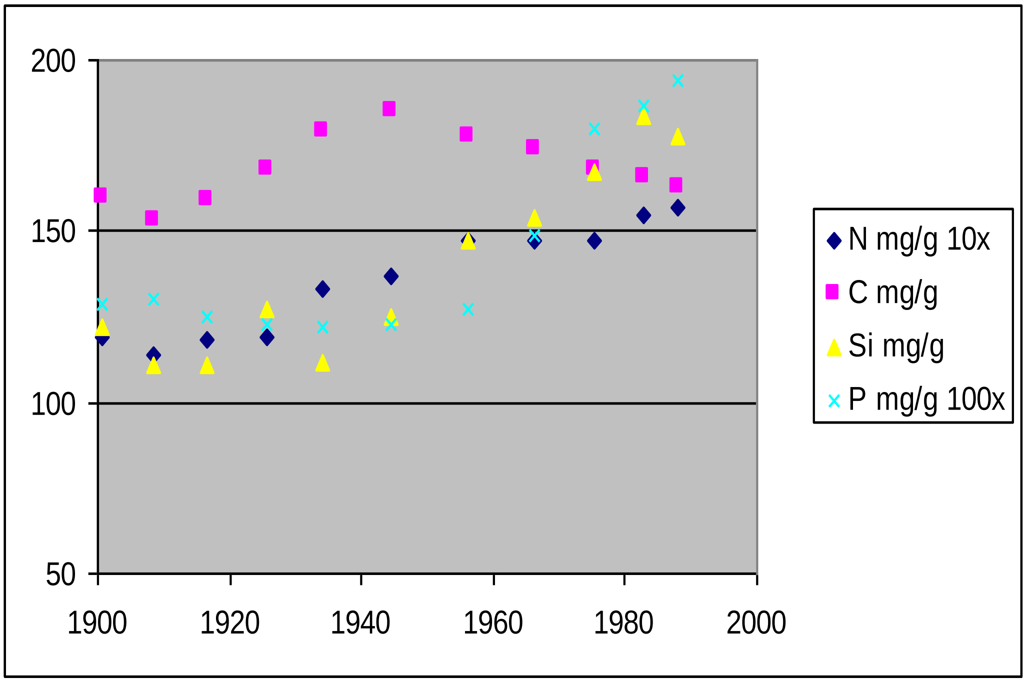

FIG. 7. Trends in C, N, P and biogenic Si as recorded between 1900 and 1990 A.D. in dated sediment core 103 from the northwest sector (Kenya) in 56 m depth (Hecky 1993). Note N and P concentrations have been multiplied by a factor to allow all parameters to be plotted together as mg/g.

CONCLUSION

The anthropogenic loads of nitrogen, phosphorus and other pollutants began to increase during the last century and by 1950 loading rates of these materials were well above natural baseline and continuing to increase. These increases in nutrient loading rates and now especially P have led to the eutrophication of the lake and further degradation of the lake's water quality will occur unless the loading rate for P is stabilized or reduced. The loads requiring most immediate attention for remedial action are the municipal and industrial loads that are clearly anthropogenic in origin. This point source loading is likely the most rapidly growing component of total loading as populations within the basin continue inward migration to urban centers and towns. The fishing villages have also grown rapidly in recent decades because of the growth of the fishery, but these villages have little or no facility to handle the increased human wastes that is deposited directly to Lake Victoria. These point sources account for 10-25% of the anthropogenic increase in loading. Addressing these point sources can have a significant effect on the eutrophication of the lake especially in the immediate vicinity of the sources and there will be substantial public health benefits in reducing morbidity and mortality from waterborne diseases. Further reduction in the anthropogenic load will require improved land management in the catchments and especially in a few catchments that currently are showing exceptional yields of sediments and nutrients because of agricultural activities within the catchments. Even a 10% reduction in loading from all rivers if combined with special efforts on the most disturbed catchments could affect a further 15-30% in the anthropogenic loads. Certainly land management practices must improve or continued catchment degradation will impoverish farmers as well as continue to overload the lake with phosphorus. In particular the large catchments such as the Kagera that dominates water inflows and annual loads among rivers cannot be allowed to continue to degrade. The largest source of nutrients to the lake is atmospheric deposition. This non-point is still poorly known both in magnitude and in the geographic distribution of emissions to the atmosphere that causes the high deposition rates. These atmospheric deposition rates of phosphorus are 10 times higher than in agricultural areas in temperate latitudes and there is substantial scope to reduce such emission through improved land management.

RECOMMENDATIONS

- The riparian states of Lake Victoria in collaboration with other basin countries through the EAC commit to stabilize or reduce the current nutrient loading to Lake Victoria.
- The riparian states with all stakeholders should set targets for nutrient reduction and develop a strategic action plan that would accomplish those targets.
- The riparian states should invest in addressing all significant point sources through implementation of primary, secondary and tertiary treatment of all sewage from all major urban centers and at least secondary treatment (including use of wetlands) for all towns and villages. Investments should be prioritized based not only on potential for nutrient reduction but also for the public health benefits that may accrue. Cleaner production technology and enforcement of national standards for waste water must be promoted and enforced with standardization across the East African Communities (EAC).
- The riparian states should commit to a continued and enhanced program of monitoring nutrient loading in order to reduce uncertainty around the loading estimates and especially atmospheric

loading. Monitoring will be necessary to evaluate progress toward agreed upon targets or documenting further degradation requiring specific action plans for catchments. Agricultural practices to reduce loss of valuable nutrients and soils from farms and plantations. Increased use of fertilizer and irrigation can contribute to improved farm productivity that will reduce the need to bring new and marginal lands into agriculture. Current use of agrochemicals is low in the basin and can expand, but only if soil erosion remains in check or is reduced in order to maintain soil fertility.

- Alternatives to open burning practices should be sought and encouraged as part of a regional program to improve land management and reduce nutrient losses from agricultural lands.
- The riparian states should continue and strengthen efforts to improve land management and programs to increase soil fertility and agricultural production in current agricultural lands in order to reduce pressure to expand onto marginal lands

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APPENDIX I. *Municipal pollution Loads 2005-HOT SPOTS.*

Catchment area	Urban Centre	Population	Resulting load (kg/day)		
		(Year 2005)	BOD_5	Total-N	Total-P
Nyashishi	Mwanza	446,623	5,359	1,005	402
Southern Shore Streams	Geita	45,798	412	69	27
Southern Shore Streams	Sengerema	43,222	389	65	26
Eastern Shore Streams	Nansio	31,880	287	48	19
Eastern shore streams	Musoma	117,943	1,061	177	71
Grumeti	Bunda	45,449	341	57	23
Eastern Shore Streams	Tarime	40,632	366	61	24
Western Shore streams	Bukoba	66,544	499	83	33
Gucha-Migori	Kisii	73,372	137	42	18
Gucha-Migori	Migori	64,637	471	114	42
Gucha-Migori	Ogembo	47,353	256	71	28
Gucha-Migori	Kehancha	165,654	895	248	99
Gucha-Migori	Nyamira	109,458	591	164	66
Gucha-Migori	Awendo	98,599	666	148	59
Gucha-Migori	Rongo	87,275	589	131	52
Gucha-Migori	Nyamarambe	72,820	393	109	44
North Awach	Kisumu	475,714	2,749	521	158
Nzoia	Eldoret	252,001	337	137	42
Nzoia	Kitale	100,063	46	34	14
Nzoia	Mumias	112,410	879	279	83
Nzoia	Kimilili	78,157	422	117	47
Sondu	Kericho	23,185	650	194	68
Sondu	Bomet	92,144	373	138	55
South Awach	Homa-Bay	66,525	358	93	44
South-Awach	Oyugis	72,067	486	108	43
South-Awach	Mbita	41,727	376	63	25
Yala	Kakamega	87,082	311	89	35
Yala	Siaya	45,003	365	14	5
Yala	Yala	43,882	355	66	26
Yala	Vihiga	119,767	970	180	72

Catchment area	Urban Centre	Population	Resulting load (kg/day)		
		(Year 2005)	BOD_5	Total-N	Total-P
Yala	Nandi Hills	84,776	458	127	51
Yala	Luanda	72,499	587	109	43
Northern Shore streams	Entebbe	102,400	1,982	364	309
Northern Shore streams	Jinja	119,258	776	191	162
Northern Shore streams	Kampala	843,817	9,153	2,253	1,678
Katonga	Masaka	124,537	2,042	64	31

APPENDIX 2. Municipal Pollution Loads-by Catchments.

Catchment area	Population/persons			
	(Year 2005)	BOD_5	Total-N	Total-P
Nyashishi	480,411	5,731	1,072	429
Simiyu	19,852	179	30	12
Magogo	28,604	257	43	17
Eastern Shore Streams	216,976	1,953	325	130
Grumeti	61,948	558	93	37
Southern Shore Streams	151,149	1,259	197	80
Western Shore Streams	64,294	482	80	32
Biharamulo	10,782	81	13	5
Gucha-Migori	883,282	4,852	1,274	507
North Awach	475,714	2,749	521	158
Nyando	133,933	769	161	60
Nzoia	891,110	3,092	920	326
Sio	78,630	497	104	39
Sondu	115,329	1,023	332	123
South-Awach	204,433	1,437	300	127
Yala	584,400	3,615	712	284
Northern Shore Streams	1,125,215	41,276	5,160	2,580
Katonga	137,032	5,460	682	341
Bukora	89,425	3,577	447	224

APPENDIX 3. Industrial Pollution Loads- Individual Industries.

Sub-Catchment	Name of Industry	Industrial Category	Resulting load (kg/day)		
			BOD	Total-N	Total-P
Eastern Shore Streams	Mara Fish Packers (T) Limited	Fish Processing	52	0.95	0.45
Eastern Shore Streams	Prime Catch Limited.	Fish Processing	29	2	0.53
Eastern Shore Streams	Musoma Abattoir	Abattoir	15	3.3	1.3
Eastern Shore Streams	Musoma Bottlers	Soft Drinks	12	0.18	0.30
Eastern Shore Streams	New Musoma Textile Limited (MUTEX)	Textile	270	54	36
Eastern Shore Streams	Musoma Fish Processors	Fish Processing	103	16	2
Eastern Shore Streams	Mara Coffee Limited	Coffee Processing	4.3	0.10	0.39
Grumeti	Bunda Oil Industries Ltd.	Vegetable Oil Refining	408	10	5
Nyashishi	Vegetable Oil Industries Limited (VOIL)	Vegetable Oil Refining	240	9	6
Nyashishi	VIC FISH Limited	Fish Processing	155	32	5
Nyashishi	Tanzania Fish Processors	Fish Processing	163	23	5
Nyashishi	Tanzania Breweries Limited (TBL)	Breweries	102	19	5
Nyashishi	Tan Perch Limited	Fish Processing	136	4	23
Nyashishi	Omega Fish Limited	Fish Processing	209	33	6
Nyashishi	Nile Perch	Fish Processing	369	78	6
Nyashishi	Mwanza Fishing Industries	Fish Processing	133	24	3

Sub-Catchment	Name of Industry	Industrial Category	Resulting load (kg/day)		
			BOD	Total-N	Total-P
Nyashishi	Mwanza Fish Meal	Fish Processing	116	3	3
Nyashishi	Birchand Oil Mill Limited	Vegetable Oil Refining	670	48.76	1.57
Simiyu	Chain Food International	Fish Processing	2.0	0.09	0.04
Nyashishi	Mwanza Abattoir	Abattoir	49	11	4
Nyashishi	New Era	Vegetable Oil Refining	192	50	24
Nyashishi	Regent Food and Drinks Limited	Soft Drinks	305	61	16
Nyashishi	Nyanza Bottling Company Ltd.	Soft Drinks	353	9	2
Nyashishi	Mwanza Fish Net	Fish Net	105	5	0
Nyashishi	Mwatex	Textile	336	97	2
Western Shore Streams	SBC Limited	Soft Drinks	816	6.20	1.20
Western Shore Streams	BUKOP Limited. Coffee Curing	Coffee Processing	4.32	0.10	0.39
Western Shore Streams	Tanganyika Instant Coffee Company Limited	Coffee Processing	8	0.20	0.02
Western Shore Streams	Bukoba Abattoir	Abattoir	10	2.20	0.90
Kagera	Kagera Sugar	Cane Sugar Processing	400	50	25
Western Shore Streams	Kagera Fish	Fish Processing	8	1.26	0.20
Gucha-Migori	SONY Sugar Co.	Cane Sugar processing	343	6	5
Nyando	ACFC(Muhoroni)	Distillery	731	1,082	90
Nyando	Muhoroni Sugar Co.	Cane Sugar processing	2	2	1
Nyando	Chemelil Sugar Co.	Cane Sugar processing	13	47	10
Nzoia	Pan African Paper Mill	Pulp & Paper mill	1,043	109	29

Sub-Catchment	Name of Industry	Industrial Category	Resulting load (kg/day)		
			BOD	Total-N	Total-P
Nzoia	Mumias Sugar Co.	Cane Sugar processing	125	121	28
Nzoia	Nzoia Sugar Co.	Cane Sugar processing	1,600	28	8
Nzoia	West Kenya Sugar Co.	Cane Sugar processing	40	18	2
Sondu	KCC-Sotik	Dairy	476	34	10
Sondu	Premier Dairies	Dairy	40	2	1
North Awach	Spectre International	Distillery	401	413	156
Northern Shore Streams	Uganda Breweries	Breweries	1,272	233.9	26.3
Northern Shore Streams	Britania Products		348	3.1	1.3
Northern Shore Streams	Mukwano Soap &Oil	Vegetable Oil Processing	8	0.5	0.3
Northern Shore Streams	City Abattoir	Abattoir	150	15.9	10.5
Northern Shore Streams	Uganda Meat Packers	Abattoir	99	11.4	6.0
Northern Shore Streams	Nakasero Soap Works,	Soap Manufacturing	17	0.6	0.3
Northern Shore Streams	Greenfield Entebbe	Fish Processing	40	10.5	2.5
Northern Shore Streams	Hwang Sung Fish	Fish Processing	26	6.9	2.5
Northern Shore Streams	Century Bottlers	Soft Drinks	107	12.0	2.3
Northern Shore Streams	Uganda Fish Packer	Fish Processing	151	14.8	40.8
Northern Shore Streams	Ngege Fish	Fish Processing	115	9.2	9.3
Northern Shore Streams	Crown Bottlers	Soft Drinks	187	22.3	2.8

APPENDIX 4. Industrial Pollution Loads-by Catchment.

Catchment area	Resulting load (kg/day)		
	BOD	Total-N	Total-P
Eastern Shore Streams	486	77	41
Grumeti	408	10	5
Nyashishi	3631	506	111
Simiyu	2.0	0.09	0.04
Western Shore Streams	846	10	3
Kagera	400	50	25
Gucha-Migori	343	6	5
Nyando	746	1,131	102
Nzoia	2809	276	67
Sondu	516	36	12
North Awach	401	413	156
Nothern Shore Streams	2520	341	105

APPENDIX 5. Industrial Pollution Loads-by Category.

Type of Industry	Resulting load (kg/day)		
	BOD	Total-N	Total-P
Fish Processing	1,807	258	107
Abattoir	323	44	87
Vegetable Oil	1534	119	38
Textile	711	156	38
Soft Drinks	2,128	114	26
Coffee Processing	16	0	1
Breweries	1,374	253	31
Cane Sugar Processing	2,524	272	79
Dairy	516	36	12
Distillery	1132	1495	246
Pulp & Paper mill	1,043	109	29

APPENDIX 6. Regional Summary of Municipal Resulting Loads.

Country	Population	BOD(Kg/day)	TN(Kg/day)	TP(Kg/day)
Kenya	3,366,830	18,034	4,323	1,625
Uganda	1,351,673	14,166	2,911	2,212
Tanzania	996,108	9,998	1,778	711

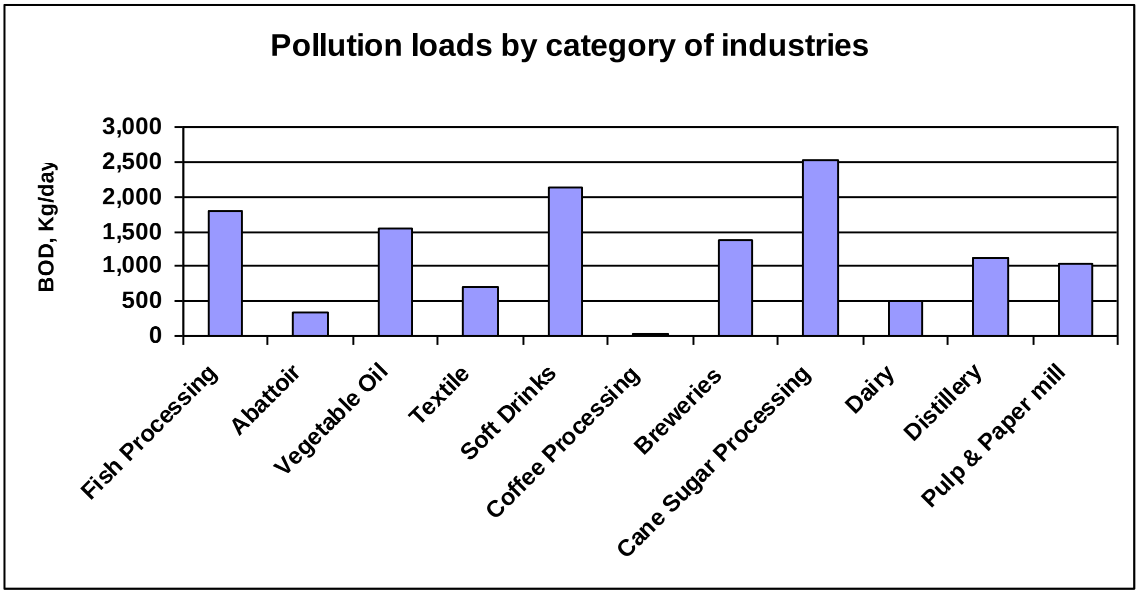
APPENDIX 7. Regional Summary of Industrial Loads.

Country	BOD(Kg/day)	TN(Kg/day)	TP(Kg/day)
Kenya	4,815	1,862	341
Uganda	2,520	341	105
Tanzania	5,200	653	185

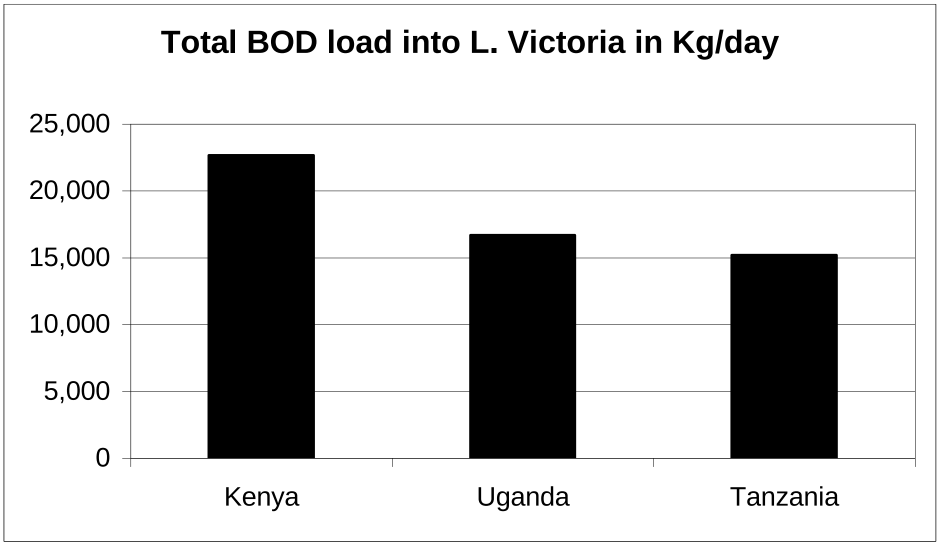
APPENDIX 8. Regional Summary of Total Point Source Loads.

Country	Population	BOD (Kg/day)	TN (Kg/day)	TP (Kg/day)
Kenya	3,366,830	22,649	6,185	1,966
Uganda	1,351,673	16,686	3,251	2,317
Tanzania	996,108	15,189	2,431	896

APPENDIX 9. Pollution loads by category of industries.



APPENDIX 10. Total BOD load in to Lake Victoria in kg/day



APPENDIX 11. MWAUWASA (Mwanza) Future Sewerage Plans.

	Year 2004	**Year 2015**	**Year 2025**
Sewer Length (Km)	21.2	92.4	243.7
Connection Fee (Tshs.)	50,000/=		
Connected Population	19,500	69,800	200,300
Max. hour discharge (l/s)	64	265	851
Max. day discharge (l/s)	33	132	475
Max. month discharge (l/s)	30	123	442
Average day discharge (l/s)	28	114	409
Average annual discharge (m^3/a)	880,000	3,590,000	12,900,000

CHAPTER 8

Water, Communities and Development in the Lake Victoria Basin

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ABSTRACT. *The impact of water quality changes in the Lake Victoria basin on beneficial uses is discussed. Beneficial uses of resources from the lake basin are very significant for the livelihoods of the riparian communities and the respective countries. The basin is also a source of fish and fish-products to national and international markets. The relationships between water quality, ecosystem health and socio-economic implications and human health are manifold and complex. Valuation of impacts and need for action in response to the impacts are addressed.*

Findings showed that banned organochlorines e.g. DDT is still being used in the catchments. Mercury contamination of soil and watercourses occurs but is still very localized. The levels of heavy metals in Lake Victoria waters and fish are within the acceptable limits of the international standards. Waterborne/water-related diseases including diarrhoea, dysentery, amoebiasis, typhoid, intestinal worms, bilharzia, malaria, skin diseases and eye infections have increased in the basin. HIV/AIDS and other STDs were also common at landing sites. Agriculture, urban runoff, municipal, domestic and industrial wastes are the major sources of pollution that contributes to the flourishing of water borne pathogens. In most fishing villages, sanitary conditions were poor, and even latrines were inadequate or lacking. Some major towns along the shores such as Bukoba and Musoma (Tanzania) have no sewerage systems while the major cities are still under serviced. Destruction of wetlands has aggravated the situation by *removing buffering capacity for pollution loads. Highly toxic blue-green algal blooms consisting of Microcystis and Anabaena spp. dominate the nearshores of bays and gulfs.*

It was noted that water quality change in the basin has adversely affected the beneficial uses of Lake Victoria basin waters by the riparian communities. These trends need to be controlled or reversed; hence the need for action. Recommendations for appropriate agencies and LVEMP phase 2 to undertake in order to restore the lake basin to pre-1980s conditions to improve on the beneficial uses are suggested.

Key words**: Lake Victoria, riparian communities, water quality, water-related diseases.**

INTRODUCTION

Water is one of the most important resources for man's survival. It is critical for sustainable development, environmental health, eradication of poverty and hunger and is indispensable for human health and well-being. The East African countries, all members of the United Nations have in accordance with the Millennium Development Goals pledged to have halted and begun to reverse the incidence of malaria and other major diseases, and reduced by half the proportion of people without sustainable access to safe drinking water and sanitation by the year 2015 (UNDP 2003). Safe water supply and adequate sanitation to protect health are among the basic human rights.

Lake Victoria is an international water body that offers the riparian communities a myriad of important uses and functions. It is a global treasure of aquatic biodiversity and contains a rich endemic fish fauna. It is Africa's largest freshwater resource and the world's second largest freshwater lake. It is used as a source of food, energy, drinking and irrigation water, shelter and transport and is a repository for domestic, agricultural and industrial wastes. Over the past four to five decades, the lake has come under increasing and considerable pressure from a variety of interlinked human activities related to population growth and in-migration to the lakeshore such as urbanization, concentrations of populations along the lakeshore to partake in the growth of the fishing industry, increasing area of land brought into agriculture, intensive fishing for commercial and domestic use, species introductions and industrial development. Other activities of concern include poor agricultural practices, over grazing, deforestation and wetlands conversion. These activities are threatening the sustainability of the lake.

Poor agricultural practices in the catchment of Lake Victoria, characterised by clearance of forests and vegetation burning in the catchments, has led to soil erosion and siltation into the lake. In the catchment, there is reported lowering of the water table leading to drying up of some springs. Increasing pesticide use over the years to boost agricultural yields, have led to potential adverse effects in the lake as well as human health. Overstocking of livestock has been increasing, resulting in overgrazing, which leads to accelerated devegetation and soil erosion causing irreversible changes to the ecosystem. Degradation and conversion of wetlands through cultivation and setting up of human settlements and industrial establishments have rendered them incapable in buffering the pollution loadings from the catchments. Consequently, industrial, municipal, agricultural and other wastes end up in Lake Victoria overloading the natural degradation and purification processes that occurred when population densities were lower. Urban settlements and landing sites around Lake Victoria have inadequate sanitary facilities. The discharge of partially treated or raw sewage from urban centres together with wastes from landing beaches has resulted in contamination of surface water sources with pathogenic microorganisms. As a result, waterborne diseases such as diarrhoea, cholera and typhoid fever have become rampant (Byamukama *et al*. 2005). Furthermore, the lake is currently under threat of organochlorine pesticides and heavy metals (especially lead, mercury and cadmium) contamination from urban centres, and a few gold mines in the catchment, albeit still in low quantities.

Excess input of nutrients in Lake Victoria has resulted in eutrophication, a condition characterised by massive blooms of algae, excess growth of aquatic weeds (such as the water hyacinth) and oxygen-depletion (anoxia) in the bottom waters of the lake. The adverse effects of eutrophication include fish kills (due to lack of oxygen and algal toxins) (Ochumba and Kibaara 1989; Mohammed *et al*. 2003), proliferation of potentially toxic species of cyanobacteria and decrease in water transparency. Algal toxins produced by some species of cyanobacteria are harmful to humans, wildlife and livestock (Okello 2004). The water transparency has declined from 5 m in the early 1930s to 1 m or less in the year 2005 in inshore areas and has reduced the habitat for the highly diverse fishes of the lake.

Introduction of alien species, notably the Nile Perch and the water hyacinth respectively have had several adverse changes in the composition and functioning of the Lake Victoria ecosystem. For example, the Nile Perch has contributed to the extinction of more than 200 native species of fish leading to changes in the food web (Odada *et al.* 2004). As a result, riparian communities have suffered loss of vital local fish species in their diets, and the diversity of fish prey that sustains the productivity of the important Nile perch has been reduced. The water hyacinth has contributed to the increase in the prevalence of water-related diseases in the riparian communities, because it harbours vectors of these diseases (such as bilharzia and malaria) and has choked the hydroelectric intakes and impeded navigation.

The increasing demand for fish for domestic, regional and the international market has led to increase in fishing effort in Lake Victoria. Over-fishing and use of illegal fishing methods have contributed to concern over possible declines in fish stocks. Additionally, use of pesticides to catch fish poses a great risk to human and environmental health and to the acceptability of the fish product on the international market.

Some of the major drivers for the environmental problems facing Lake Victoria basin stem from the ever-increasing population and rural to urban migration, exerting extreme pressure on the resources of the lakeshores and lake basin (Darwall *et. al.* 2005). The changes in the ecosystem of Lake Victoria have had far reaching socio-economic consequences on the riparian communities of East Africa. Whereas these communities have depended on the lake for their livelihood for centuries, their living standards have remained very low. Water supply, sanitation, diseases, transportation and communication have all continued to be huge problems for the riparian communities despite ready availability of water for various uses. Poverty reduction has remained largely elusive for riparian communities. Policy makers, development agencies and other actors only understand their needs to a limited extent. Many projects have not been participatory; hence catchment communities have tended to be largely ignorant and inadequately mobilized for development. Similarly impacts on the lake from various uncoordinated activites also escaped notice allowing impacts to accumulate over time. Attempts to develop upstream resources can have negative and unappreciated impacts downstream unless comprehensive environmental assessments are undertaken. If downstream adverse effects offset perhaps elusive or short-lived upstream benefits, economic development is negated. Lake Victoria basin has great potential as a focal point for socio-economic development and has been identified as an economic growth zone for the East African region. It is therefore necessary to put in place proper planning of socio-economic activities in the catchments and ensure sound environmental management in order to improve the livelihoods of the riparian communities and alleviate the chronic poverty of these communities.

Beneficial Aspects of Lake Victoria Waters

The East African Community II common vision for the lake basin is to have a "prosperous population living in a healthy and sustainably managed environment providing equitable opportunities and benefits" (EAC 2004). The potential for socioeconomic development in the Lake Victoria basin lies in the opportunities for investment in fisheries, tourism, transport and communications, water and energy, agriculture, trade and industry. The potential includes the abundant natural resources in wildlife, forestry, minerals and relatively fertile soils. In 2001 the riparian population of Lake Victoria was about 30 million, but with a population growth rate of about 3–6% (including immigration to the basin), this may increase by 55% in the next decade (EAC 2004). The benefits that the riparian communities derive from the lake basin are discussed in this section.

Water for Domestic Use

Lake Victoria is an important source of water for various domestic purposes for the riparian communities. A large population of these communities source their water directly from the lake without any treatment. There is potential for ground water exploitation for the benefit of the riparian communities. Other potential sources of water such as rainfall need to be harvested to improve accessibility to water especially through the dry seasons. Other communities in the catchment source their drinking water from rivers, streams and springs. The cities of Mwanza (Tanzania), Kisumu (Kenya), Kampala (Uganda) and other urban centres around the lake also source their water directly from Lake Victoria. Accessing potable drinking water remains a daily drain on potential productive labour when individuals have to carry it from long distances. Treatment of that water if necessary is an additional cost at the individual or urban level when distribution systems are developed.

Sustainability of the Fisheries Sector

Fish has for a long time been the main source of cheap protein for the riparian communities. Currently, the main commercial species of fish in Lake Victoria are the introduced species: *Lates niloticus* (Nile Perch), *Oreochromis niloticus* (Nile Tilapia) and native *Rastrineobola argentea* (mukene / daaga / omena). Nile Perch and Nile Tilapia have transformed the fishery from subsistence to a major commodity for domestic, regional and international markets and the provide employment for thousands of people in the fisheries industry. Maintaining the productivity, health and marketability of the fishery requires that Lake Victoria be kept in a healthy condition to support the food webs necessary for the fisheries.

Habitat for Biota / Wildlife

Water is home to a variety of living organisms. These range from microorganisms to higher forms of life. Different organisms occupy different depths of the water column. The organisms play different ecological roles, which enable the proper functioning of the lake. For example, some bacteria are producers, while others are decomposers. Phytoplankton (microscopic plants) produce energy not only for themselves but also provide energy to fish and other aquatic organisms. Some microorganisms directly fix nitrogen from the atmosphere into usable form in the lake ecosystem. Zooplankton (microscopic animals) are consumers, benthos occupy the bottom of water body and consumer detritus and are prey for fishes. Neuston such as beetles, occupy the surface film of water. When aquatic systems are in balance food energy produced by plants is efficiently transferred to the animal consumers. Accumulation of plants, especially algae, to high standing crops in aquatic systems is a sign that energy is being inefficiently utilized within the lake. Aquatic weeds, which may be submerged or freely floating, are also primary producers, and similarly their excess growth can disrupt aquatic food webs and impede use of the water resource. The most important vertebrates in the lake are fish because of its high value as a ready and healthy food source as well as an income generator for fishers and fishing enterprises. Other vertebrates include crocodiles and hippopotamuses although increasingly rare. Wetlands are a home to a variety of flora and fauna, which are important elements filtering surface water inputs to the lake ecosystem and often serve as nursery areas for fishes.

Agriculture and Livestock

More than 80% of the population in the Lake basin is engaged in agriculture and livestock-keeping activities. The soils in the basin are comparatively more fertile than those further away from the lake especially the floodplains of tributary rivers. Also, these of these lands receive comparatively more rainfall (due to convectional currents around the lake) than areas further away, and the excess of rainfall over evaporation sustains the water balance of the lake and gives rise to the power benefits and downstream utilization of the Nile River. These conditions have supported a growing agriculture sector for domestic and international market. Bananas, oranges, maize, cassava, sugarcane, tea, rice, coffee and horticultural crops are widely grown in the catchments. These crops would not grow well in these areas without the climate-moderating effects of the lake. Small-scale irrigation is also practiced and likely its increase will be essential to improve agricultural productivity in the region. Livestock rearing is common due to availability of water and pasture in the catchment.

Climate Moderation

The East African region is generally tropical in climate, with rainy and dry seasons. In comparison to other fluids, water takes in large amounts of heat, with relatively minimal change in temperature. This phenomenon is referred to as 'high specific heat capacity of water' and enables water bodies to act as buffers against wide fluctuations in temperature, and therefore modifying the terrestrial climate adjacent to them. Climatic conditions are responsible for major differences in both soils and vegetation and therefore play immensely critical role in agriculture and livestock as well as other human activities. Lake Victoria also greatly influences the various steps in the water cycle in the East African region. In turn the lake is vulnerable to climate change. Fifteen thousand years ago, when East Africa was more arid, there was no Lake Victoria. Instead, vast grassland dotted with wetlands occupied the basin. Consequently, the lake and its levels and quality are sensitive to changes in climate, and it will not escape some impacts of global climate change. Although the magnitude of these likely changes are still poorly know, it is known that all the African Great Lakes are warmer than they were in the middle of the last century.

Buffer of Pollutants and Sink for Wastes

Traditionally, there was no grasp of the need to treat effluents entering Lake Victoria as administrators were confident in the capacity of the lacustrine wetlands and the lake itself to assimilate such effluents when populations were low and widely dispersed over the landscape. Now Lake Victoria is the final recipient of growing domestic, municipal, industrial and agricultural wastes from natural and human-initiated processes in the basin. Vegetation and wetlands in the catchment are able to filter and absorb nutrients and sediments before reaching the lake. Typically, 55-58% of organic matter and 50-85% of suspended solids can be removed by this vegetation (van Bruggen, 2002).

Power Generation and Industrialisation

Most hydropower generation takes place at the Owen Falls Dam on the Victoria Nile near Jinja, Uganda. Owen Falls (also called Nalubaale) dam was completed and commissioned in 1954. Owen Falls Extension Dam (also called Kiira), was built adjacent to Owen Falls Dam, designed to use diverted water behind Owen Falls Dam and commissioned in 2002. The Government of Uganda is in the process of establishing a third hydro-electric generation plant at Bujagali Falls further downstream from the source of the Nile. Hydropower generation is expected to increase as a result of the trans-boundary distribution of electricity and the increase in rural electrification, industrial and in domestic demand (Ndege 2005). In Kenya, a major hydropower station in basin is being constructed along River Sondu/Mirio and a smaller operating station is at Gogo Falls on River Kuja. These demands on the water resource to produce power are critical for economic development, but they can alter water levels and reverse seasonality of river flows unless the power plants operate as run-of-the river-plants in which power production varies with the natural water regime. Withdrawals for power production in excess of what the natural water balance can provide can lead to unexpected effects on water levels and have widespread effects both upstream and downstream.

Most of the industries in the catchment process raw materials from agriculture, livestock, and forestry. Major industrial activities include the production of textiles and garments, leather, sugar, foods, soft drinks, beer, and flour. These activities are scattered within the catchment. Most of these industries processing biological material require water and produce waste with high biological oxygen demand and nutrients that can alter the water quality of receiving waters unless these wastes are adequately treated.

Transport

Lake Victoria offers a cheap transport for goods and passengers to various destinations in the region. There are four main vessels, MV Uhuru, Umoja, Pamba and Kaawa in additional to several smaller boats operating on the lake. However, the safety of these vessels and boats is cause for concern, for example, in May 1996; the Tanzanian ferry MV Bukoba sank with the loss of 800 lives and in May 2005, MV Kabalega sank after a collision with MV Kaawa. These ships and other vessels are themselves potential sources of pollution both for waste disposal but also for the possibility of marine accidents that could dump pollutants into Lake Victoria where water movements could cause widespread impact of potential toxic wastes. Only carefull management of lake commerce can ensure the safety of crews and passengers and prevent catastrophic spills. Conversely, if water quality is not managed and aquatic weed growth becomes excessive because of high nutrients, and then transport can be impeded and even stopped by blockage of navigation channels and harbours with floating aquatic weeks.

Tourism and Recreation

The main tourist attractions in the region include national parks and game reserves, lakes, islands, mountains and rivers. Development of the tourism industry in the Lake Victoria basin can potentially provide very important livelihoods for riparian communities through activities such as boat building, artifact making and the hotel industry. Currently, fewer tourists visit Lake Victoria region than other areas. The tourist destinations in the region continue to be visited predominantly by foreign tourists. It is important that the domestic tourism market be encouraged to realize appropriate education, appreciation of natural beauty and socio-economic development in the region.

Lake Victoria has a great potential to serve its riparian community as a source of various recreational activities such as sport fishing, swimming, sailing and boat racing. A few recreational activities take place in Lake Victoria and its shoreline. Whereas recreational activities are important for the well being of riparian communities, they must be conducted in a responsible and cautious manner to avoid ecosystem degradation and conversion. The current state of the waters of the lake do not encourage water sports because of risks of pathogens, schistosomiasis, skin reactions to algal toxins and concern about accidentally drinking water containing pathogens and toxins. Algal blooms around the world are taken as visible evidence of lake degradation and discourages by tourists and other recreational activities. To grow a tourist industry for the lake will require improvements in the lake's current water quality.

Impacts of Water Quality Change on Uses

The main impacts of water quality change on beneficial uses of waters of Lake Victoria basin are manifold and discussed by use in the following subsections.

Impact of Microbiological Contamination on Water Use

Microbiological contamination of water takes place when faecal material from human and other warm-blooded animal finds its way into water bodies. This waterborne biological pollution (faecal pollution) introduces faecal bacteria into the water body (Muthoka *et al*. 1998). Presence of faecal bacteria is an indication of recent faecal contamination and poses a high risk of contracting water borne diseases if the water is consumed without treatment (Odada *et al*. 2004).

The combination of unsafe drinking water and inadequate sanitation facilities constitutes the major causes of death among the poor in developing countries (Byamukama *et al.* 2005). The simplified model (Fig. 1) illustrates the inter-relationships between water quality, sanitation and health education.

Surveys in the fishing villages around the lake indicated that the inhabitants were mainly migrants from various areas in the region suggesting origins from diverse and heterogeneous cultures. Their education level was mostly primary with shelters comprising mainly of semi-permanent structures constructed near the shoreline. The soils are mostly sandy and frequent foot trampling creates paths, which become small watercourses during rains. Migration makes information dissemination difficult and disease transmission more likely. It concentrates populations and creates problems for local infrastructure that becomes overwhelmed further aggravating the situation. The result is poor sanitary conditions in the communities contributing to the high prevalence of waterborne and water related diseases. Indeed, the most prevalent diseases recorded in health surveys were malaria, dysentery, diarrhoea, bilharzia, cholera, skin-related infections and influenza (Figs. 2 to 4). Children and women were most affected. There are many malaria cases often leading to death as well as frequent incapacitation of productive people. For instance, 93% of the total population in Uganda is at risk from malaria (MOH 2005). Due to malaria, up to 100,000 deaths occur every year in Uganda, and Tanzania reports 1 death every 5 minutes, most of them being children below 5 years.

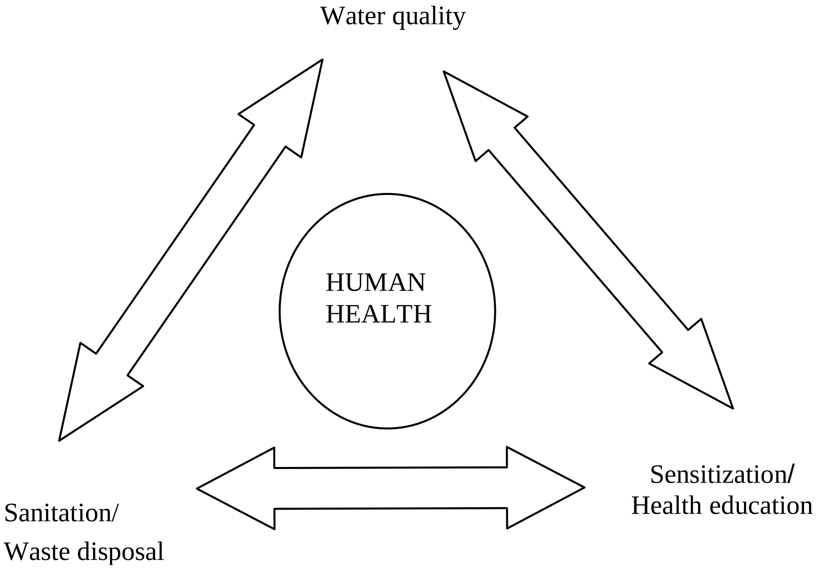


FIG. 1. The relationship between water quality, sanitation, health education and human health.

The distribution pattern for various water borne diseases is probably determined by people's activities. For example, fishermen and associated fishing villages have frequent and prolonged contact with water. For example, the incidence of Bilharzia in Uganda districts (Fig. 2) is inversely proportional to the presence of urban populations, for example Kampala and Jinja or where most of the population in the district is involved in agricultural activities e.g. Rakai, while districts with high relatively high fishing populations have a higher incidence. Common periods in the year in which people mostly felt sick coincided with the major rainy seasons when most households were busy in their farms, significantly lowering agricultural production. The study also indicated that about 65% of the respondents collected water from the lake for domestic use. Collection of water from the lakeshore was mostly done by women (64%), making them more vulnerable to contact diseases. The riparian communities' vulnerability to diseases was further enhanced by inaccessibility to both health facilities and personnel.

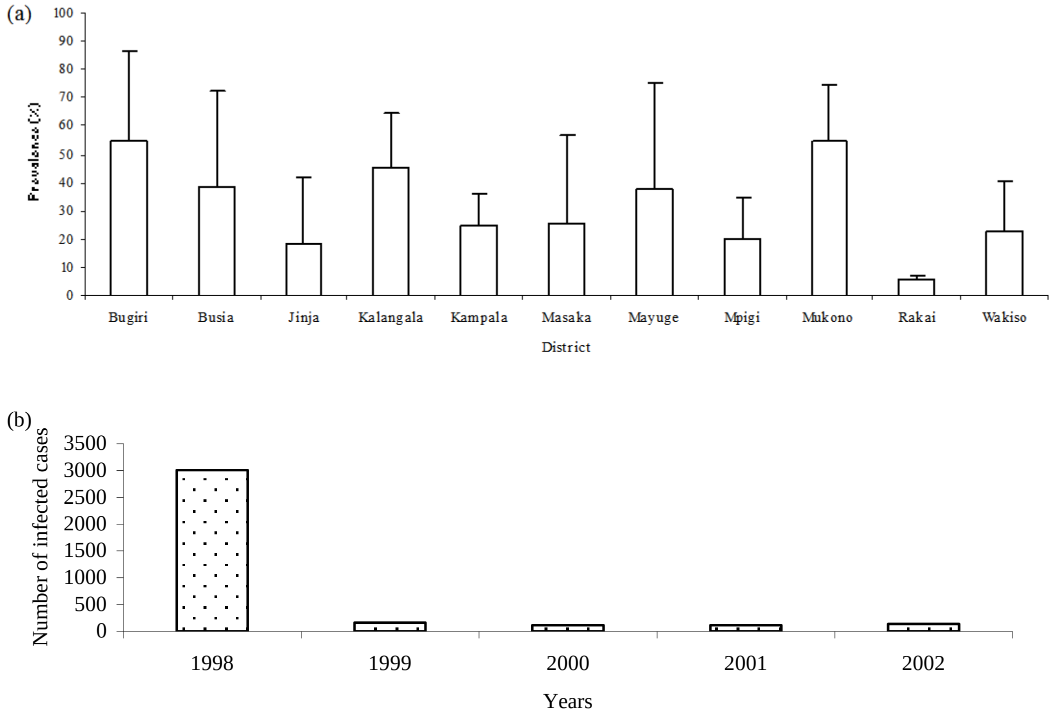


FIG. 2. Prevalence of Schistosomiasis in (a) eleven lake districts around Lake Victoria, Uganda for the year 2005, and (b) in Kenya for the period 1998 to 2002.

The prevalence of clinically diagnosed cases of malaria in some districts of Uganda, Kenya and Tanzania are presented in Fig. 3, while Fig. 4 presents the relative prevalence of selected diseases in Tanzania. Generally, areas around the lake experience higher prevalence of water-related diseases than those far from the shores. It is possible that the deteriorating quality of Lake Victoria waters may be contributing to the high prevalence of these diseases in the lakeshore communities. Increasing population densities in lakeshore areas, especially in fishing villages with little infrastructure for waste handling, also increases the probability of successful transmission of pathogens to new human hosts.

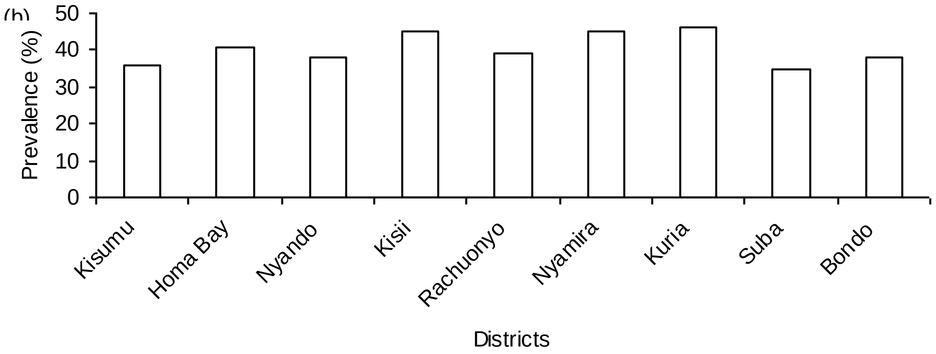


FIG. 3. Prevalence of malaria in the Lake Victoria basin for (a) Uganda, 2004, and (b) Kenya, 2001/2002.

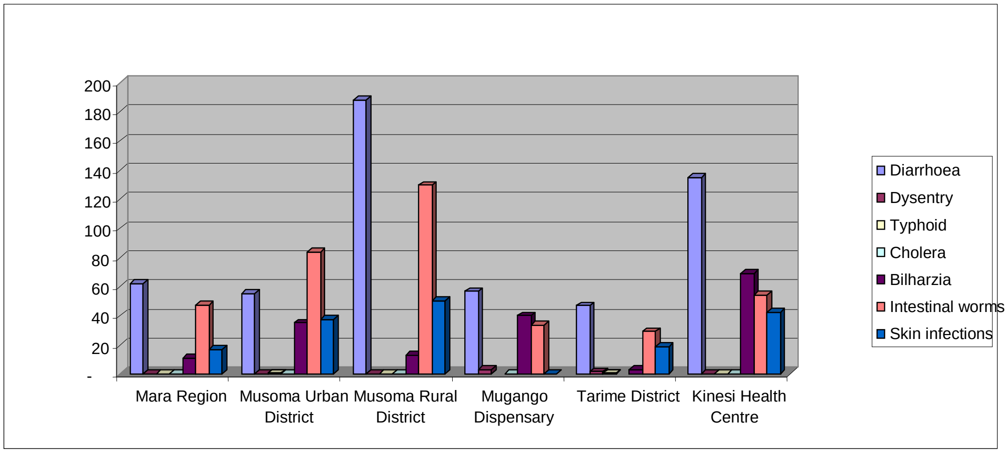


FIG. 4. Relative prevalence of selected diseases (per 1000 inhabitants) in selected sites of Lake Victoria, Tanzania (adopted from LVEMP-Tore Report-2004).

The HIV/AIDS scourge has also affected the riparian communities of Lake Victoria. The scourge has unleashed severe impacts on children and the region as a whole, notably, the straining of the health system, socio-economic disruptions, reductions in productive capacity, increase in AIDS orphans, with related problems such as street children and child abuse. It has also exacerbated poverty at household and community levels. It was found out that because of the large proportion of migrating persons, the fishing villages presented populations with high risks for HIV infection (UNICEF-IRC 2002). For instance in Kenya, the riparian district rates stand at 15% (CBS, MOH and ORC Macro 2004) while for Uganda it ranges from 10 to 13%. This increased risk is imposed on populations that already are suffering from other health problems and inadequate access to health clinics. Highly mobile populations such as fishers that move about the lakes searching for better fishing also increase the probability of transmission.

Impact of Chemical Pollution on Water Use

Use of agricultural chemicals in the Lake Victoria catchment has increased in recent years. 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 in the basin. The US-Environment Protection Agency (EPA) has estimated that between 10,000 and 20,000 physically diagnosed pesticide illness and injuries occur widely among agricultural workers per year in developing countries, a disturbingly high number relative to the amount of pesticides used (Vorley and Keeney 1998).

Organophosphate compounds are used in commercial farming for control of weeds. Findings showed that organophosphate herbicides, such as, Touch Down (48% Glyophosate trimesium) and Gasepax (2,4-D and Ametryne) used in sugarcane cultivation were not detected four months after field application and therefore posed no environmental threat in runoff water, soil, sediment and fish. However, organochlorine pesticides persist in soil for a long time. For example, in some sugarcane farms in Kenya, these pesticides were detected five years after application. Endosulfan, lindane and heptachlor concentrations in soils were found to be 1.55, 1.29 and 0.24 ppm respectively. In another study in Tanzania, three organo-chlorine pesticides namely DDT, HCH, and Endosulfan with concentrations ranging between zero and 2 μg/l were detected in surface waters from Speke gulf. Some fishers out of ignorance or avarice use pesticides for killing fish to increase their harvest. Endosulfan was detected in fish in the marketplace in Uganda and led to the closure of the fishery for export to the EU for an extended period of time while fish, water and sediment from the lake were screened for pesticides and other contaminants. This required rigorous new survey programs to insure that fish in the lake were suitable for the lucrative export market, but it also brought new costs into the fishery. A sediment core from Lake Victoria indicated that DDT concentrations were still increasing through the 1990's. However, measured levels in fish remain below advisory guidelines.

Elevated metal concentrations (Mn, Zn and Cr) detected in some rivers were related to industrial activities or runoff from urban areas. In Uganda, total Hg concentrations were higher in recently deposited lake sediments than older ones, indicating increased environmental degradation. Nevertheless, Hg and other heavy metals concentrations in soil, sediment, water and fish (biota) from Lake Victoria were below the WHO and international environmental guidelines maximum allowable concentration. For example, in Tanzania, mercury concentrations in most fish species were generally lower than the WHO standard of 0.2 ppm in fish muscle. In Kenya, levels of lead, cadmium, iron, nickel and copper in fish fillet, lake water and river water ranged from 0.12-1.68, 0.09-0.19 and 1.21 ppm respectively. The observed increase in metal concentrations may be due to increase of industries in the urban centres within the lake basin resulting in discharge of industrial and municipal waste directly into the receiving waters and also from automobile exhaust fumes and oil spillage.

Impact of Sediments and Sedimentation on Water Use

Sediments are suspended matter including soil particles in water. Sedimentation is the settling of particulate matter produced in the catchment and in the lake (e.g. dead plankton, calcium carbonate, diatom shells, faecal pellets from zooplankton and fish). Excessive sediment concentrations in water or sedimentation on the lake bottom can have adverse effects on water quality. They increase turbidity, and cause undesirable changes in palatability and aesthetic quality of the water hence impairing its use. Turbidity reduces water transparency and can limit primary productivity. High turbidity and algal abundance leads to increased costs of water treatment. Sedimentation also leads to accumulation of chemicals in sediment and introduction of various microbial organisms alongside the sediment leading to pathogenic contamination of waters. Sedimentation rates in the lake are higher at littoral compared to pelagic stations because of higher algal production and algal blooms in shallow littoral regions (Chapter 7). The composition of the settling material was highly organic and of algal origin. Most rivers currently transport higher sediment loads into the lake than they did before agriculture became a dominant land use in their catchments and these sediments are likely increasing the growth of deltaic areas.

Impact of Excess Nutrients on Use Of Water

Excessive increase in nutrients (eutrophication) has become one of the most important causes of water quality deterioration in Lake Victoria. Excessive nutrients in Lake Victoria arise from a variety of anthropogenic activities that include deforestation, intensive cultivation, and runoff from agriculture, municipal and industrial effluents, animal husbandry and mining. Atmospheric deposition also significantly contributes to the nutrients loading and is much higher in the Lake Victoria basin than reported elsewhere in Africa.

Excess nutrients have led to proliferation of macrophytes and algal blooms whose decomposition leads to depletion of oxygen in the bottom waters contributing to fish kills and loss of habitat. Algal blooms lead to clogging of water filters at water intakes and cause foul tastes and smell. Increased treatment costs are is evident in water treatment plants that abstract water from the lake. Further, algal blooms and macrophytes especially water hyacinth contribute to impairment of water usage for swimming / recreational purposes as infested waters cause body itching. The rapid proliferation of the water hyacinth caused negative social, economic and environmental impacts that prompted mobilization of resources to control it. Other negative impacts of the water hyacinth infestation include harbouring of several disease vectors such as mosquitoes and snails and impairing of navigation. The dominance of Cyanobacteria (blue-green algae) could have contributed to reduction of available food for some aquatic biota, for instance, the native fish species. Cyanobacteria are not readily utilized by phytoplanktivores and therefore accumulate to high abundances (blooms). The poor utilization arises because of their colonial and filamentous growth forms, poor palatability and their toxic effects on aquatic consumers and potentially on domestic animals and humans. Eutrophication also has direct impacts on fish habitats and fish diversity as it leads to deoxygenation of deep waters, restricts light penetration that reduces the habitat for fishes requiring visual mate selection, such as the endemic species flocks of cichlids, and restricts light penetrations and self limits primary production by phytoplankton and benthic algae. Many of the endemic species of fish specialized on grazing benthic algae and the reduced productivity of these groups reduces the fish prey available to Nile perch. The availability of fish prey, as opposed to availability of invertebrate prey, has been linked to the condition and growth rates of Nile perch.

Impact of Lowering of Water Table and Drying Up Of Springs on Water Uses

Land-use activities in the catchment have contributed to degradation of the basin including lowering of the water table and drying up of springs in some areas of the catchment. Associated impacts include inadequate water supply to the communities further contributing to waterborne and water-washed diseases through excessive water reuse and over use of remaining water supplies. Additional time is spent looking for water instead of performing more productive activities. Children are used in sourcing water, which can make them miss going to school. Loss of spring's forces increased dependence on available surface water which is generally more likely to be contaminated by animal wastes.

Reduction in the water table also leads to modification of the hydrological cycle which in turn modifies the climate and hence productivity. As water sources dry up, there is loss of biodiversity resulting from loss of wetland habitat. Reduced water availability leads to reduced milk production from livestock, which reduces income to the communities including reduced agricultural production. As livestock scramble for the limited watering points, trampling and land degradation as well as the spread of livestock diseases increase. Further, water scarcity increases conflicts amongst communities, especially between upstream and downstream users of the same water source.

Impact of Species Introductions on Water Use

Water hyacinth invaded Lake Victoria in 1989 and by 1998, the overall water hyacinth cover over Lake Victoria was 12,000 ha (Bugenyi and Balirwa 1998). The most serious environmental impact of the massive floating mat was oxygen depletion in the sheltered bays and the associated loss of breeding and nursery grounds for fish. The weed also affected aquatic productivity by disrupting important food chains. For example, through its vegetative cover, the weed shaded phytoplankton from sunlight, an important ingredient in primary production sustaining aquatic food webs including fish. Furthermore, the weed provided breeding habitats for bilharzia vectors e.g. *Biomphalaria* and *Bulinus* snails, and malaria vectors, the mosquitoes. The water hyacinth infested habitats were also a haven for snakes. The most prevalent diseases associated with water hyacinth infestation included abdominal worms, diarrhoea, and skin infections.

Socio-economically, the water hyacinth affected fish production, water transport, water quality, water supply, human health and hydropower generation, among others. Other aquatic weeds existing in the Lake Victoria basin include water lettuce (*Pistia stratiotes*), water chestnut (*Trapa natans*), and water fern (*Ceratophyllum demersum*) which also threaten waterways, wetlands, dams, and irrigation schemes. The success and continued maintenance of water hyacinth populations in Lake Victoria is directly related to the increased nutrient content in the lake and especially high nutrient concentrations near urban areas and river mouths where residual water hyacinth populations remain. In Lake Malawi, which has only one-tenth of the phosphorus concentrations of Lake Victoria, water hyacinth is present but is never able to grow to nuisance covers in the lake.

Eucalyptus is a genus of fast growing exotic species. The most common species takes up a lot of water from the ground making it inappropriate for planting in critical catchment areas. It exhibits high evapo-transpiration contributing to drying up of wetlands. However, eucalyptus growing has become an important economic cash crop among communities in the catchments.

Prior to the introduction of Nile perch and other exotic species in the Lake Victoria basin in the 1950s, the most dominant fishes were the 300-plus haplochromine cichlids that comprised at least 80 percent of the lake's fish biomass (Kudhongania and Cordone, 1974). These haplochromines virtually exploited all food resources in the lake. Predation by Nile perch has contributed to the rapid decline of the endemic fish fauna. Decline in herbivorous endemic fish species in turn contributed to excess growth of algal species.

Impacts of Water Quality Change on Industrial Uses

The deterioration of the water quality has impacted on water treatment plants with the key parameters requiring treatment increasing drastically. Parameters like colour and turbidity have been increasing steadily since 2000 as shown in the Fig. 5. The increase in turbidity and colour has consequently resulted in reduced filter life and increased down time to change filters. As a result there is need for new treatment processes and highly trained manpower, which require heavy investment and running costs. Turbidity also has an effect on disinfection because high levels have been shown to protect microorganisms from the action of disinfectants (APHA, 1998) and to increase the chlorine and oxygen demand.

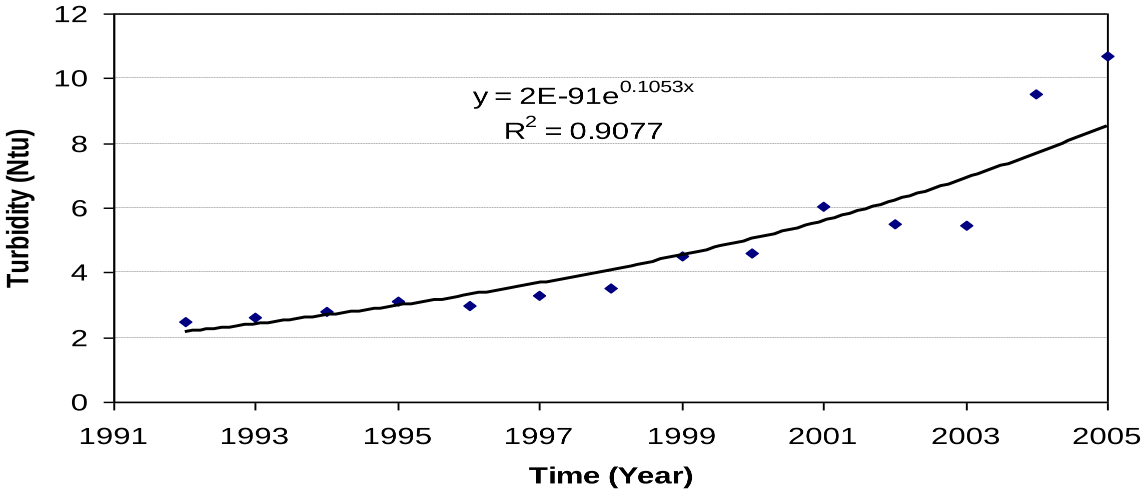


FIG. 5. Raw water turbidity trends at Gaba waterworks intake, Murchison Bay, Uganda.

Water needed for industrial use, for example in the food and fish processing industries, must be of high quality. Poor quality water necessitates treatment before use and this increases production costs that are later translated into high consumer prices.

Impacts of Water Quality Change on Livestock and Agriculture

Contaminated water may contain excessive nutrients, heavy metals and excessive proliferation of organisms, such as, algae and macrophytes, among others. Algal blooms may contain Cyanobacteria that produce toxins, leading to death of aquatic organisms, livestock, and wildlife. Heavily contaminated water cannot be used for irrigation or for livestock watering. Bioaccumulation and biomagnification of heavy metals in the upper trophic levels from primary to secondary consumers to predatory fish affect the safety of the food. Poisoning may lead to death of animals and crops. This in turn leads to economic loss in livestock/agriculture production as well as in fisheries and aquaculture. It may also be a health hazard to humans.

Impacts of Water Quality Change on Tourism and Recreation

Tourists are deterred and do not visit polluted waters because of health risks, augmented by poor publicity contributing to loss of income in the tourism sector. Swimming and other sports activities are also impaired. Deterioration in water quality contributes to high cost of water especially bottled water, affecting tourism albeit indirectly.

Growth of aquatic weeds impaired navigation/transportation using boats in the three riparian states therefore affected recreational activities such as sport fishing. The aquatic weeds harboured snakes and pathogens, caused blockages of watercourses and formed breeding grounds for vectors of *Schistosoma mansoni* (*Biomphalaria* spp. snails) thus impairing use of water for recreational purposes as people avoid such waters, especially tourists who have other options for their recreation.

Impacts of Water Quality Change on Generation of Hydroelectric Power

The high costs incurred in removal of water hyacinth at hydropower generation points raise cost of generation of power. Sedimentation of dams used in generation of hydroelectric power leads to closure or high cost of desilting. These in turn lead to increase in tariffs, which are also passed down to consumers.

Impacts of Water Quality Change on Its Role in Climate Moderation

Lake Victoria and its catchment vegetation (e.g. forests, wetlands) play an important role in climate moderation through contribution to precipitation, air humidity, and moderation of air temperatures. Riparian wetlands and aquatic vegetation such as papyrus help to moderate local climates through their high rates of evapotranspiration which are much higher than evaporation from a free water surface. Uncontrolled loss of vegetation may result in less tolerable climate, reduced rainfall, water levels in streams and lakes, and in extreme cases, desertification, thus directly impacting on the nature of vegetation cover and consequently, its role in climate moderation (Jensen *et al.* 1993). A rise in temperature of lake waters can contribute to stress in fish, lower oxygen concentrations and contribute to fish kills.

Impacts of Water Quality Change on Habitat for Flora and Fauna (Wildlife)

Increased turbidity limits light to algae and submerged aquatic macrophtyes. Decreased oxygen release at depths from these primary producers limit habitat use for various organisms (e.g. Nile perch) causing death and loss of habitats. The decreased oxygen concentration contributed to fish kills, emigration and also loss of employment and food for man. Change in biodiversity may cause animals and people to migrate away from points where water is highly contaminated. Encroachment on forests in the catchments may lead to interference in watering points resulting into wildlife migration. It also leads to loss of breeding grounds of fish. Wetlands are breeding grounds and act as refugia for various fish species. Sedimentation also leads to turbidity of water causing poor navigation and vision for the aquatic organisms.

Encroachment and wetland conversion affect habitats for important fauna in the wetlands e.g. the crested crane in Uganda has been displaced from many areas. Various wildlife e.g. hippopotamuses, crocodiles have also lost habitats following increased occupancy of shoreline for settlement. The immigration of people to the lakeshore for participation in the fishing industry and access to readily available water has indirect effects on many plants and animals, and direct conflicts between wildlife conservationists and communities have also resulted from this.

Impacts of Water Quality Change on Fisheries Industry

The bans on fish exports resulting from microbiological contamination and use of pesticides to catch fish resulted into loss of employment, income, foreign exchange and exacerbated poverty in the riparian communities. Exceptionally clean water is necessary for processing fish to international standards. Water treatment costs are increased for fish processors just as it is for municipalities and for individual users that should treat their water for disease prevention. A artisanal gold mines in the region use mercury as an amalgam to extract gold and this creates a health hazard. As mercury biomagnifies in aquatic food chains, the risk for possible poisoning if people eat contaminated fish increases. Accumulation and biomagnification of mercury and other heavy metals in fish can pose health risks. Burning of vegetation containing mercury can lead to mercury vapour in the atmosphere that is absorbed in water. Levels of heavy metals in water and the food chain are currently low, however, there is need to keep monitoring and prevent processes that may increase their concentration in the environment. Around the world their have been incidences of closures of fisheries because of Hg contamination including great lakes such as Lake Erie and Lake Winnipeg in North America.

Impacts of Water Quality Change on Buffering Capacity and Use as a Sink

Lake Victoria is used as a repository for domestic and industrial wastes. Loss of important biodiversity used in buffering of pollutants in the wetlands is affected by changes in water quality. The buffering capacity of water may be exceeded, rendering it useless in buffering pollutants. When natural buffering capacity is overwhelmed, discharge of effluents in untreated or insufficiently treated forms impairs the quality of the receiving water such as Lake Victoria. The extent to which a water body can regenerate itself is also impaired as nutrients stimulate organic production in the lake and that in turn leads to deoxygenation of deeper waters.

Valuation of Impacts

In the following section, the impacts of water quality change on beneficial uses are discussed qualitatively and, where possible, converted into monetary terms.

Excess Increase of Nutrients

Invasion of the lake by the water hyacinth led to a number of direct negative economic impacts such as, interference with commercial water transport making it slower, costly and risky, 50-70% reduction of access to fish landings and interference in electric power generation at the peak of the weed infestation. At Owen Falls Dam, for example, manual removal of water hyacinth to keep the turbines free of the weed costs over US $ 600,000/year (Ong'ang'a and Munyirwa 1998). The annual cost of water hyacinth control was estimated to be US$ 6 – 10 million in 1998 during peak infestation.

Loss of Nutrients on Agricultural Production

Presently, about 40% of the Lake Victoria basin is under agriculture and the rest is under a mixture of unimproved pasture and natural vegetation. The human population has been expanding rapidly, resulting in increased agricultural and livestock activities. Some of these activities include clearing of forests in water catchment areas, biomass burning and overgrazing. The combined effect of these activities is increased soil erosion, pollution of the rivers and increased atmospheric deposition of nutrients. The loss of nutrients from the agricultural areas through surface run-offs results in reduction in agricultural production and hence affects the economy. Over the past 50 years, over 200,000 tonnes of phosphorus (above natural weathering rates) in the region have been transported from within its water and air-shed and accumulated in Lake Victoria and its sediments. If this quantity of phosphorus were to be replaced to the land by buying phosphorus fertilizer it would require the expenditure of US $ 17.4 million on average per year amounting to about US $ 870 million over the past 50 years. Instead the loss is being borne through declining agricultural production. The addition of the phosphorus to Lake Victoria has led to substantial loss in value of many of the beneficial uses.

Loss of Biodiversity

The deteriorating quality of water and eutrophication in Lake Victoria and its catchment has in part, been blamed for loss of biodiversity (Seehausen *et al.* 1997), contributing to reduction and in some cases, extinction of some aquatic flora and fauna. About 400 endemic fish species in Lake Victoria were estimated to be approaching extinction by the 1980s (Witte *et. al*. 1992). This has been attributed to land degradation, eutrophication and introduction of Nile perch into the lake in the early 1950s.

Studies in the region have demonstrated the important role wetlands play in purifying contaminated water, in addition to providing other valuable benefits like fishing, mitigation of floods, provision of raw materials for crafts, among others. For instance, economical valuation of wetlands in Uganda is estimated to be US $ 300-500/ha/year, and thus there is need to invest in their conservation (Wetlands Inspection Division, Uganda 2004).

Waterborne and Other Water-Related Diseases

Findings show close relationship between the incidence of common diseases and deterioration in water quality in the Lake Victoria catchment. In Tanzania, about 18 million cases of malaria are reported each year. Tanzania loses 3.4% of its gross domestic produce (GDP) estimated at US $ 350 million as direct and indirect costs of the disease (The Express News Paper, Tanzania ISSN 0856 39 85 Issue No. 832 of May 12-18, 2005).

Pegram *et al.* (1998) assessed the impacts and costs of diarrhoeal diseases in South Africa, which indicates that every year about 43,000 deaths, 3 million incidences of the illnesses requiring treatment and US$ 534.3 million may be directly attributed to diarrhoeal disease. It also indicates that the *Shigella dysenteriae* type 1 epidemic in KwaZulu-Natal may have cost about US$ 18.5 million and caused 1,000 deaths in 1995.
Although not a water-related disease, AIDS remains one of the most prevalent diseases in the basin. The number of cumulative AIDS cases has continued to rise as a result of a large pool of HIV infected people who fall sick (UNICEF- IRC 2002). In Uganda, recurrent costs on anti retrovirals (ARVs) are estimated at about US$ 18 million for the year 2005/2006 (MoH 2005). Although economic studies have not been done specifically in the Victoria basin there is little doubt that water borne diseases reduce the productivity of riparian peoples as well as imposing direct treatment costs upon them.

Pesticides Contamination

Among other factors, contamination of fish by pesticides led to a fish export ban to the European Union and other international markets in the late 1990s. Commercial fishing around the lake and subsequently the economies of the three riparian countries were greatly affected as a result. Total loss of income due to the ban was estimated to be more than US$300 million (European Commission 1999). Although this incident was imposed by illegal fishing the risks from pesticides contamination remains in the basin and will grown as the use of these chemicals increases.

Tourism

The infestation of water hyacinth and growth of algal blooms affects the tourism industry in the lake region, by preventing beaches and lakeshores from being used for swimming and other water sports. Experience gained from elsewhere showed that in 1991-92 blue-green algae outbreak along the Darling River (Australia) caused Australian $2.4 million loss of revenue to the tourism industry (Murray-Darling Basin Initiative 2003). The opportunity costs for tourism with Lake Victoria in its present condition are substantial because blue-green algae are now present in bloom quantities nearly continuously throughout the year.

Drinking Water Impairment (Treatment Cost)

The deterioration of water quality resulting from eutrophication is responsible for increased water treatment and plant maintenance costs especially in urban centres around the lake as polluted water resources are more costly to treat for domestic purposes, industrial and other uses. Figure 6 presents costs for water treatment chemicals at Gaba Water works (Uganda).

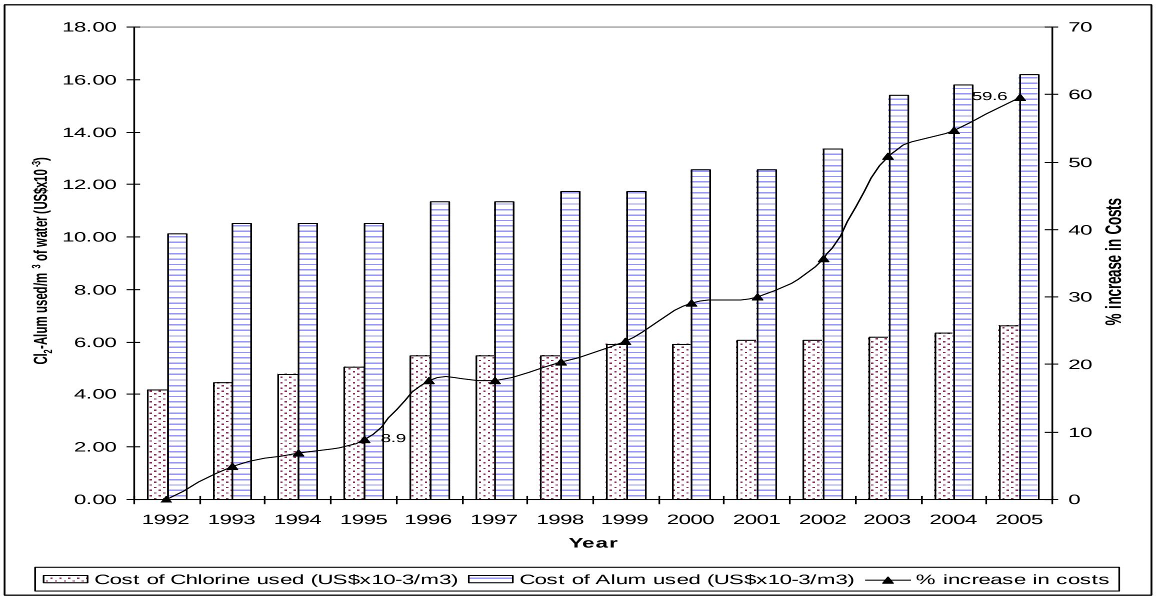


FIG. 6. Increasing costs for water treatment chemicals in Gaba Water Treatment, Kampala.

Total extra cost incurred for water treatment chemicals, from 1995 to 2005 end of June, was US$ 1.7 million. This extra cost could have been put to other beneficial use e.g. extension of section of water main to urban poor. The impact of change in water quality of Inner Murchison Bay (IMB) has not only increased costs for chemicals used in water treatment but has also raised costs for water filtration. The increase in filter backwash frequency has resulted in cost increased by 5% of the total water production costs. This implies that if water production per day, in Gaba, costs US$ 2,800 then extra US$ 140 /day is used in filter backwash. If the deteriorating water quality is not checked then Gaba waterworks will continue using not less than US$ 51,000 /annum in excess for filter backwash. Therefore, the total extra cost for chemicals and filter backwash is US $ 221,000 per annum.

The Gaba waterworks services a population of 950,000 people. If all the current estimated 15 million people in the basin who directly rely on lake water were to have been served by a waterworks like Gaba then the incremental costs to the basin would have been US $ 4.42 million per year. However, not all people are served by a Gaba-like facility and cannot accomplish the scale of economies possible in such a water works. But all the people directly taking their water from the lake are bearing costs of increased treatment either directly in fuel costs if they treat or boil there water or indirectly through poor health and mortality.

CONCLUSIONS

The present study has shown that the banned organochlorine pesticide compounds are still being used in the catchments. It was observed that most farmers are ignorant of the safe use and handling of the agro-chemicals being used in the catchment, which results in some injuries and illnesses and poses risks to water courses and aquatic food webs.

The study also showed that mercury contamination of soil and watercourses is localized. Food crops (especially tubers and rice) grown quite close to gold mining areas inevitably contain elevated mercury levels. The determined levels of lead showed reasonable increase. However, the levels of heavy metals in Lake Victoria waters and fish are within the acceptable limits of the international standards.

Under the WHO guidelines, *E. coli* must not be detectable in any 100 ml sample of drinking water (Havelaar et al. 2001). Waterborne/water-related diseases including diarrhoea, dysentery, amoebiasis, typhoid, intestinal worms, bilharzia, malaria and skin diseases as well as eye infections have increased in the Lake Victoria basin. However, a few success stories in the region have reported reduced incidence of water-related diseases like cholera, bilharzias, diarrhea and dysentery, following improvement in water quality for domestic use, especially where such efforts are accompanied with improved sanitation, hygiene and community sensitization.

Agriculture, urban runoff, municipal raw sewage, domestic and industrial wastes are the major sources of pollution in near shore areas. In most fishing villages, sanitary conditions were poor and there were inadequate latrines.

Some major towns along the shores such as Bukoba and Musoma (Tanzania) have no sewerage systems. In Kisumu, Mwanza, Kampala cities and other towns the sewerage systems are overwhelmed and hence much of the effluent undergoes only partial treatment before discharge into watercourses. Agricultural activities and destruction of wetlands aggravate the situation. Other human activities like fish processing, washing, cargo handling, and local boat making at the lake shores also significantly cause pollution in the lake.

Highly toxic blue-green algal blooms consisting of *Microcystis* and *Anabaena* spp. dominate the near-shores of bays and gulfs. In the inner Murchison Bay, where microcystin levels have been measured higher than the WHO guideline, posing a threat to human and other animal health.

HIV/AIDS and other STDs were common at landing sites due to high rates of prostitution, lack of safe sex, lack of health centers, and existence of migrant HIV infected persons, amongst other causes. Lakeside urban centres had higher numbers of HIV/AIDS cases compared to other urban centres away from the lake.

It was noted that water quality change in the basin has adversely affected the beneficial uses of Lake Victoria basin waters by the riparian communities. Although detailed costing of all lost beneficial uses has not been done and should be done, rough estimates of *some* cost exceed many tens of millions of dollars per year largely imposed on some of the most poverty stricken populations in the basin with economic risks extending to valued industries like fisheries extending into the hundreds of millions of dollars. These trends need to be controlled or reversed; hence there is need for action.

Need For Action

The current status of the quality of the waters of Lake Victoria calls for urgent remedial measures to save it from further deterioration. This is especially so for the near shore areas including gulfs and bays where serious pollution and eutrophication have occurred. The following are the options to take and recommended measures.

Analysis of Cause-Effect Relationships

Matrices of cause-effect relationships between specific activities and effects on Lake Victoria were assessed by LVEMP scientists and technical staff. A similar exercise should be conducted among stakeholders in the basin as a first step in prioritizing stresses on the ecosystem. LVEMP rankings suggested that land degradation was the most severe cause of lake degradation. While species introduction had the least cause (Fig. 7). The most significant effect of lake degradation was the adverse change in the overall quality of life of the riparian communities.

Future Options

The Lake Victoria basin has undergone rapid increases in population and agricultural production in the past century and especially after the Second World War. Today the basin's population is rapidly approaching 40 million people in five countries sharing the basin. This regional growth has had consequences for Lake Victoria. The report establishes changes in the lake in the last few decades and the causes for some of the changes.

Eutrophication, arising from associated processes of land degradation and untreated domestic wastes that have driven up phosphours concentrations, is recognized has caused widespread loss of beneficial uses of the lake waters. The three possible options to address eutrophication are: "do nothing", maintain the status quo or restoration of the degraded ecosystem (Fig. 8). The focus for action must be the excessive loading of phosphorus into the lake as this drives the eutrophication. Phosphorus concentrations have been increasing the lake at the rate of 1 ug/l per year (Chapter 7) for the past 50 years and the steady rise in sedimentary phosphorus concentrations is continuing unabated (Fig. 8). The options to address these increasing concentration are open for decision and action and should be considered by riparian communities, governments at all levels and the international community through LVEMP2, but little can be accomplished without consensus and cooperative action by all the stakeholders in the basin.

The 'do-nothing' option allows for deterioration to continue with little direct costs of investment, but indirect costs to communities and the national economy will continue to rise and eventual costs of corrective action increase, as do political risks. It is necessary that we reject the do nothing option. Going for the 'status quo' option implies no further degradation. This can only be achieved by, addressing at minimum, the most rapidly growing portion of the loading, which are the urban and peri-urban point sources.

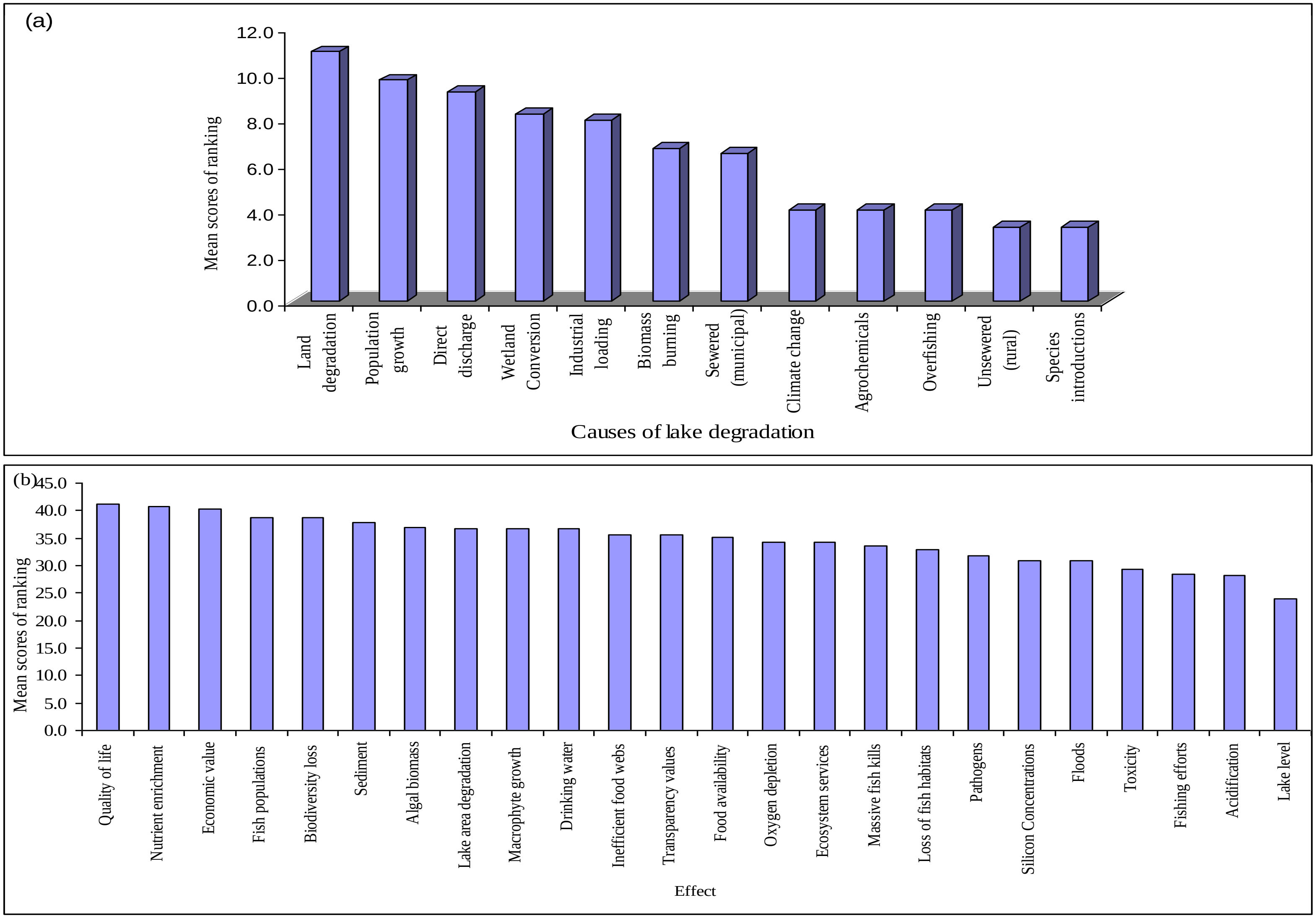
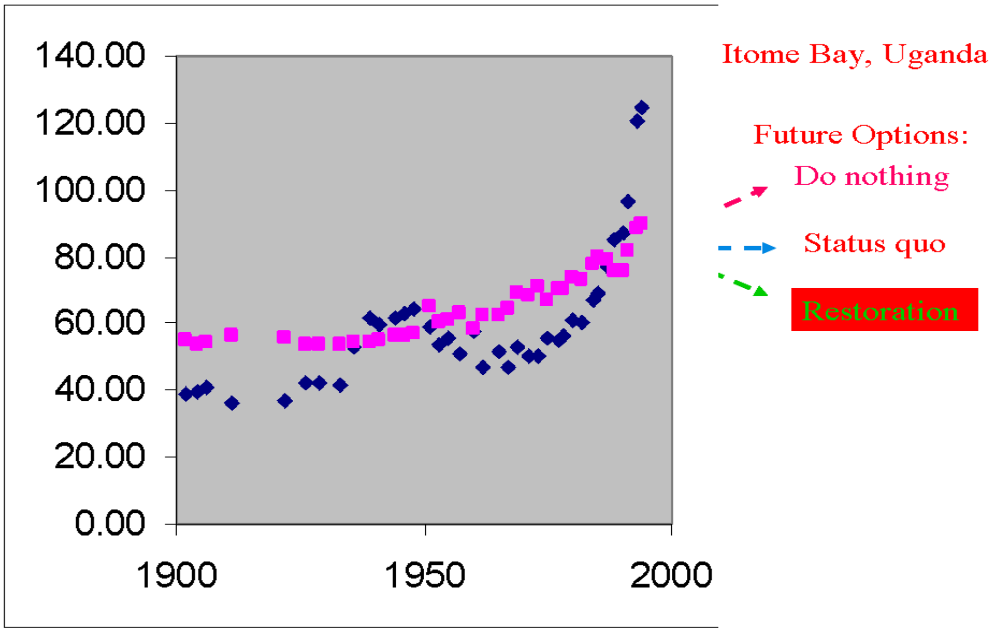


FIG 7. Cause-effect relationships between specific activities and impacts on Lake Victoria: (a) cause of lake degradation, (b) effects resulting from the causes.

This might be accomplished by increasing waste treatment that would also reduce public health hazards but must also bring about tertiary treatment to enhance phosphorus (P) removal from the wastewater stream. Approaches include P precipitation in sewage plants, composting and recycling nutrients especially P back to the land as fertilizers, removing P from detergents, and protecting wetlands especially those receiving urban runoff.

In order to reduce non point loadings significantly including atmospheric loadings, we must improve land management focussing on reducing soil erosion, reducing burning, maintaining more continuous vegetation and crop cover through integrated agroforestry, and improve soil fertility to boost agricultural production on existing agricultural lands to reduce the need for bringing more marginal lands into agriculture. Trying to maintain the status quo lays only prevents further degradation and will not restore many lost beneficial uses due to eutrophication. But success in maintaining the status quo can provide the basis for stakeholder action to address restoration.

The most desirable option is that of ecosystem restoration. It can be achieved by addressing point and non-point sources of pollution. Reducing point source pollution in theory could be done quickly (within a decade if investments are made now) while addressing non-point sources is a longer term strategy (up to about 30 years) required to bring about desired change. The ecosystem degradation has evolved over that time period and it will take nearly as long to achieve significant reversal. It is estimated that reducing non-point loadings by 30% is necessary to restore desirable aspects of the system that were present at least into the 1980's. Such a reduction would not affect the fisheries of the lake. Aggressive restoration of the degraded ecosystem during LVEMP2 of beneficial uses of the lake will involve high direct costs of intervention but if well planned, social and economic benefits will be realized.



KEY

Phosphorus

Biogenic Si (BSi) from diatoms

FIG. 8. Historical changes in Biogenic Si (BSi) and P in the Itome Bay core.

Note that P concentrations are multiplied by 50 to present them on the same scale. Phosphorus concentrations in the lake and in the sediments will continue to rise unless actions are taken to reduce increasing phosphorus loadings driving the eutrophication of Lake Victoria.

RECOMMENDATIONS

A summary of the recommendation for the continuation of the project is given in this section but draw upon other chapters of this report in making these recommendations. These recommendations are aimed at reducing Lake Basin degradation and consequently the costs incurred through loss of beneficial uses of the lake by implementing corrective measures.

1. Stringent enforcement on use of banned organochlorine pesticides (e.g. DDT) to protect applicators, the terrestrial and aquatic environment especially the fishery industry.

2. Use of lead free petroleum products should be encouraged and legislated by the riparian governments.
3. Urban centres, markets and fishing villages should have appropriate solid waste management facilities.
4. Urban centres and industries should ensure that wastewater treatment facilities are in place and their effluents comply with recommended discharge standards. Further expansion of existing treatment facilities to handle increased waste discharges and where necessary construction of new plants should be done.
5. Sensitization of people within the catchment on the use of best land-use and environmental management practices should be intensified. Priority should also be given to marginal land cropped to annuals and degraded hillsides which are potential sources of runoff and loss of soils and phosphorus.
6. Activities leading to an increase in atmospheric deposition such as biomass urning and overgrazing should be controlled
7. The environmental laws in all partner states should be enforced to ensure compliance.
8. It is necessary to undertake proper planning of urban and rural centres to provide social services such as waste treatment plants, potable water, electricity, roads and other utilities.
9. Establishment of institutions that will encourage stake-holders' participation in conservation and management of resources at the village, local, national and regional levels is essential for the Lake Victoria resources utilization and should be encouraged.
10. East African Community could play a stronger role in regional policy coordination and at the national levels the respective riparian governments should show both political will and policy direction in establishing policies that engage the public in enforcing existing environmental rules and regulations and where deficient, making new ones.
11. Cultivation of food crops close to artisanl mining areas should be discouraged.
12. Continuous monitoring to collect data on trends and for evaluating future management purposes should be carried out. This applies to meteorological, hydrological, pollution loadings and water quality monitoring in both the catchment and the lake.
13. Water and sanitation programmes aimed at reducing water-borne and water-related diseases in the riparian communities should be incorporated in LVEMP 2 in order to complement other on-going efforts.
14. Alternative fast-growing environmentally friendly tree species with high economic returns should be identified and promoted to increase tree cover in the basin.
15. More studies and monitoring of pesticide and metal contamination in the atmosphere, water, sediments, flora and fauna should be carried out and required capacity (human, equipment) should be acquired.

Other Programmatic Recommendations to fulfil the recommendations above

1. Purchase missing field and laboratory equipment (e.g. sediment corers, water purifiers, laboratory automation equipment) suitably equipped fast survey vessels for all three countries.
2. Construction of a second central laboratory for Uganda will ease the serious onstraint to the Entebbe laboratory.
3. More training/capacity building is required in a number of fields:

Limnology: A selection of staff from the three WQ Components should participate in a full course in Limnology.

Field data collection: It is recommended that a field data collection specialist from a consultant should participate in 1-2 lake cruises in each country to give more on-the-job training in the use of instruments, on board analysis, and improvement of routines and efficiency.

Laboratory analyses: A training-on-the-job programme is required for the laboratory staff in the three countries of Uganda, Kenya and Tanzania with the purpose of improving the efficiency, precision, accuracy and develop routines to avoid analytical and data processing errors. The training should continue for at least two years with visits by a specialist for 1 month each year.

Pesticides and heavy metal pollution: There is urgent need for training of staff and acquisition of equipment

Modelling: Comprehensive training of the staff with responsibility for the Lake Victoria Water Quality Model is required. At least a hydraulic specialist and a biologist from each country should receive training in modelling, calibration and practical application. Resources should be allocated to the upgrading of this model from a demonstration model (its present form) to a full management tool.

4. Hold annual working sessions in all disciplines to update databases, extend records, perform data validation, analyse new data, refine the model, and to revise the conclusions, the recommendations for environmental protection and the proposals for remedial measures.
5. A strategy to facilitate free flow and rapid exchange of information relevant to the management of shared resources to the stakeholders between institutions, nationally and regionally needs to be developed in next phase.
6 Integrated approach to management of the lake resources involving the local communities and all other interested stakeholders is a must.

7. 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.
8. There is need to rehabilitate, protect and improve the quality of wetlands in the catchment, in order to further reduce the load of nutrients into the Lake Victoria.
9. More clean water sources need to be availed to the fishing villages or treatment for lake water provided.

The Way Forward

LVEMP 2 should address the gaps, needs and investments that have been identified in this report.

Involvement of riparian communities in all programmes to instil a sense of ownership of the resources is necessary for LVEMP 2 to be realised.

Lessons learnt from LVEMP 1 should be used to address project implementation concerns that may have hindered achievement of some of the LVEMP 1 objectives

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