CHAPTER TWO
Lake monitoring on the Ugandan portion of Lake Victoria

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ABSTRACT. *Studies to monitor Lake Victoria water quality, quantity and ecosystem were carried out to determine the present state of the lake's waters in order to take informed management decisions. Analysis of water quality parameters relevant to estimation of biological processes and limiting factors for algal growth and the eutrophication of Lake Victoria were done. Littoral, pelagic, and urban lake stations were selected and studied. The present study gives a description of the monitoring on Lake Victoria. It also gives an overview of those parameters and recommendations for future lake monitoring.*

Keywords: Monitoring, littoral and pelagic stations, Lake Victoria, seasonal cycles.

INTRODUCTION

Fresh water is a finite resource, essential for agriculture, industry and human existence. Without freshwater of adequate quality and quantity sustainable development will not be possible. Water pollution and wasteful use of freshwater threaten development projects and make water treatment essential in order to produce safe drinking water. Discharge of nutrients from point and non-point sources that promote algal growth (leading to eutrophication), toxic chemicals, over-pumping of aquifers, long-range atmospheric transport of pollutants and contamination of water bodies with substances are some of today's major causes of water quality degradation.

A pressing need has emerged for comprehensive and accurate assessments of trends in water quality in the world's largest lake, in order to raise awareness of the urgent need to address the consequences of present and future threats of contamination and to provide a bias for action at all levels. Reliable monitoring data are the indispensable basis for such assessments.

Monitoring as defined by the International Organisation for Standardisation (ISO) is "the programmed process of sampling, measurement and subsequent recording or signalling, or both, of various water characteristics, often with the aim of assessing conformity to specified objectives" (Chapman 1996). Water quality requirements or objectives can be usefully determined only in terms of suitability for a purpose or purposes, or in relation to the control of defined impacts on water quality. For example, water that is to be used for drinking should not contain any chemicals or micro-organisms that could be hazardous to health. Similarly, water used for steam generation and related industrial uses should be low in certain other inorganic chemicals. Preservation of biodiversity and other conservation measures are being recognized increasingly as valid aspects of water use and have their own requirements for water quality management. Water quality data are also required for pollution control, and the assessments of long term trends and environmental impacts.

Lake monitoring provides the baseline data that is required for better and informed lake management. The study was aimed at determining the present state of the lake and the lake ecosystem, analysing the importance and the factors contributing to eutrophication. In order to achieve the objectives of the water quality and monitoring component, a programme for monthly and quarterly sampling on the lake was undertaken. Estimates of loading of nutrients to Uganda sector of Lake Victoria are addressed under eutrophication (in Chapter 8). Sedimentation, biological uptake and processing of nutrient entering the lake results into recycling or conversion to gaseous forms that can be lost from the lake ecosystem. The in-lake monitoring describes the resulting concentrations of the elements critical to affecting the beneficial uses of Lake Victoria water.

Municipal waste and industrial effluents (COWI and VKI Report, 1998; MottMacDonald and Beller, 2003) are of particular concern to water quality in Inner Murchison Bay, which receives treated and untreated effluent from a large part of Kampala, the capital city of Uganda with an estimated population of about 1.2 million (UBOS 2005). Inner Murchison Bay is also the source of water supply for Kampala city. As the city grows and pollution loads increase there is concern that the Inner Murchison Bay could soon become unsuitable as a raw water source. Most of the pollution enters the bay through the Nakivubo Channel, which is the main drainage channel for Kampala.

The expansive open areas of Lake Victoria support one of the world’s largest fisheries and provides water for drinking, domestic and agricultural use by millions of people in lakeshore communities. Some work was carried out on Lake Victoria as far back as 1961 by Talling (1961). Talling’s open lake station in Uganda was approximately where the present Bugaia [UP2] station is located. He also made a round the lake cruises in May 1961 where he did acquire data from other parts of the lake. Those early results along with subsequent observations e.g. Hecky (1993) are available for comparison with the results of the in-lake monitoring program.

MATERIALS AND METHODS

Pelagic and Littoral Sampling Sites

A number of sampling sites were selected on Lake Victoria, Uganda. The naming followed the agreed regional convention for the stations, where the first letter U represented Uganda while the second letter L represented littoral for the inshore and P, pelagic for the offshore stations. The criteria used for selecting the stations was their closeness to the transects along and across the lake. Table 1 and Figure 1 present the description and location of the monitoring stations. All together, 9 littoral (UL) and 10 pelagic (UP) monitoring stations were selected.

Monthly and quarterly programmes for sampling on the lake were agreed upon regionally. During the quarterly cruise all stations were sampled, however during the monthly cruises only a selected few stations were sampled. The water quality component planned the monitoring cruises, prepared on-board procedures and field forms for recording of field observations. It also provided hands-on training through participation in sampling cruises. A summary of the number of cruises is shown in Table 2.

A relatively limited number of key stations were visited during the monthly cruises, while all stations were sampled on the quarterly cruises. Offshore and some inshore stations could also be sampled in one continuous cruise as on-board night sampling was possible. Table 1 presents a summary of the planned / undertaken cruises.

TABLE 1. Description of Sampling points in Lake Victoria and the mean Secchi Disc visibility over the period of the program.

Station Code	Station Name	Longitude	Latitude	Average Depth (m)	Average Secchi Depths (m)
UL1	Wanyange	33,15'22.6"E	00,26'59.6"N	7.5	1.13
UL2	Napoleon	33,14'52.0"E	00,24'10.4"N	18.0	1.60
UL3	Buvuuma	33,17'00.9"E	00,20'56.3"N	23.0	1.80
UL4	Gaba	32,37'05.1"E	00,11'02.0"N	12.2	1.30
UL5	Gaba	32,37'01.6"E	00,07'01.4"N	12.0	1.60
UL6	Katonga	32,11'05.9"E	00,07'01.1"S	9.0	1.78
UL7	Bukora	31,45'05.4"E	00,46'02.1"S	9.0	1.78
UL8	Kagera	31,48'07.9"E	00,55'04.9"S	11.0	2.52
UL9	Sango Bay	31,54'05.9"E	00,44'01.1"S	16.0	3.65
UP1	Open – Sigulu	33,44'01.6"E	00,04'00.3"N	27.0	2.70
UP2	Bugaia	33,16'07.9"E	00,04'07.8"S	68.0	2.90
UP3	Open	32,55'03.4"E	00,03'03.6"S	47.0	2.91
UP4	Open	32,55'05.4"E	00,19'01.9"S	55.0	3.22
UP5	Open	32,41'06.2"E	00,32'03.5"S	51.0	3.48
UP6	Open	32,19'03.1"E	00,47'56.4"S	47.0	2.83
UP7	Open	32,43'05.4"E	00,52'01.6"S	60.0	2.80
UP8	Open	33,19'02.0"E	00,25'01.3"S	67.0	4.00
UP9	Open	33,42'03.5"E	00,31'02.2"S	67.0	3.39
UP10	Open	33,26'00.3"E	00,44'01.2"S	69.0	2.78

Key

(yellow) Monthly Monitoring Cruise Station

A total of 500 annual profiles each consisting of 5 to 10 samples depending on depth and 15 to 20 nutrient and biota parameters provided a balanced monitoring programme based on the component objectives, the field and laboratory capacity.

A sampling vessel, RV Ibis, from the Fisheries Resources Research Institute (FIRRI) was used for the cruises. The field equipment used for the monitoring included Hydrolab and profilers for physical parameters such as pH, temperature, oxygen, electrical conductivity and column depth. ADCPs (Acoustic Doppler Current Profiler) were occasionally deployed and used for determining wind speed, wind direction, temperature, wave height, wave direction and wave period, Secchi disks were used for turbidity / transparency determination. Sediment traps were used for determining sedimentation rates. Automatic Weather Stations were used for determining weather patterns, Van Dorn and Schindler water samplers were used for collecting water samples. Ekman dredge samplers were used for sampling macro-benthos and core samplers for sediment cores from the lake. On-board computers were used for immediate data entry from the hydrolab and ADCP. Samples collected were preserved in sampling containers and stored in deep freezers and transported to the laboratory for analysis of nutrients (N and P) and silicon, Si. On-site data collection was also done using field meters.

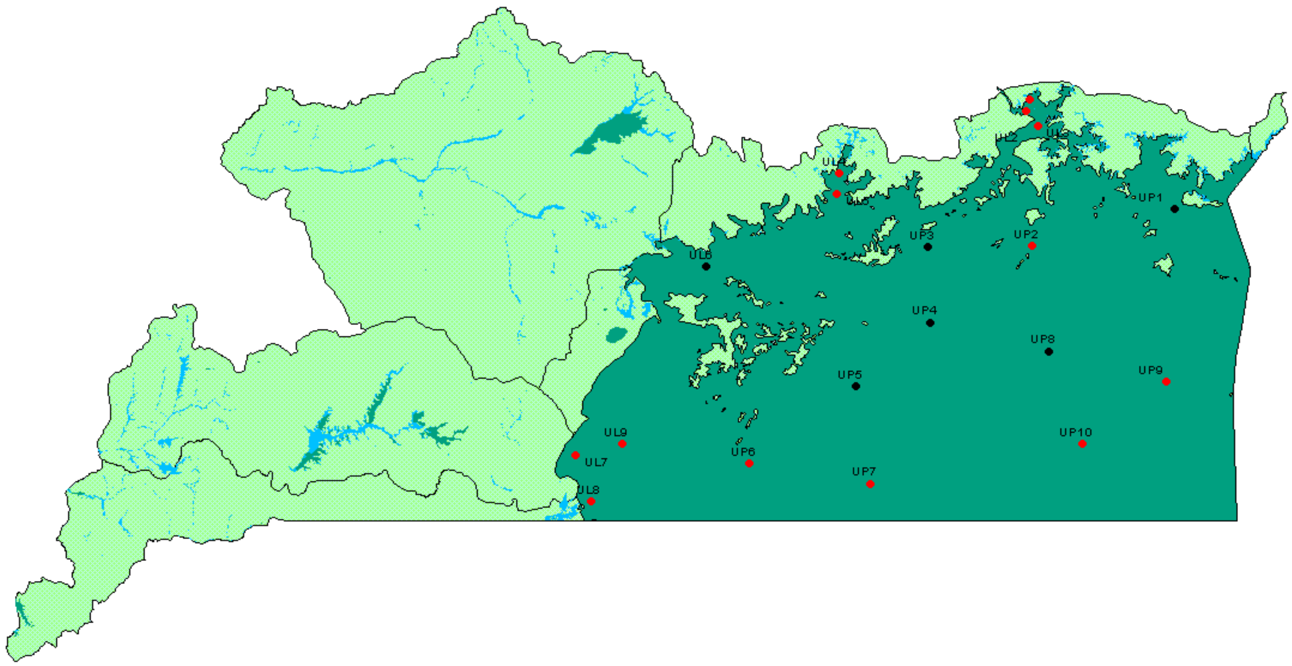

FIG. 1. Location of pelagic and littoral monitoring stations in Lake Victoria, Uganda.

TABLE 2. Summary of the planned cruises.

Station / sampling	Number, Uganda
Nearshore monthly	9
Nearshore quarterly	9
Offshore monthly	6
Offshore quarterly	4
Total annual profiles	196

Sampling Procedures

Pelagic and Littoral Lake Monitoring

The on-board procedure consisted of a number of tasks beginning with recording of position, depth, wind speed, wind direction, air temperature, wave height, wave direction and wave period. These were followed by measurement of secchi depth and recording of profiles for temperature, dissolved oxygen, conductivity, pH, light and current speeds and directions. Column depth and temperature, dissolved oxygen (DO) and light profiles determined the appropriate depths for collection of samples for phytoplankton and zooplankton.

Samples were collected at the following depth:

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)

Ekman dredge samples were taken for benthos quantification and sediment traps deployed and retrieved according to standard procedures (APHA, 1998). Water samples were filtered through glass fibre filters (1μm) for determination of total particulate nitrogen (TPN), total particulate phosphorus (TPP), total particulate carbon (TPC). Samples for chlorophyll determination were filtered through membrane filters (0.45 μm pore size), for total biogenic silicon (TBSi). The filters and filtrate were stored by freezing or kept below $4^{\circ}C$. Phytoplankton samples were preserved with Lugol's solution. Zooplankton samples were filtered through 50 μm net and preserved in 4% formalin while benthos were sieved through 500 μm screen and preserved in 4% formalin.

Field forms covering profiles of physical parameters and water samples were provided for all field personnel. Sampling was done from year 2000 to 2005 (for approximately 52 months). Data was analysed using descriptive statistics. Findings are presented using tables and figures here and in other chapters.

Urban Lake Monitoring Stations

Urban towns in the Uganda catchments which have monitoring stations are Kampala, Jinja and Entebbe. All these towns abstract raw water from Lake Victoria for their drinking water supply and each has a station for monitoring the raw water quality. The monitoring point is located at raw water intake and is part of the process control at the water treatment plant. In the Inner Murchison Bay in Kampala, there are 23 monitoring points, fixed at distance of 250 m apart and covering approximately 25 Km^2 (Figure 2).

Surface currents influenced by both the wind direction and the periodic oscillations of water level caused by seiching in the expanse of water within the lake were measured using an Acoustic Doppler Current Profiler. Water quality data was collected by taking water samples using a water sampler. Samples were taken at surface (0.3 m), mid depth and bottom (0.5 to 1.0 m above the bed). Depths were measured using an Acoustic Doppler Current Profiler and confirmed by depth sampler.

Water samples were analysed at the Water Resources Management Department and National Water and Sewerage Corporation's Central Laboratory. Total nitrogen (TN) and faecal coliforms were determined using standard methods (APHA 1995). Total Dissolved Solids (TDS) were estimated from electrical conductivity readings taken on site by an electric conductivity meter.

Initial wind, air temperature and humidity surveys were carried out to determine the correlation between wind patterns at the chosen locations and those recorded at Entebbe. Wind, air temperature and relative humidity measurement were taken using a hand held digital Kestrel 3000 environmental meter. Wind direction was determined using a hand held windsock and compass. Wind and air temperature data provided by the Meteorological Office at Entebbe was also used.

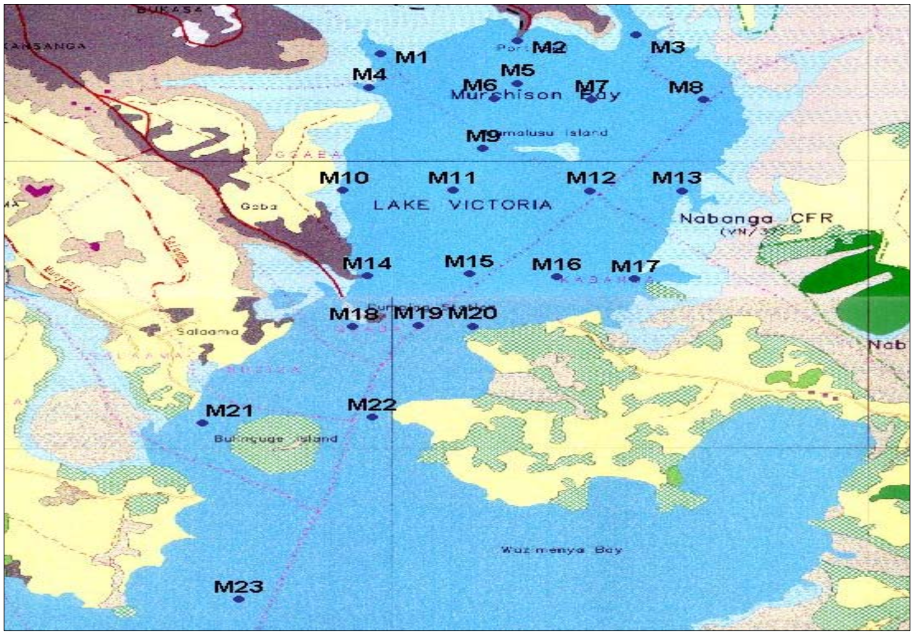

FIG. 2. Murchison Bay Area (M1, M… are sampling points).

Sampling points were located using Garmin 12 Global Positioning System (GPS). This gave locations accurate to about 5 to 8 metres, which was adequate. Three sampling runs were to be carried out on days 1, 3 and 9. In reality, it proved difficult in the case of Murchison Bay to complete a run in one day as the points were many, so sampling was carried out on days 1, 2, 3, 4, 9 and 10.

The frequency of monitoring was based on the objective of the monitoring. Thus the points located at the intake points were monitored on daily basis as part of process control. The 23 stations located in the Inner Murchison Bay are monitored monthly to assess the impact of Nakivubo channel discharge through model simulation.

From the comprehensive program only a few physico-chemical parameters are reported here. Other data are found in the chapters on hydrometeorology, hydraulic conditions and eutrophication.

RESULTS

Lake cruises

The number of cruises that were accomplished is presented in Table 3. During the cruises, the number of stations that were sampled is presented in Table 4. More nearshore cruises were carried out compared to the offshore ones. Most of the offshore cruises were conducted in the year 2001 while in the years 2003 and 2004, very few cruises were conducted.

Urban Lakeshore Water Quality

Figure 3 shows mean electrical conductivity profile at sampling points along the Inner Murchison Bay water starting from the Nakivubo entry point up to the open water outside the bay. Results indicate that the bay appeared to be heavily contaminated at the discharge point where the mean EC was 250 µs/cm. This sharply dropped to 100 µs/cm in the middle of the bay.

TABLE 3. Summary of monitoring cruises carried out from year 2000 to 2005.

Month	**Nearshore**	**Offshore**
Jan-2000	X	
Feb-2000	X	
Apr-2000	X	
Nov-2000	X	X
Dec-2000		
Jan-2001	X	X
Feb-2001	X	X
Mar-2001	X	X
Apr-2001		
May-2001	X	X
Jun-2001	X	X
Jul-2001	X	
Sep-2002	X	X
Aug-2003	X	
Sep-2004	X	
Nov-2004	X	
Feb-2005	X	X
Apr-2005	X	X
Total	**16**	**9**

TABLE 4. Summary of nearshore and offshore stations sampled during the monitoring programme.

Station / sampling	**Number, Uganda**
Number of nearshore stations	9
Number of offshore stations	10
Number of nearshore profiles	1,260
Number of offshore profiles	628
Total number of profiles	1,888
Total number of samples	1,888

Figure 4 shows the total nitrogen (TN) and total phosphorus (TP) profiles in the Inner Murchison bay. TN levels are lower in the Nakivubo area as compared to the middle of the bay and the open water area. On the other hand, the TP levels show a pattern different from that of TN levels. The TP level significantly decreases from the inlet point up to around Gaba area. However, after Gaba area there is no significant change in the TP level. There is changing TN:TP ratios across the bay. TN was kept high probably by N fixation while P was diluted and some sunk into the sediments.

From the middle of the bay up to the open waters, there is no significant change in the mean EC values.

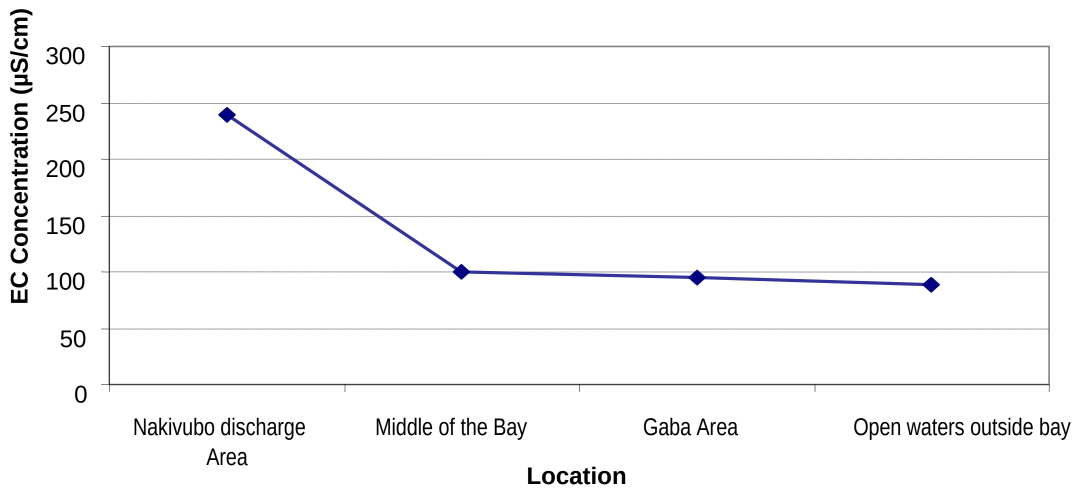

FIG. 3. Inner Murchison Bay mean electrical conductivity (EC) profile from discharge point to open waters.

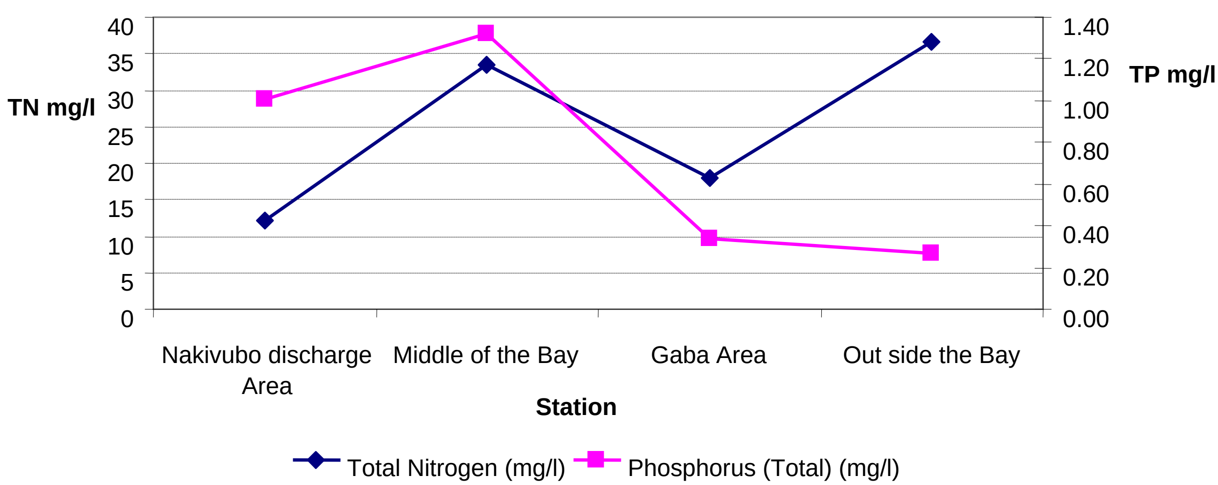

FIG. 4. Inner Murchison Bay mean TN and TP profiles

The levels of BOD and TSS in the bay do not vary significantly with distance from the discharge area towards the open waters. However, there is a strong correlation between the BOD and TSS levels at all the monitoring stations. Figure 5 presents mean values of TSS and BOD in the Inner Murchison Bay. TSS and BOD can be maintained by high algal growth especially N fixing cyanobacteria. This also maintains the PN and TN

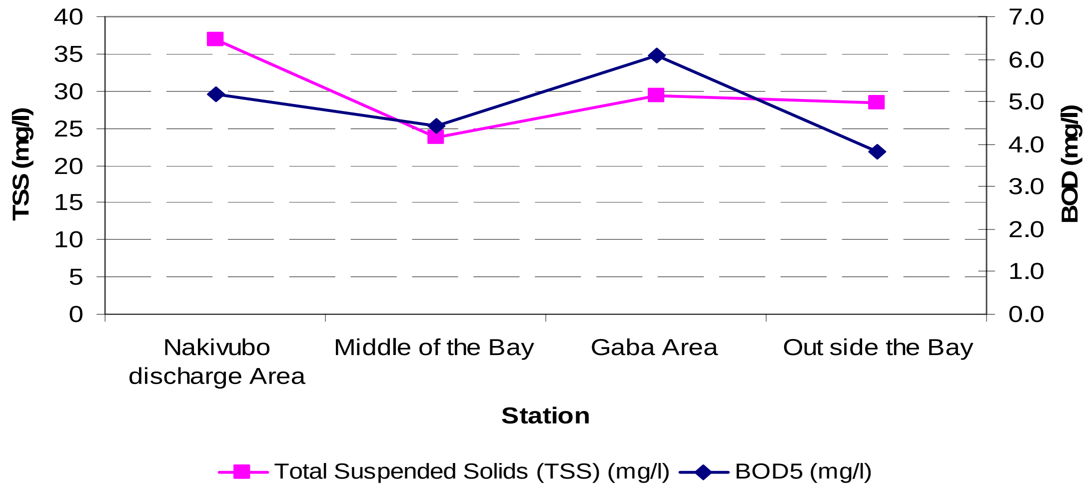

FIG. 5. Mean values of TSS and BOD profiles in the Inner Murchison Bay

Figure 6 presents mean values of faecal coliforms in the Inner Murchison Bay. High counts of faecal coliforms were observed at the Nakivubo discharge area. However, there is a noticeable reduction in faecal coliforms across the bay probably due to dilution factor (see Figure 3), sedimentation as the water flows towards the open water or consumption by bacterivorous organisms. From the middle of the bay up to the open water there is no significant change in the faecal coliforms levels.

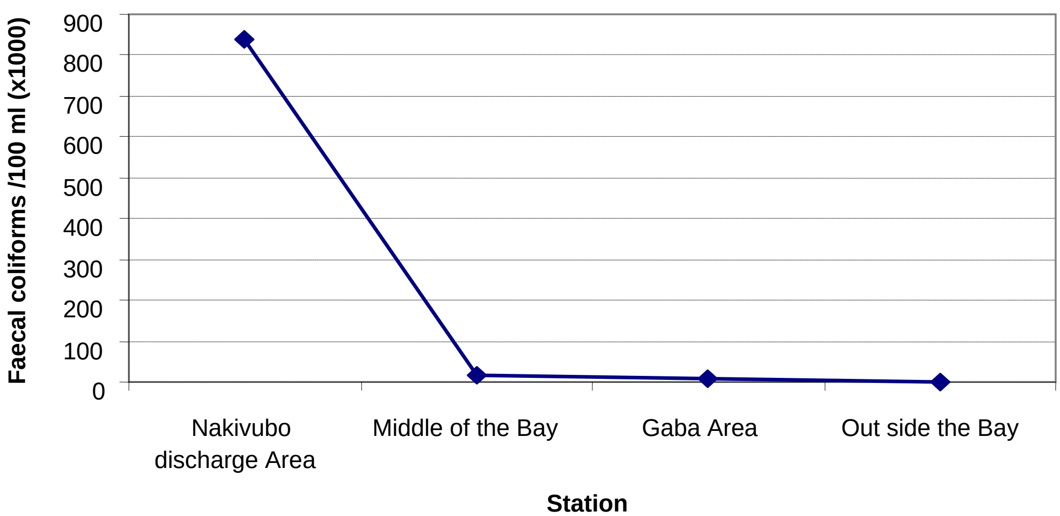

FIG. 6. Mean values of faecal coliforms in the Inner Murchison Bay

DISCUSSION

In the urban lake monitoring stations, the highly turbid waters at discharge points initially suppress algal productivity but by mid bay algal blooms occur. TN concentrations are likely maintained by fixation of nitrogen by cyanobactera. The TP level significantly decreased from the inlet point up to around Gaba area probably due to the uptake and sedimentation of the phosphate. However, after Gaba area there is no significant change in the TP level.

The low variation in the BOD and TSS levels across the Inner Murchison bay is probably due the presence of algal blooms for most part of the bay. The higher mean values at the Nakivubo area is due to the discharge of storm drain water which carries much suspended solids (Bugenyi 1991). This value dropped in the middle part due to the settling of the particulates. The increase around Gaba area is due to enclosed nature of the area which tends to accumulate much of the algae.

The high faecal coliform counts observed at the Nakivubo discharge area may be attributed to the discharge of partially treated sewage effluent from Luzira Prison ponds and Bugolobi sewage treatment plant (Byamukama *et al*. 2000; 2005). However, the observed decrease in numbers of coliforms across the bay may be due to natural die off, lake dilution and sedimentation as the effluent water flows towards the open lake.

CONCLUSIONS AND RECOMMENDATIONS

Pelagic and Littoral Lake Monitoring

The total number of stations visited during the period were 19. In the previous studies, it is observed that the lake is spatially inhomogeneous with regard to hydraulic conditions and eutrophication levels. It is therefore recommended that all stations be retained until a more complete picture of this variability is obtained.

During the period from January 2000 to April 2005, 1,888 profiles of water quality samples were taken out of the 8,990 profiles planned for a 65 month period. Seventy percent of the planned cruises were not carried out due to, among other things, the unavailability of cruise vessels, although the main problems were financial and logistical.

The time spent per cruise varied from 7-15 days. The time for cruising is a factor limiting the capacity for the monitoring programme. Staff from the laboratory participating in the cruises are blocked from doing laboratory work during the cruise time and, moreover, some analyses are time-limited and cannot be made if the samples arrive late to the laboratory.

It is recommended that the original plan of one cruise per month be retained. The observed temporal variations in the state of the lake show that monthly cruises are required to resolve the changes that occur.

For cruises in the immediate future, it is recommended that planning and co-ordination with all parties concerned be improved.

Delays in the flow of funds for consumables and planned cruises should be avoided in future. Monitoring is indispensable, without it there are no possibilities for rational management.

For the next phase of LVEMP, it is recommended that a fast survey vessel be procured for the component for cruises to be completed in much shorter time. This would give the survey and laboratory staff more time for other activities.

With regard to field equipment, the following recommendations are made:

- Water sampling equipment (bigger water samplers and winches) should be procured.
- Reliable communication (satellite telephones) and navigation equipment should be installed on all survey vessels. Equally important, contingency plans for rescue operations should be put in place.

The monitoring teams experienced a number of technical problems with the survey vessels during the cruises as well as accidents. For example, an engine failure left the RV Ibis helpless on the lake for several days. It was extremely fortunate that Kisumu could be contacted by radio call to get help.

Urban Lake Monitoring

For the Inner Murchison Bay, the results indicated that Gaba water supply intake was still suitable as a source of raw water for Gaba Water Treatment Plant. However, if pollution continues to increase, as it will if no pollution control actions are taken, then within few years the water quality at Gaba will have deteriorated to a point where it will no longer be suitable to be a raw water source.

The main public health benefit for both water quality and sanitation interventions lies in the reduction of faecal-oral diseases. Good water quality is important as faecally contaminated water can lead to direct ingestion of disease-causing organisms. Therefore, to reduce water bone diseases transmission from faecal material, sanitation facilities improvement and effective hygiene promotion are very important to the protection of the water quality (Clare, 1998). Species of cyanobacteria produce toxins that are a serious health risk to humans. These toxins have been confirmed in IMB water. Current water treatment for Kampala removes these toxins but people taking water directly from the lake are exposed, these bloom forming cyanobacteria also clog the intake filters and increase treatment costs at the Gabba plant (see Chapter 5, Industrial and Municipal Loadings).

Recommendations include:

- To protect Gaba water supply intake, sanitation and waste handling in Gaba landing site be given high priority.
- To maintain the water quality status in Inner Murchison Bay pollution reduction is needed. Based on the information collected during the project the following annual reduction in loads is required to match increasing loads from increasing population (BOD 58 tonnes /year, total nitrogen 16 tonnes/year and total phosphorus 11.5 tonnes/year) (MottMacDonold, and M&E Associates, 2001**)**.
- The Inner Murchison Bay model should be developed to include additional parameters such as BOD, chlorophyll and phosphorus to enable species study interaction with benthic layers.

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