LAKE VICTORIA ENVIRONMENT REPORT - UGANDA
WATER QUALITY AND ECOSYSTEMS STATUS
SUMMARY

1.0 BACKGROUND

1.1 Coverage of the Report

The report summarises findings and gives the current state of the lake basin water quality and quantity based on the following aspects:

- Lake monitoring
- Meteorology and hydrology
- Non-point pollution
- Industrial and municipal effluent Management
- Hydraulic conditions
- Sedimentation
- Eutrophication in Lake Victoria
- Pesticides and Heavy Metals
- Water quality and health
- The impacts of water quality change on beneficial uses of Lake Victoria
- Recommendations for action in LVEMP II are presented at the end of each topic

2.0 Lake Monitoring

Water quality study results indicate that the Inner Murchison bay is heavily contaminated especially at the discharge point where the mean electrical conductivity (EC) was 250 µs/cm. This is supported by high total nitrogen (TN) and total phosphorus (TP) profiles in the bay. TN level is kept high by N fixation while P is diluted and adsorbed to sediments.

The levels of biochemical oxygen demand (BOD_5) 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_5 and TSS levels at all the monitoring stations. Total suspended solids (TSS) and BOD_5 are maintained by high algal growth especially nitrogen-fixing cyanobacteria. This also maintains the high levels of PN and TN.

High counts of faecal coliforms were observed at the Nakivubo discharge area. However, there is a noticeable reduction of the faecal coliforms bacteria across the bay may be due to the dilution as the water flows towards the open lake.

The low variation in the BOD_5 and TSS levels across the Inner Murchison bay is probably due to the presence of algal bloom in most part of the bay. The high BOD_5 values at the Nakivubo area is due to the discharge of storm drain water which carries much suspended solids.

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 plants.

2.1 Conclusions and Recommendations

Results indicated that Gabba water supply intake was still suitable as a source of raw water for Gaba Water Treatment Plant. However, if pollution continues to increase, the water quality at Gaba will eventually deteriorate to a point where it will no longer be suitable as 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 borne diseases transmission from faecal material, sanitation facilities improvement and effective hygiene promotion are very important to the protection of the water. The current low N:P ratio of IMB maintained by the sewage and urban runoff creates a nitrogen deficit that favours nitrogen fixing and non-fixing low nitrogen specialized cyanobacteria. Species of these 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 Gabba.

3.0 Hydrology and Meteorology

Quantification of lake water inflows and outflows is essential for understanding the quality and hydro dynamics of a lake system. Hydro-metrological data for the period running 1950-2004 was analysed to provide flows for estimating pollution loads into Lake Victoria from the Ugandan side of the lake. These also form input to the lake water balance. Continuous rainfall and evaporation records were generated. Full records of land discharge 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 indicated that Uganda's land catchment annual contribution to Lake Victoria is about 312 Million m^3/s; forming about 1.3% of the total land discharge. The mean annual rainfall over the Ugandan side of the lake is about 2020 mm and this forms 35.2% of the mean annual lake rainfall. No significant trends in rainfall were observed over the period of study. Evaporation was less than rainfall by a factor of 0.66 implying that the Ugandan sector of the lake plays an important role in determining the lake's Net Basin Supply.

Examination of the lake levels in relation to the River Nile outflow shows that there has been a close relationship between the levels and amount of water released through the Owen Falls dam implying that the natural process of the lake has always been followed. However this relationship was interrupted since 2000, which partially explains the drastic fall in Lake Victoria levels. The disparity between the two parameters continued and reached its peak in July 2004.

3.1 Temperature variability

Observed records show that temperature reaches a maximum in February, just before the March equinox (date when sun is overhead equator or the tropics of Cancer and Capricorn) and gets its lowest records in July after the June equinox.

3.2 Wind patterns

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. In the months of January-February and June-September, the wind pattern is predominantly East West, parallel to the equator, with origins from the Nandi hills in western Kenya. These are fairly dry winds. The moisture they pick are deposited to the western catchments especially Bukora catchment. During the period of March-May and October-December, the wind pattern changes towards the northern parts of the lake.

3.3 Catchments rainfall on Lake Victoria, Uganda

The rainfall pattern over the lake and land areas of the basin exhibits a typical bimodal characteristic. The pattern shows that the lowest rainfall amounts fall in the months of August and September for pre-LVEMP and LVEMP periods. The Second and equally severe low spell occur in February each year for both periods. On the other hand, peak rainfall totals annually occur in April for both pre-LVEMP and LVEMP periods. This pattern closely resembles the wind pattern already described where the winds in January-February and June-September are predominantly westerly. For the months when peak rainfalls occur, seasonal winds are observed to be a convergence of south-westerly and south-easterly winds. This observation reveals a strong influence of winds on rainfall incidence in and around Lake Victoria. Table 3.1 shows the rainfall statistics for both periods.

Table 3.1 Annual mean, maximum and minimum rainfall (mm) for the pre and LVEMP periods

	Bukora	Katonga	Northern Shore streams	Average	Lake Rain
Pre-LVEMP Average	882	948	1307	984	2011
Average LVEMP	838	1048	1426	1043	2241
% of Average	95	111	109	106	111
Monthly maximum (pre-LVEMP	1375	1340	2290	1379	3114
Monthly maximum (LVEMP)	1035	1265	1734	1244	2868
Monthly minimum (pre-LVEMP)	674	560	916	664	1374
Monthly minimum (LVEMP)	677	810	1111	873	1378

Spatially, the rainfall pattern shows influence of relief and location with regard to rainfall incidence. The highest rainfall in Uganda (including the rest of Lake Victoria Basin) is received around the Ssesse Islands. This reaches totals of about 2,400 mm annually. On reaching land to the west and north-west of the lake, most of the moisture is deposited and the rain shadow effect is felt from Bukakata towards River Bukora and some parts of River Katonga.

3.4 Lake rainfall

The estimate of lake rainfall for the Uganda sector puts the mean annual rainfall at 2020mm occurring over the lake. Annual lake rainfall during the LVEMP period was 11% above the mean annual lake rainfall. According to the weights awarded to each of the lake's rain boxes, Uganda's annual contribution to the lake is approximately 35.2% of the total mean annual lake rain which translates into 711mm of rainfall.

On average, Kalangala received the highest rainfall for the period 1950 – 2004. Bumangi, Buvuma and Bukasa closely followed the rainfall level of Kalangala.

3.5 Lake evaporation estimation

Computation of lake evaporation suggests that evaporation tendencies are relatively homogeneous compared to rainfall. The deviation from the mean annual evaporation is 155mm as compared to 270mm for the mean annual rainfall. Evaporation from the Uganda part is less than rainfall by a factor of 0.66 and accounts for 29.9% of the lake evaporation.

3.6 River discharges

Computation of the mean discharge illustrates that the Uganda part of Lake Victoria catchment contributes about 312 million m^3/s to the lake, which is approximately 1.3% of the total land catchments discharge. Results further show that of the three Ugandan catchments, Katonga has the highest variation in monthly flows with a standard deviation of 1.74 m^3/s and the northern streams having the least variation in monthly flows with a standard deviation of 0.52 m^3/s (Table 3.2).

Table 3.2 Monthly means from rainfall-discharge modelling 1950-2005 for all catchments and total national contribution

	River Bukora	River Katonga	Northern shore streams	Whole Uganda Catchment
Area (km^2)	8392.00	15244.00	4288.00	27924.00
Average flow (m^3/s)	3.24	5.17	1.48	9.89
Std	1.15	1.74	0.52	2.96
Max m^3/s)	5.45	8.10	2.46	15.59
Min m^3/s)	1.84	3.11	0.85	6.59
Annual flow (MCM)	102.00	163.00	47.00	312.00
Flow (mm)	12.20	10.70	10.90	11.20
Annual Rainfall (mm)	882.00	938.00	1295.00	976.00
Runoff coefficient	1.38	1.14	0.84	1.14

3.7 Lake Victoria levels

Prior to 1961 the average annual Lake Victoria level was 1133.93m above mean sea level (AMSL). Following the intense rains of 1961 through 1964, the lake level rose by 2.34m in a period of two and half years. The lake has since remained at relatively higher levels at an average of 1134.97m (AMSL) for the period 1960-2004 (Figure 3.1). The long-term average lake level (1950-2004) is 1134.77m (AMSL). For the last 40 years, the lake levels have exhibited a significant downward trend with drastic drops occurring in the period 2001 - 2004. The year 2004 (in November) recorded the lowest level at 1133.96m which picked up to 1134.l8m at the end of the year.

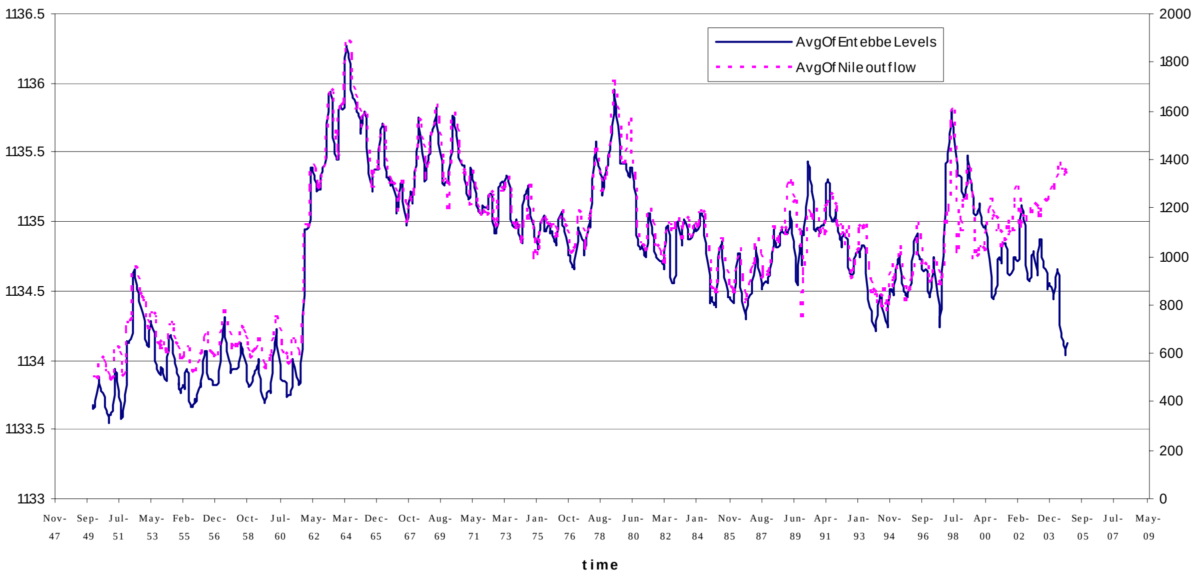

Figure 3.1 Lake Victoria levels and the River Nile outflow

3.8 Hydro-meteorological trends over observed historical records

In general, there is an upward linear trend in rainfall on the Uganda Lake Victoria basin. Lake Victoria rainfall exhibits a steeper trend gradient than catchment rainfall. However examination of the LVEMP period shows that lake rainfall is on a downward trend with a trend gradient about two times the pre-LVEMP period. Catchment rainfall has continued to follow an upward trend but with a gradient of four fold of the pre LVEMP period.

Lake levels have been observed to have decreased especially after the year 2002. It is probable that the lake level would have finally reverted to its pre–1960 levels which are considered as the natural levels. However this process has apparently been accelerated by the reservoir-release practices at the Owen Falls dam. The Owen Falls reservoir operation policy follows a rule that restricts the amount of water flowing through the dam to that which would have flowed had the dam not been in place. It is represented by a mathematical equation (equation 1) agreed upon between Britain and Egypt in 1954. The equation was derived from water level-discharge relationship established at the then Rippon Falls. It must be noted that when the level-discharge rating was done at Rippon Falls, flow was unregulated, as it is the case now. As expected if this rule is violated, releases into the River Nile can affect the lake level to a great extent due to the interconnectivity of the hydro-power reservoir and the lake.

$$Q = 132.923(h-8.486)^{1.686} \ldots\ldots\ldots\ldots\ldots\ldots \text{Equation 1.}$$

Where: Q is discharge and
h is elevation (above mean sea level, a.m.s.l.)

The stipulated release policy was closely followed until 2002. This deviation from the historical release policy partly explains the accelerated drop in water level in the recent. The observed minimum lake level in the last 40 years is still within the natural fluctuating band of the lake.

On the other hand, it has been noted that the stipulated release policy does not represent the optimum way of utilising the lake resource. The increasing economic development in Uganda implies increasing power demand. There should always be enough water for power generation so as to meet the demand. To ensure this, there should be storage during periods of high inflow to boost generation during low flows.

3.9 Conclusions and Recommendations

3.9.1 Conclusions

Generally there is an upward trend in rainfall over the Ugandan sector of Lake Victoria basin. It is expected that this general upward trend will continue for the near future.

The variation in water levels of Lake Victoria is determined by interplay between hydrological processes that bring water into and take it away from the lake. Presently the declining levels of Lake Victoria are of utmost environmental concern. General absence / limited rains on the lake in recent years resulted in falling of lake levels. Increased outflows at the Owen Falls dam for power generation resulted in a further fall in lake levels by about 0.34 m from 2001 - 2004.

The deviation from the historical release policy for the power reservoir operation has partly contributed to the accelerated drop in lake level. Complete understanding of the process necessitates computing the Net Basin Supply to the lake.

3.9.2 Recommendations

(a) There should be increased and consistent relevant data collection in Uganda and the riparian countries in general.
(b) There is need to constantly update the water budget for Lake Victoria using national and regional data from the riparian countries.
(c) Efforts should be made to determine the role played by groundwater in the water budget of Lake Victoria.
(d) Efforts should be made to synchronise water quality and quantity data collection to make it possible to relate the water budget to water quality conditions.
(e) Data collection equipment and instruments should be procured and standardized so that uniform data can be collected and used.
(f) More studies on water circulation are required to understand fully the dynamics within the lake.
(g) Gauging stations for the ungauged catchments should be established as soon as possible.

Undertake intensive studies on the possibility of regulating the lake to increase its potential towards sustainable exploitation for socio-economic development of the riparian states.

4.0 Non-point pollution into the Uganda catchment

Estimates of nutrient loading are essential for understanding primary productivity and ecosystem function and for planning nutrient management strategies. This is particularly important for the Lake Victoria which is believed to have reached a critical degradation stage. Two sub-catchments, namely Katonga and Bukora, were investigated in this study. Rivers draining the two sub-catchments were sampled from 1998 to 2004 intensively during the growing period, and at least monthly for the remaining periods of the year. Water samples were analysed for seventeen water quality parameters including Total Suspended Solid (TSS 105^{o}C and TSS 500^{o}C), Total Nitrogen (TN) and Total Phosphorus (TP). Concurrently rainfall samples were collected from Bukasa, Entebbe and Lolui stations representing the three isohyets zones of Lake Victoria for atmospheric wet deposition estimation. Atmospheric deposition samples were collected and analysed for the seventeen parameters, including TSS, TN and TP. Results showed that the TSS, organic matter (OM) and TN concentrations were catchment dependent. Bukora had significantly higher concentrations for TSS and OM, and lower TN concentrations compared to Katonga ($P<0.01$). The TP concentrations were similar in Katonga and Bukora, and increased linearly with time ($p=0.05$). The concentration of TSS fluctuated during the six years of study, with a peak in 2000 for Bukora and 2001 for Katonga ($p<0.05$). TSS also fluctuated significantly only in Bukora and showed a peak in 2001 ($p<0.05$). The two sub-catchments loaded 2.1 t/day of total nitrogen and 0.3 t/day of total phosphorus in average for the six years, confirming the relatively small contribution of the catchment into the Lake compared to atmospheric deposition, which loaded 26.4 t/day of TN and 5.6 t/day for TP from the wet deposition.

4.1 Average overall concentrations and loads

The TSS, OM and TN concentrations were stream dependent (Table 4.1). River Bukora maintained significantly higher concentrations of TSS and OM compared to the other two streams, while River Katonga had the lowest ($P<0.01$). Conversely, TN concentration was highest for Katonga and lowest for Bukora ($P<0.01$).

Table 4.1 Differences in selected water quality parameters as observed in the three streams (6-year means)

Stream	TSS (105°C)	TSS (500°C)	OM	TN	TP
	mg/l				
Bukora	305.0	229.1	75.6	0.82	0.21
Katonga	19.0	11.8	7.5	4.03	0.21
Kisoma	202.0	150.7	51.7	1.18	0.23
LSD(0.05)	54.5	42.2	17.9	1.34	NS

Overall, Bukora maintained significantly higher flow rate over the six years than the other two streams ($P<0.05$), with Kisoma, which is a much smaller stream, having the lowest flow (Table 4.2). Correspondingly, TSS (105°C), TSS (500°C) and OM loads were significantly higher for Bukora and lowest for Kisoma ($P<0.05$). Mean TP load was slightly higher for Bukora than that of Kisoma ($P<0.10$) while TN loads for the three streams were not significantly different.

Table 4.2 Main effect of difference in stream on flow and pollutant loads (6-year means)

Stream	Flow	TSS [105°C]	TSS [500°C]	OM	TN	TP
	m^3/s	ton/day				
Bukora	7.04	129.9	63.3	21.3	0.76	$0.25^{\#}$
Katonga	2.31	9.1	5.9	7.4	1.06	0.07
Kisoma	0.54	5.9	3.4	1.1	0.07	0.01
LSD(0.05)	3.25	49.6	12.7	10.7	NS	0.21

$^{\#}$ Significant difference at $P<0.10$

4.2 Annual trends of pollutant concentrations and loads

Mean annual TSS concentrations fluctuated irregularly during the 6 years of this study, with peak values observed in 2000 for Bukora, 2001 for Katonga and 2004 for Kisoma. The lowest values for TSS concentration occurred in 2002 for all three streams. These variations were statistically significant for Bukora and Kisoma ($P<0.05$), but not for Katonga. Like TSS, organic matter (OM) concentrations fluctuated irregularly across the years. There is a progressive increment in TN concentrations for Bukora and Kisoma over the six years of monitoring, with peak TN values observed in 2003.

There was an overall linear increment in TP concentration for all three sites over the six years, with lowest TP values in 1998. The TP concentration was positively correlated with TSS (500^{o}C): $TP = 0.0011*TSS – 0.022$; $R^2=0.45$, $P<0.05$ for Kisoma. The six years trend in loads of TSS (105 and 500 ^{o}C), and OM was similar in Bukora, while no variation was observed for all the parameters in Katonga ($p<0.05$). TSS (105 and 500 ^{o}C) and OM loads fluctuated over the years, with peaks occurring every two years after 1998.

4.3 Seasonal trends of pollutant concentrations and loads

Table 4.3 presents data for seasonal effects on the flow and concentrations of different parameters. Data presented are mean values for the three rivers, averaged over a 6-year period. Overall, flow was highest during the long rains season (March 15th to June 30th) and lowest during the short rains (1st September to 15th December), although the differences in flow were not statistically significant across different seasons. Conversely, TN concentrations were highest during the short rains (periods of lowest flow) and lowest during the long rains ($P<0.05$). However, these seasonal differences were not significant for TSS, OM and TP.

Table 4.3 Seasonal concentrations of pollutants (6-year means)

Stream	Flow	TSS (105^{o}C)	TSS (500^{o}C)	OM	TN	TP
	M^3/s	mg/L				
Dry season	3.00	163.8	147.2	51.2	2.03	0.21
Long rains	4.94	140.8	119.4	44.8	0.95	0.28
Short rains	1.99	165.4	119.1	60.0	3.05	0.14
LSD(0.05)	NS	NS	NS	NS	1.34	NS

Generally, the flow had moderate and significant linear relationship with TSS (105 ^{o}C), OM and TSS (500 ^{o}C) in Bukora. The correlation between TSS 105 ^{o}C and flow is strong during the long rains for Kisoma and Bukora ($R^2 = 0.51$; $R^2 = 0.49$ respectively), and moderate or low for the other periods. TSS 105 ^{o}C decreased with flow for Kisoma and Bukora.

TN decreased with flow during the dry season in Bukora ($R^2=0.60$), ($p<0.05$). TP increased moderately with flow during the long rains, and decreased exponentially with it for the two other seasons ($p<0.05$). Organic matter was independent of flow for all seasons and all rivers ($p=0.05$).

Table 4.3 presents data for pollutant loads as affected by differences in seasons. The TSS (500^{o}C) load was highest during the long rains (season of highest flow) and lowest during the short rains ($P<0.10$).

Table 4.3 Main effect of seasonal differences on the pollutant loads (6-year means)

Season	TSS (105°C)	TSS (500°C)	OM	TN	TP
	ton/day				
Dry season	47.6	19.7[#]	10.2	0.39	0.06
Long rains	67.7	40.7	14.7	0.76	0.24
Short rains	29.5	12.1	4.9	0.74	0.03
LSD(0.05)	NS	12.7	NS	NS	NS

[#] Means are significantly different at 10% level.

4.4 Total loads

The average catchment loads for the different water quality parameters is presented in Table 4.4. The export per unit area is relatively higher in Bukora sub-catchment compared to Katonga. The export of TN, TP and TSS from Bukora was one and half times greater for TN, six times for TP and about thirty times greater than the corresponding value from Katonga.

Table 4.4 Average annual loads of total nitrogen, total phosphorus and suspended solid from the catchment and atmospheric deposition.

Source	Location	TN	TP	TSS
		Kg/yr/km^2		
Catchment	Bukora	41.0	12.8	6702.8
	Katonga	27.8	1.8	238.4
Wet atmospheric deposition	Box 12	1038.5	141.9	2534.2
	Box 13	1897.7	159.7	3726.8
	Box 14	469.9	207.8	4281.2

Results show that most of the load comes from the atmosphere for nutrients (TP and TN), the catchment contribution being only 7% for TN and about 5% for TP.

4.5 Conclusions and recommendations

Bukora and Katonga drain from relatively wider catchment, meaning that most of the river discharge measured reflect multitude of conditions even in the far upstream position.

The difference in the loads between Bukora and Katonga may also be attributed to the difference in sizes. In the Lake Victoria, the Bukora (8,392 km^2) exports 30 times more sediments than Katonga (15,244 km^2). It is believed that smaller catchments are generally steeper, and so tend to exhibit higher specific sediment yields. Bukora has many rounded and flat topped hills, with slope steepness reaching 30° angle while Katonga is made of plateaus with relatively lower steepness.

There was high correlation between soil type and land-use/cover distribution in both sub-catchments, although Bukora sub-catchment soils are very rich in phosphorus and organic matter compared to those of Katonga (Majaliwa, 2005; Mulebeke, 2004). Generally, perennial crops are grown on deep soils, while rangelands, which generate most of the runoff, are established on very shallow soils of ridge summits. In the catchment, degraded rangelands have been identified as hot spot areas for sediments and nutrients exports. The distribution and the cover status of this particular land-use are different for both catchments. Experimental measurements have demonstrated that in the two sub-catchments, soil loss in Bukora from rangelands was about twenty times the value recorded in Katonga mainly because of poor ground cover in Bukora sub-catchment.

Land-use management is perhaps the most important factor amplifying soil erosion. Lake Victoria catchment rivers passing through forested lands are less enriched by nutrient as compared to those crossing agricultural lands. In the Lake Victoria catchment, land-use types highly susceptible to erosion are those located on very steep slopes and more often coupled with poor land management (Majaliwa, 2005; Mulebeke, 2004). Studies have demonstrated that atmospheric deposition load increases are associated with increased burning and soil erosion in the catchment, emphasizing the role played by the land-use systems and management in the deterioration of the quality of the Lake Victoria and its tributaries. Bukora being an area with intensive livestock rearing, the difference in the levels and loads of pollutants with Katonga could also be attributed to mismanagement of animal waste associated with open grazing. These changes reflect increasing land-use/cover and soil degradation in the two sub-catchments.

Atmospheric deposition remains the major contributor of TN and TP loads into Lake Victoria. TP and TN from the atmosphere arise from several local and regional sources. The major sources of nitrogen in the atmosphere include burning of fossil fuels and vegetation, volatilization from feed lots and fertilizer fields. Phosphorus deposition may also arise from phosphorus rich soil particles originating from fertilized and exposed agricultural fields or heavily grazed lands.

It is therefore recommended that:

- Non-point pollution loading should be controlled in the catchment by adopting best management practices, which have been identified, including contour bunds, mulching and afforestation of bare and degraded hills and other marginal lands which are potential sources of sediments and nutrients into the lake. These practices have also been shown to improve the productivity of farm plots and so the benefits accrue to the farmer as well as the lake.
- Sensitization of people within the catchment on the use of best management should intensify in order to increase the rate of adoption of these technologies and therefore reduce ‘flushier loads’ and flash flooding. Priority should also be given to marginal land cropped to annuals and degraded hillsides which are potential sources of runoff, soil and phosphorus.
- Activities leading to increases in atmospheric deposition such as biomass burning, overgrazing should be controlled in the catchment.
- 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 Lake Victoria.
- Monitoring of the northern shore streams should be initiated in order to estimate the contribution of this sub-catchment, and the whole catchment into Lake Victoria and monitor improvements in water quality to be expected with better land management practices.

5.0 Industrial and Municipal Effluents Management

The Industrial and Municipal Waste Management component of the Lake Victoria Environmental Management project carried out an assessment to determine pollutant loads from point sources, which included industrial and municipal effluents and urban run-off from the Uganda catchment of the lake. Identification of pollution hotspots that pose threats to Lake Victoria was done, and the fishing villages were found to have significant impacts because of their high number, population density and proximity to the lake. Similarly, factories in Kampala, Jinja and Entebbe with potential threats were identified. The results show that each day 14.17 tons of biochemical oxygen demand (BOD_5), 2.91tons of Nitrogen and 2.21 tons of phosphorus are discharged into the lake from urban centres, while 2.96 tons of BOD_5, 0.37 tons of nitrogen and 0.19 tons of phosphorus are discharged daily from 124 fishing villages with a total population of 92,000. Industrial loads reaching the lake were estimated to be 2.52 tons of BOD_5, 0.34 tons of nitrogen and 0.11 tons of phosphorus per day. These values show that the major threat comes from urban centres which are responsible for nearly 70% of BOD_5 and 80% of the nutrient loading into Lake Victoria. Kampala city accounts for about 60% of the discharging population and 65% of the total BOD_5 load. Studies on the use of natural and constructed wetlands showed that they can play a significant role in further reduction of pollutants from municipal and industrial effluents.

Pollution management strategies proposed for urban centres focus on improved garbage collection and sanitation, particularly in the Nakivubo catchment of Kampala and more proactive protection of wetlands. Sanitation improvements advocated include improved operation and maintenance of the existing municipal wastewater treatment works, strengthening of process engineering expertise, use of wetlands to treat effluents and greater on-site sanitation coverage. Similarly, sanitation recommendations apply for fishing villages but here the strategy is to focus on improving the ability of fishing village communities to help themselves through awareness raising programs and how to lobby for local development funding. The strategy for industries is adoption of ‘cleaner production’ and use of the Pollution Control Manual for training and guidance, strengthening of process design capacity, a staged approach to treatment plant development and strengthening of discharge agreements.

5.1 Municipal sewage treatment

The final effluent quality from Bugolobi sewage treatment plant recorded 68% and 89% frequency of non compliance with the national standard for total suspended solids and BOD_5, respectively. On the other hand, the final effluent quality from the Kirinya wastewater stabilization ponds recorded 77% and 89% frequency of non compliance with the national standard for TP and TN, respectively.

5.2 Industrial pollution

Out of the 16 monthly average data sets, BOD_5 was non compliant all the time, TP 50%, TN 69% and TSS 75%. COD was 93% of the time non compliant. The monitored parameters were most of the time above the national standards for discharge into the environment.

5.3 Load Discharged to Lake Victoria

The pollution loading is categorized according to whether it is from urban centres, industries or fishing villages. Kampala, Masaka, Rakai and Mpigi districts account for 82% of the BOD load, 86 % of the total Nitrogen load and 87% of the phosphorus load discharged from urban centres and fishing villages.

Fishing villages account for about 25% of the BOD_5 load, 20% of the TN load and 15% of the phosphorus load discharged from urban centres and fishing villages.

The estimated urban population in Uganda that contributes to the pollution load into the lake is about 1,220,000 (2002 Population Census). The total pollution load discharged to the environment, but not directly to the lake was calculated for all three categories of waste generation sources. Percentage contribution of the sources to the total pollution loading is shown in Table 5.1.

Table 5.1 Pollution loading (Kg/day) from main point sources

Point Source Type	BOD_5	TN	TP
Urban Centres	50,313	6,289	3,145
Fishing Villages	2,325	291	146
Industry	7,056	2,184	683
Totals	**59,694**	**8,764**	**3,974**

The estimated total loads discharged from urban centres, fishing villages and industry into Lake Victoria after passing through wetlands, river systems and other natural purification systems is summarized in Table 5.2.

Table 5.2 Pollution loading (Kg/day) reaching Lake Victoria

Point Source Type	BOD_5	TN	TP
Urban Centres	14,166	2,911	2212
Fishing Villages	2,960	366	190
Industry	2,520	341	105
Totals	**19,646**	**3,618**	**2,507**

Based on the data collected, Kampala accounts for about 65% of the BOD and 73% of the total Nitrogen and 73% of the phosphorus load discharged from the urban centres into Lake Victoria. Mpigi District accounts for about 20% of the BOD load, 12% of the TN load and 11% of the TP load. Contributions from urban centres in other districts are relatively small.

5.4 Urban Pollution Loading

The loads are represented by district and the summary of these loads is given in Table 5.3. These loads are based on domestic wastewater and garbage generation and do not take into account industrial loads.

Table 5.3 Basic Pollution Loading (Kg/day) from Urban Centers

Urban Centre (City/Town)	Population Year 2000	Pop'n Est. Year 2005	Pollutant Loads (Kg/day)		
			BOD_5	TN	TP
Busia	37,601	46,061	18.42	2.30	1.15
Entebbe	83,592	102,400	4,095.99	512.00	256.00
Jinja	97,354	119,258	2,862.20	357.77	178.89
Kampala	688,830	843,817	33,752.69	4,219.09	2,109.54
Lukaya	10,200	12,495	478.43	59.80	29.90
Masaka	101,663	124,537	4,981.51	622.69	311.34
Mbarara	73,000	89,425	3,576.99	447.12	223.56
Mpigi	11,167	13,679	547.17	68.40	34.20
Totals	**1,103,406**	**1,351,673**	**50,313**	**6,289**	**3,145**

5.5 Industrial Pollution Loading

The largest polluters that discharge eventually into Lake Victoria and the load that they discharge into the environment are shown in Table 5.4. Results show that Uganda Breweries accounts for about 80% of the BOD load, 85% of the COD load, 93% of the total suspended solids load, 60% of the total nitrogen load and 82% of the phosphorus load discharged by factories into the lake.

Table 5.4 Pollution Loading (Kg/day) from selected Industries reaching Lake Victoria

Factory	BOD	TN	TP	Receiving environment
Uganda Breweries	1,272	233.9	26.3	Lake Victoria
Britania Products	348	3.1	1.3	Kinawataka wetland
Mukwano Soap and Oil	8	0.5	0.3	Nakivubo wetland
City Abattoir	150	15.9	10.5	Nakivubo wetland
Uganda Meat Packers	99	11.4	6.0	Nakivubo wetland
Nakasero Soap Works	17	0.6	0.3	Nakivubo wetland
Greenfield Entebbe	40	10.5	2.5	Lake Victoria
Hwang Sung Fish	26	6.9	2.5	Kinawataka wetland
Century Bottlers	107	12.0	2.3	Namanve-Wankolokolo
Uganda Fish Packer	151	14.8	40.8	Kinawataka wetland
Ngege Fish	115	9.2	9.3	Nakivubo wetland
Crown Bottlers	187	22.3	2.8	Kinawataka wetland
Total	**2,520**	**341**	**105**	

5.6 Pilot projects

5.6.1 Tertiary municipal effluent treatment

Electrical conductivity (EC) was used as a tracer. The EC reduced indicating improvement in the water quality as the water flows through the wetland towards Napoleon Gulf. Generally, the faecal coliforms levels also followed similar trend to that of EC. The concentration of nitrogen and phosphorus along transects were significantly higher. It seems there is a release of these nutrients probably due to mineralisation of plant material, which could have been accelerated by more water flowing along the wetland after bio-manipulation.

5.6.2 Tertiary industrial effluent treatment

There was an increase in the pH average values in the wetland system. On the other hand there was a general reduction in BOD, ammonia and COD in both the water hyacinth and papyrus set-ups.

The variation of key wastewater quality parameters with depth is presented in Figure 5.1. There was a reduction in the COD with depth and along the wetland.

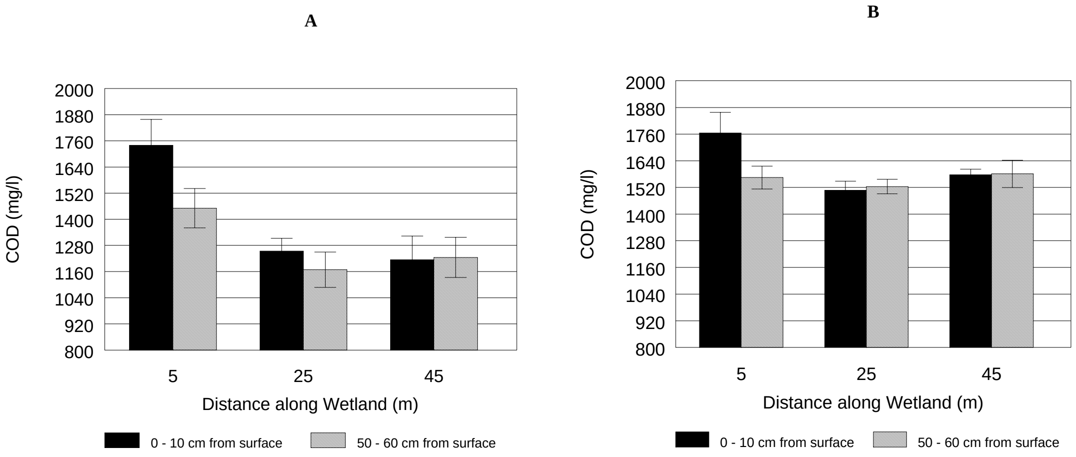

Figure 5.1 Variation of COD with depth in (A) Water hyacinth (B) Papyrus.

The slightly higher COD values were observed near the surface probably due to organic materials releasing nutrients into the water. There was a reduction in BOD$_5$ with depth. The near-surface average ammonia-nitrogen concentrations were lower at the inlet of water hyacinth and papyrus than those recorded near the bottom probably due to aeration effect, where ammonia-nitrogen is converted to nitrate-nitrogen.

Decaying plants near the surface would also lead to an increase in ammonia-nitrogen. Slightly higher nitrate-nitrogen values were recorded near the surface in papyrus and at the inlet of the water hyacinth than near the bottom.

5.7 Pollution Management Strategies

The strategies adopted in reducing the pollution loading into Lake Victoria are highlighted.

5.7.1 Municipal Waste Management

At present only 10% of the sewage generated in the large urban centres is collected and treated at central wastewater treatment facilities. About 50 to 70 % of wastewater is treated in pit latrines or septic tanks. Small urban centres rely largely on pit latrines (50%) with some septic tanks (about 5%). The remainder of human waste is discharged directly to the environment. In this regard, the NWSC component has embarked on raising awareness of the local communities in small towns and fishing villages about improving sanitation habits.

5.7.2 Wastewater Treatment Facilities

Management of the central wastewater treatment facility at Bugolobi is being improved to bring the performance to optimum to cope up with the expansion of the sewerage network. The high non conformity of the effluent quality to the national standard is probably attributed to the frequent break down of the system and increased loading in the system due to increased sewer network. This is because by collecting wastewater in sewers and failing to treat properly, pollution loads are concentrated into a single stream, which are transferred more directly to receiving waters without necessarily improving the quality of the effluent. Addition of a maturation pond after humus tanks to improve effluent quality from the conventional plant has been planned for to deal with non-compliant TP and TN quality. This is the same reason why effluent from Kirinya wastewater treatment ponds has to be improved by use of the bio-manipulated Kirinya natural wetland.

Results of the tertiary municipal effluent pilot study show substantial improvement in effluent quality through transects of the bio-manipulated wetland. Control of septic sludge tankers (cesspool emptiers), which is used to discharge in a relatively uncontrolled way to sewage works, is now in place. ‘Trade-effluent’ discharge agreement procedure is being administered and controlled as more factories get connected to the sewer. Staff training is being conducted and expertise in processing wastewater treatment is now in place to operate the treatment plant.

5.7.3 Garbage Collection

Data indicated that only 30 to 40% of garbage is collected and considerable amount of garbage is burnt. About 40% of the garbage remains uncollected and thus may contribute to the pollution of the lake. In regard to that, urban authorities have involved private sector participation in garbage collection as a strategy in improving solid waste management. Furthermore, the role of women in the management of waste at source is being encouraged. Effort is being made to discourage the burning of garbage, as this leads to acidification of rain, and contributes to dry deposition on the lake.

5.7.4 Urban runoff

Urban runoffs carry untreated municipal and industrial wastes and uncollected garbage into the rivers and wetland systems and eventually into Lake Victoria. In order to reduce on the pollution due to urban runoff, the following measures are being implemented:

- Improved garbage collection through private sector participation.

- On site treatment of domestic waste and use of ecological sanitation toilets.
- Wise use of wetlands to reduce their encroachment and degradation and where necessary gazetting of the wetlands, for example, Nakivubo wetland.

5.7.5 Fishing villages

The survey conducted indicated that fishing villages have less than 20% of pit latrines coverage. Most human waste is discharged directly into the environment. This has got a direct bearing to the public health and water quality of the lake. Garbage collection is also poor. In terms of central garbage collection probably less than 30% of garbage is collected. This has negatively impacted on the lake water quality as considerable quantity of garbage is washed into the lake after rainfall. Poor sanitary conditions and garbage collection have resulted in high prevalence of water-borne and water related diseases like diarrhoea, typhoid fever, cholera, skin irritations, cough, malaria, bilharzias and scabies.

In regard to poor garbage collection and sanitation management at the fishing villages, the following strategies are being implemented: public awareness meetings, local communities have been educated in ways of improving sanitation in fishing villages, such as the use of ECOSAN toilets. Micro-projects were initiated to address the issue of lack of toilets (however, there is less than 50% of acceptance due to local beliefs and taboos. Water borne toilets in Lukaya town and ECOSAN toilets in Dimo (Masaka district) and Musonzi (Kalangala district) were constructed as pilots for other fishing villages to learn from.

Environmental management committees have been set up in fishing villages and are expected to work with the beach management units (BMUs) in enforcing cleanliness and environmental management in general at the fishing villages. Garbage volume reduction by encouraging domestic composting of solid waste is being done. Communities are being encouraged to build strong self-help groups to address their organizational capability and improve fishing village prosperity. Promotion of private sector participation in waste management is also taking place.

5.7.6 Industrial effluent

Most factories do not have effluent treatment plants, even where they are existing, most industrial wastewater treatment plants are poorly designed and constructed. Of those that have wastewater treatment plants, few, if any, of those examined were achieving effluent discharge standards. The following strategies are therefore being implemented:

- Promoting the use of the Pollution Control Manual as a guide for all government officers involved in industrial pollution control.
- Preparing pollution control pamphlets, based on the Pollution Control Manual, for distribution to factory managers or owners.
- Strengthening the process design capability in Uganda both among consultants and pollution management agencies.
- Adopting a stager approach to pollution control enforcement e.g. emphasis on well-designed and constructed primary treatment instead of poorly designed treatment plant.
- Promoting the use of constructed wetlands in the treatment of industrial effluents. Tertiary Industrial Effluent Pilot study was carried at Port Bell using factory effluent from Uganda Breweries Limited (UBL) with results showing good performance of the system. Application of the pilot project was adopted by UBL, with some modifications, in designing facilities for treatment of the factory effluents. The UBL wastewater treatment plant is under construction.
- Facilitating implementation of cleaner production by coordination with the Uganda Cleaner Production Center.

5.8 Conclusions and Recommendations

5.8.1 Conclusions

1. Pollution loading into Lake Victoria is highest from urban centres (72%) followed by shoreline settlements - fishing villages (15%) and industries (13%).
2. There is continuing increase in industries opening in main cities and towns within the northern shores thus imminent increase in pollution loading from industrial sources.
3. Urbanization and growing human population in urban centres is significant, therefore, increased pollution loads are expected yet there are no clear near future plans by urban authorities to construct more municipal wastewater treatment facilities.
4. Management of solid waste (garbage) in urban centres is poor resulting in accumulated heaps, which are leached by runoff into the watercourses and finally into the lake.
5. Pollution in fishing villages is on the increase as more settlements are registered because of the increased income from fish sales to fish processing industries. However, sanitation facilities remain limited, waste management is still poor due to low awareness by local communities.
6. There is high prevalence of waterborne and water related diseases due to inadequate sanitary facilities, poor solid waste management and lack of alternative safe water sources besides the lake.
7. Micro-projects for ECOSAN toilets have not been fully acceptable and adopted by local communities in fishing villages due to religious, cultural and socio-economic issues, which require expert and long term handling.
8. Water Quality Model for Inner Murchison Bay (IMB) showed increasing pollution loading into the bay especially from Nakivubo channel, Port Bell and Ggaba fishing village as indicated by EC and faecal coliforms measurements.
9. The deteriorating water quality in the IMB because of discharge of polluted water through the Nakivubo channel/wetland has resulted in increased expenditure on water treatment in Gaba water treatment facilities of National Water and Sewerage Corporation
10. Tertiary Municipal Effluent Pilot Project bio-manipulation of the natural wetland in Kirinya – Jinja improved effluent quality from the municipal wastewater treatment and can be adopted by other municipalities.
11. Tertiary Industrial Effluent Pilot Project using constructed wetland for treatment of industrial effluent in Port Bell improved effluent quality from Uganda Breweries and could be used for other effluents.

5.8.2 Recommendations

1. There is need for continuity in mapping out and monitoring industrial, municipal and shoreline settlement pollution loading in the catchment so as to assess whether there is improvement or not after mitigation measures are put in place.
2. Industries ought to adopt cleaner production and where necessary must put in place wastewater pre-treatment facilities.
3. All municipalities (large urban centres) should have wastewater treatment facilities and ensure compliance with effluent standards.
4. Solid waste (garbage) management in urban centres and fishing villages has to be improved and private operators’ involvement should be encouraged.
5. More clean water sources need to be availed to the fishing villages besides lake water.
6. By laws to deal with industries and municipalities whose effluents do not comply with effluent standards should be put in place. Strong enforcement of the set by laws should be ensured.

7. Information dissemination workshops and barazas on cleaner production and effluent pre-treatment (use of pollution control manual) are required for industrialists.
8. It is important that strategic management of Nakivubo channel/wetland be focused on wastewater purification through gazettement, reticulation, bio-manipulation and rejuvenation of the already destroyed wetland macrophytes by encroachers. There is need for continued monitoring and evaluation of extent of improvement or deterioration of water quality in the wetland and IMB.
9. There is urgent need to put in place expert and long term awareness programs on sanitation and waste management for local communities in fishing villages and in all primary schools. There is need to spread and build public awareness on use of ECOSAN toilets and their technology for more of the sandy soil and high water table areas.
10. There is need to continue operations and maintenance of the two pilot projects plants for Tertiary Municipal Effluents and Tertiary Industrial Effluents Treatment in Kirinya – Jinja and Port Bell – Kampala, respectively.

6.0 Hydraulic Conditions of Lake Victoria, Uganda

Hydraulic conditions (including temperature, water velocities, oxygen concentration and Secchi depths) of the Ugandan portion of Lake Victoria were studied from 1999 to 2005. Influents from River Kagera into Lake Victoria were studied on a monthly basis. The temperature distribution profiles on the eastern part of the lake showed similar patterns to historical observations. Water column temperatures and stratification are very prominent in the months of February, March and April in the entire Ugandan portion of the lake. The western part of Lake Victoria is much influenced by winds and therefore experiences more mixing and cooling patterns. The eastern part of Lake Victoria is much more influenced by thermal stratification patterns and therefore mixing is mainly due to density currents. The eastern part of Lake Victoria experiences higher water temperatures throughout the year due to a lower rate of light penetration and weaker mixing.

6.1 General trends of hydraulic forcing mechanisms

6.1.1 Solar radiation patterns

There are marked periods of low and high solar radiation over the lake. January to March and September to October experience high values of solar radiation while April to October and November to December are periods of low solar radiation.

6.1.2 Thermal stratification in Lake Victoria

a) Temperature profiles at Bugaia Island (UP2) 1960-61

Talling (1966) described the development of the temperature profile at Bugaia Island during 1960-61 and identified three phases of development:

Phase 1: September to December, there is a gradual warming of the water column, with heat slowly dispersing from the surface to the bed. There are no strong thermoclines, but more of a gradual decrease in temperature from the surface downwards.

Phase 2: January to May, a thermocline develops at depths of about 40 m. The surface temperature reaches a maximum in March, after which cooling starts.

Phase 3: June to August, cooling and almost completely mixed water column is observed. There is some speculation as to whether this mixing is due to oscillations of the interface across the lake or other factors.

b) Temperature profiles at Bugaia Island (UP2) 1994-95

In comparison to Talling's observations, the general pattern of temperature changes is similar. There is continuous cooling to a nearly mixed water column between July to early September. Then there is gradual warming and weak stratification of the profile between September and November. This is followed by the development of a strong stratification and warming in February to March, starting from the column surface downwards. The water column is almost fully mixed for the remainder of the year. Examination of the temperature profiles for littoral stations shows no significant variations in temperature along the water column.

6.2 Wind mixing and water movements

The wind speed over the lake is gentle to moderate, with maximum wind speeds during storms rarely exceeding 12 m/s. The waves generated by the wind are correspondingly low, with maximum (1 in 100 years) significant wave heights of 2.5 m. The daily waves generated by the onshore-offshore breezes normally do not exceed 1 m. The waves cause mixing of the surface waters of Lake Victoria to depths of 5-15 m.

Langmuir circulations are generated by surface waves at wind velocities above 2 to 3 m/s. Streaks are seldom observed at wind speeds above 7 m/s. These currents are sufficient to markedly influence the distribution of micro flora and fauna suspended in the surface waters of lakes. Algae and zooplankton, with limited powers of locomotion, tend to aggregate. The result is the non-uniformity in the distribution of biodiversity that is important not only in sampling of organisms for estimation of population size and distribution, and in metabolic measurements, but also in determining the distribution of predators, which converge in these zones of high prey density.

The biggest part of the lake (south of the Sesse Islands) experiences wind patterns that are similar to the global wind patterns, the north-western part of the lake (north of Sesse islands) might be influenced by different wind patterns. The upward and down motions are brought about by the cycloid motion caused by the surface waves that have quite a big influence in about the top 10 m of water and diminishes thereafter.

The global wind pattern shows that from October to December the winds approach the lake from southeast and, as they cross the lake, they turn towards the 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. From February to May the main global winds flow from east to west. 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. A reduction in wave length occurs with a marked increase in wave height. With increased height the waves become asymmetrical and unstable and hence very turbulent. This accounts for the mixing of the water column on the western part of the lake for most period of the year.

These strong movements cause very turbulent water mixing that reach the bottom of the lake and thus possible re-suspension of bed material. The strong currents force the suspended solids in rich waters of River Kagera to move along the northern shores of the lake to join with the inflows from River Bukora, both of which continue eastward and slowly mix with the northern shore waters. From west to east, these forces decrease and capacity to have a fully mixed layer decreases.

Between January to February, and June to September the eastern part of the lake is shielded from the easterly winds by the Kenyan islands and their influence on heat distribution is felt only within the top 10-15m. Wind movements in this area are largely due to land and sea breeze phenomena. However, due to increased solar radiation between January and February, wind 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.

Between March to May, and October to December, the eastern part of the lake experiences some increased wave action from the southeast winds and remarkable increase in the wind fetch. However, due to the deep-water column, development of turbulent waves is minimal. This results into a cooler and mixed western part of the lake, and warm and hardly mixed eastern part of the lake.

The areas north of the Sesse 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 results in the distribution of sediments and nutrients from River Kagera to the northern shores of Lake Victoria around Dimo and Bukora.

6.3 Oxygen Distribution

When Oxygen levels get below 4 mg/l, fish and mobile animals migrate to areas of higher oxygen concentrations. The western part of the lake below River Kagera has the most favourable oxygen conditions for fish and other animals throughout the year. The northern shores of Lake Victoria are badly hit especially areas near the influence of Rivers Katonga, Bukora and Sio; and the Gulfs of Napoleon and Wanyange.

6.4 Seiches

Seiching is a resonance phenomenon just like the oscillation of water back-and-forth in a bath tub. It occurs in Lake Victoria during strong winds that cover most of the lake. A half-wave oscillation mode across the lake would have a period of 5-6 hours. Examinations of currents at different depths show consistent flow in particular directions that tend to reverse after about 5-14 days. The flow is counterbalanced by a reversal flow at lower depths. This suggests existence of seiching on this lake but this phenomenon needs further research.

6.5 River Inflows

Water entering Lake Victoria from several rivers may have different temperatures from that of the lake. If the river water is warmer, hence less dense, it spreads out over the top of the lake water. If it is colder, it sinks to the bed and spread out under the lake water. If the lake is stratified, the river water may sink to the level of the interface and spread out. Under all circumstances, these phenomena will be restricted to the immediate vicinity of the river mouth (a few kilometres from the river influence). River Kagera water may be detected up to 5 km from its mouth into the lake. This may not be very important for the overall circulation patterns in the lake but it affects the quality of the northern shores of the lake.

6.6 Conclusions and recommendations

6.6.1 Conclusions

Examination of the temperature profiles, wind patterns, secchi depths and oxygen profiles lead to the following conclusions:

1. The gradual warming of the water column is weak, and almost total mixing occurs in December-January at some stations.
2. The western part of Lake Victoria is much influenced by the wind forces and therefore experiences more mixing and cooling patterns. The eastern part of the Lake is much more influenced by thermal stratification patterns and therefore mixing is mainly by density currents. This implies that there is more potential for nutrient transfer in the western part of the lake, which may imply favourable conditions for fish cage culture. On the contrary, it also implies that nutrients from River Kagera and the western shores are capable of moving into the deeper waters of the lake.
3. Due to a lower rate of light penetration in the eastern part of the lake, and weaker mixing action, the eastern part of the lake experiences higher water temperatures throughout the year. This may imply higher capacity for primary production in the eastern part of the lake.
4. The northern shores of the Lake Victoria experience critical oxygen levels especially near Rivers Sio, Bukora and Katonga influents and also around Entebbe.
5. River Katonga plays a very big role in the nutrient loading and therefore management of a significant part of the north-western inshore areas of the Ugandan portion of Lake Victoria.

6.4.2 Recommendations

- Emphasis should be put towards implementation of the hydrodynamics model so that management issues can be investigated and potential solutions discussed.
- A detailed bathymetric survey is required for the project to guide proper model development, calibration and investigation of lake residence time.
- Development of a land use management plan for the Kagera basin should be taken as a priority as its impacts on the northern lake shores is very significant.

7.0 Sedimentation in Lake Victoria Waters, Uganda

Sedimentation rates were determined from successive sediment trap retrievals that generated 346 samples. The samples were analysed for particulate nutrients, nitrogen (N), phosphorus (P), carbon (C) and silicon (Si). Sedimentation rates into traps were highest at littoral stations compared to pelagic stations. In littoral areas, the settling velocities of P, N and BSi are higher ranging from 0.25 – 0.30 m/d. The composition of the settling material is highly organic and of algal origin. Both inshore and offshore settling velocities are relatively low than those for sedimentation in large lakes. This is probably a result of the dominance of slow sinking cyanobacteria in Lake Victoria. There is high nutrient regeneration and resuspension in the lake. Exceptions to this occur in protected embayments sheltered from strong wave action. Sediment cores indicate that increased loading of P began prior to 1940 and continues present. The increased loading of P has depleted dissolved Si in the lake's mixed layer and oxygen in the deeper waters, created a nitrogen demand by phytoplankton that can only be met through nitrogen fixation, and has created conditions where cyanobacteria now dominate sedimentation. Restoration of ecological conditions characteristic of the first half of the last century will require reductions in P loading to rates that occurred at that time.

7.1 Areal Flux Rates

The average areal downward flux rates for sedimenting material for pelagic and littoral stations are given in Table 7.1. Flux rates are substantially higher on average in littoral stations. The higher particle production near shore and the shorter water column over which decomposition can occur result in the higher sedimentation flux rates at littoral stations.

Table 7.1. Mean sedimentation flux rates for pelagic and littoral stations.

	TPP mg/m^2/d	TPN mg/m^2/d	TPC mg/m^2/d	TBSi mg/m^2/d
Pelagic Stations	1.56	41.02	283.32	7.45
Littoral Stations	5.92	78.67	777.03	20.17

7.2 Settling Velocities

The settling velocity of P is 0.14 m/d and the one of N is 0.18 m/d which are somewhat higher than the settling velocities of BSi of 0.09 m/d. The settling velocities of P, N and BSi at littoral stations are of the same magnitude ranging from 0.25 – 0.30 m/d but somewhat higher on average than the pelagic stations. These settling velocities are nearly double the pelagic rates despite the similarity in their elemental composition. Slow settling velocities result in longer times necessary to clarify the water column if algal growth slows and this contributes to the reduced visibility reported currently in Lake Victoria as compared to earlier in the last century.

7.3 Sediment accumulation rates as measured in sediment cores

Sediment accumulation rates in Lake Victoria cores that have been dated range from 100 g m^{-2} y^{-1} to over 300 g m^{-2} y^{-1} as dry weight accumulation. In terms of linear rates these are comparable to rates of about 0.5 to 1 mm per year. These rates are comparable to or somewhat higher than those observed in other great lakes. The accumulation rates realized in both inshore and offshore cores are similar indicating similar conditions and microbial process during burial and the nutrient ratios in the buried sediments are more similar to each other than to the trap material (C:N:P:Si of 310:24:1:37 for littoral cores and 206:16:1:65 for pelagic cores.

After sedimentation on the lake bottom and subsequent burial in the cores, C and N continue to be regenerated from the sediment while P and Si are relatively retained compared to the material settling into traps. Much of the C and N regenerated from the sediments is eventually lost from the lake as CO_2, CH_4 and N_2 gases due to microbial activity especially under low oxygen conditions that occur over these organic sediments and in the water column in pelagic areas.

Hecky (1993) compared historic dissolved Si concentrations with recent data and demonstrated a substantial drawdown of dissolved Si concentrations over the last 50 years. Burial rates of biogenic Si in the past have exceeded the amounts of Si entering Lake Victoria, and the apparent current deficit in sedimenting BSi is consistent with the depletion of BSi in the lake. Current rates of BSi sedimentation, as measured in the sediment traps, are much lower than the recent rates of burial. The declining soluble Si concentrations have caused changes in the diatom community with a shift toward thinly silicified species that have slow sedimentation rates.

7.4 Historical changes documented in sediment cores

There is yet no evidence that the rate of accumulation of sediments in Lake Victoria have changed over the last few decades in response to eutrophication. However, the nutrient content of Lake Victoria sediments has changed over time with very significant changes over the last 50 years. Hecky (1993) first reported on these changes from core 103 from Kenya waters. The rise in biogenic Si in this core was consistent with the decline in dissolved Si compared to 1960's and the rise in the P content of the core also was of the same magnitude as for total phosphorus concentrations in the lake. These changes were consistent with classical changes reported in other large lakes in response to nutrient enrichment (Hecky 1993).

All studies indicate that sedimentation of P and Si have increased over the last half of the past century and continue at historically maximally high rates. Although soluble Si concentrations have decreased since 1960 as sedimentation exceeded supply, the total phosphorus concentrations in Lake Victoria waters have actually risen, approximately doubling in that period. These changes in nutrient availability have caused changes in the algal communities, as large rapidly sinking diatoms of the genus *Aulacoseira* (formerly *Melosira*) have been replaced by the thinly silicified forms of slow sinking *Nitzschia* in Lake Victoria's accumulating sediments. This change in diatom community has been accompanied by the increase in cyanobactera taxa (*Anabaena, Cylindrospermopsis, Microcystis and Planktolyngbya*) that now dominate the algal biomass.

7.5 Conclusions and Recommendations

The sedimentation flux rates in the water column are higher at littoral stations compared to pelagic stations. Settling velocities are also higher at littoral stations. Higher biomass of cyanobacteria and their detritus in shallow waters is responsible for this pattern. Despite higher sedimentation fluxes in the shallower areas of the lake, highest rates of sediment permanent accumulation occur in the deepest areas of the lake >40 m. Eighty to ninety per cent of the sedimenting C and N to the bottom is returned to the water column as dissolved nutrients, but only sixty percent of the sedimenting P is similarly regenerated on a lake wide basis. Current sedimentation flux for BSi is less than the longer term estimates of BSi accumulation measured in sediment cores indicating that Si depletion remains severe and may limit diatom production.

The recent enrichment of the lake by P is evident in sediment cores from both shallow and deep waters. This enrichment caused increased deposition of biogenic Si in sediments and depleted the dissolved Si in the lake. The diatom community response to these changes over the last 50 years is evident in the change in microfossils deposited in the sediments. Away from riverine deltas (not investigated by this study), sedimentation in the lake is now determined by the productivity of the slow settling cyanobacteria. To restore the lake to earlier ecological conditions of the past century it will be necessary to reduce phosphorus loading to rates that occurred at that time.

8.0 Eutrophication of Lake Victoria, Uganda

Excessive fertilization (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 cultural activities in the catchments that include deforestation, intense cultivation, animal husbandry and mining. These activities disrupt biogeochemical cycles and accelerate the transport of nutrients (phosphorus, nitrogen N and other elements), which have consequences on water quality and ecosystem health. The lake receives water enriched with nutrients from a variety of sources that include dry and wet fall from the atmosphere, runoff from agriculture and from sewage and municipal systems.

Phosphorus concentrations have risen by a factor of 2 to 3. Total phosphorus concentrations range from 1.0μ M to 12.0 μ M, average (2.7 μ M). The total nitrogen concentrations vary from 20 μ M to 250 μ M, with average values increasing from 37.0μ M in offshore to 110 μ M in inshore. The amount of nitrogen in the lake has not increased to march the increase in phosphorus as indicated by the total nitrogen (TN) to total phosphorus (TP) ratios in the range 8.0 to 42.0, average 15.7. Average TN: TP ratios were almost double in inshore compared to offshore indicating that P is excess relative to N in offshore than inshore. The higher phosphorus relative to nitrogen concentrations have stimulated growth of nitrogen fixing algae that fix and bring in approximately 480 kilo tonnes a year of atmospheric nitrogen.

The average Silica concentrations (17.3 ± 13.6 μM) have decreased by a factor of 10 since the 1960s, as a result of increased phosphorus loading. The high nutrient concentrations support elevated algal primary production and algal biomass that has risen by a factor of 2 and 6 to 8 respectively. Algae, macrophytes and invertebrates species composition have responded to changes in nutrient enrichment. Average algal primary production has increased 2-fold and supports a 4 – to 5 – fold increase in fish yield compared to the 1950s. However, adverse eutrophication effects include excessive algal biomass, harmful algal blooms associated with fish kills, reduction in lake transparency, changes in algal and invertebrate communities, loss of desirable fish species and seasonal bottom water oxygen depletion (anoxia).

Copepoda, Cladocera, Rotifera constituted the zooplankton community of Lake Victoria while several groups of which Diptera and Molluscs are the more distinctive taxa made up the macro-invertebrates. Estimated abundance indicated generally higher densities of organisms and diversity indices around littoral compared to pelagic habitats. These trends can be partly explained by a more productive inshore area that receives nutrients from adjacent hinterlands and to some extent due to groups such as rotifers that show greater diversity and abundance in shallow near-shore area of the lake.

The changing climate in Lake Victoria basin could be enhancing eutrophication effects and putting additional stress on the beneficial uses that are already impaired. In Lake Victoria, therefore it is effective to control phosphorus given that nitrogen can be fixed from the gaseous atmospheric source.

8.2 Physical Environment of Lake Victoria

8.2.1 Temperatures and Thermal Stratification

Generally, three major phases of thermal stratification were recognized in Lake Victoria from 1997 to 2003. The lake rapidly warms in September throughout to March/April and cooling occurs between May to August. Early thermal stratification occurs between September and December, persistent thermal stratification in January to April and deep and stronger mixing as indicated by re-oxygenation of deeper waters both inshore and offshore occurs in June. The lake experiences high surface water temperatures in the range 23.0 to 29.0 ^{o}C throughout the year.

Overall, Lake Victoria is now more thermally stable than in the 1960s (Hecky 1993). Minimum water temperatures during the mixing period in June-July are 0.5 ^{o}C warmer in the 1990s to 2000s than it used to be 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, 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 water remains well oxygenated. In Lake Victoria, complete mixing of the lake occurs around June-July allowing almost uniform distribution of dissolved oxygen and nutrients in the water column. On the other hand, thermal stratification shortens the mixed layer, which in turn affects the vertical distribution of nutrients as well as light availability.

A less visible but fundamental and threatening eutrophic effect is the seasonal bottom water oxygen depletion (anoxia) in Lake Victoria. Lake Victoria experiences seasonal deoxygenation of deep waters ($\geq$ 60 m) created by decomposition of algal biomass, uptake of oxygen by microorganisms and aggravated by stronger thermal stability. Low oxygen condition is an undesirable change that directly affects distribution of organisms including invertebrates and precludes stable demersal fishery in lakes.

Data collected from the 1990s to 2003 indicate that hypolimnetic anoxia has spread horizontally into the inshore shallow bays and gulfs such as Napoleon Gulf (UL3) (Table 8.1 and 8.2), and vertically into the water column to as high as 30 to 40 m deep in some deep offshore waters. This spread has led to loss of approximately 50% of aerated fish habitat since the 1960s, and lowered the potential of fish production in Lake Victoria.

Table 8.1 Temporal variation of temperature and dissolved oxygen from inshore waters UL3 (Napoleon Gulf) of Lake Victoria, 1998 to 2003.

Month	**Temperature (^{o} C)**		**Dissolved oxygen (mg l^{-1})**		**Mixing depth**
	Surface	Bottom	Surface	Bottom	Z_{mix} (m)
January	27.4	26.4	8.3	2.1	12.0
March	28.1	26.9	9.7	4.4	8.0
July	25.3	24.3	10.6	6.2	20.0
August	25.9	25.3	6.6	0.04	10.0
October	25.6	25.4	5.8	1.3	6.0
November	27.7	25.8	9.8	0.5	6.0
December	26.8	23.9	7.0	0.6	8.0

Table 8.2 Temperature and dissolved oxygen from offshore (≥ 65 m) deep water (UPL2) of Lake Victoria, 1998 to 2003.

Month	**Temperature (^{o} C)**		**Dissolved Oxygen (mg l^{-1})**		**Mixing depth (m)**
	Surface	Bottom	Surface	Bottom	
March	26.7	24.4	8.2	0.4	25.0
May	26.6	25.7	7.7	5.6	40.0
July	25.4	25.1	6.1	6.0	65.0
September	26.6	24.4	9.0	4.7	40.0
November	27.7	25.8	11.0	2.2	30.0
December	25.2	24.7	7.4	2.4	30.0

Bottom water oxygen depletion (anoxia) is thought to have forced haplochromine and tilapiine fish species into the surface waters where they experienced heavy predation by the predatory Nile perch. Among the invertebrates, *Caridina nilotica* has become a keystone species as it is resilient to low oxygen conditions. Overall, the length of the food chain from algae to invertebrates and leading to the Nile Perch has been shortened due to both trophic cascading effects as well as eutrophication effects.

8.2.2 Inshore and Offshore Trends in Nutrient Concentrations

Lake Victoria is spatially variable with relatively high algal biomass and high nutrient concentrations in inshore than in offshore regions of the lake (Table 8.3). In inshore shallow waters dissolved inorganic P is about 2 to 4-fold lower than in offshore regions of the lake. In contrast, inshore waters had the highest values of particulate P, N and C. Chlorophyll-a, particulate P, N and C decreased along the transect from Portbell in Uganda to the Tanzania offshore waters and then increased again on the Tanzanian inshore waters. Total N was higher in the Ugandan and Tanzania inshore portions of Lake Victoria.

Table 8.3 Average nutrients, chlorophyll-a, euphotic and mixing depth and their standard deviation in Lake Victoria.

Parameter	**Inshore**	**Offshore**
Chlorophyll-a (μg l^{-1})	70.0 ± 100.4	13.5 ± 5.8
Particulate N (μM)	48.8 ± 7.1	10.6 ± 4.4
Total N (μM)	106.4 ± 28.2	37.1 ± 18.7
Total P (μM)	2.7 ± 2.1	3.1 ± 0.9
N-fixation (g N m^{-2} y^{-1})	14.0 ± 4.2	7.3 ± 3.7
Euphotic depth (m)	4.7 ± 1.2	9.2 ± 2.0
Mixing depth (m)	7.1 ± 2.6	35.0 ± 12.6

8.2.3 Total Phosphorus and Nitrogen

Total P concentrations were in the range of 1.5 to 12.0 μM. Variance analysis of total P concentrations showed no significant differences between inshore and offshore stations (P = 0.05). Average total P concentrations were in the range of 2.3μM to 3.1 μM. Data collected from inshore shallow bays, gulfs and deep open waters of the lake since the 1990s compared to historic records of the 1930s and 1950 - 1960s show that phosphorus concentrations are 2 to 3 times higher today. Similarly, total nitrogen concentrations varied from 20 µM to 250 µM, and average values increased from 35.0 1µ M inshore to 110 µ M offshore. Total nitrogen concentrations were 3 to 4-fold higher inshore than offshore. Generally, average total N, total dissolved N and particulate N were two to three times higher near shore than offshore. Average total N was of similar magnitude in the shallow Napoleon Gulf, Pilkington Bay and Buvuma Channel.

8.2.4 Total Nitrogen and Total P Ratios

Examination of total nitrogen (TN) to total phosphorus (TP) ratios indicates that nitrogen has not marched the increase in levels of phosphorus in Lake Victoria. Total nitrogen to total P ratios was in the range 8.0 to 43.0 (average 16.0) (Table 9.5). Average TN: TP ratios are almost double in inshore (14.5) than offshore (9.1) indicating that P was in excess relative to N in offshore than inshore of Lake Victoria. Based on the TN: TP ratios; Lake Victoria is classified as a P-sufficient ecosystem with inshore shallow bays tending to N-deficiency during the mixing period.

Table 8.4 Average soluble reactive phosphorus (SRP), total dissolved phosphorus (TDP) and total phosphorus (TP) and their standard deviation from the inshore (0-5 m) and offshore (0-10 m) surface waters of Lake Victoria. Numbers in brackets indicate sample size.

Station	**SRP (µM)**	**TDP (µM)**	**TP (µM)**
Bugaia	2.0 ± 0.7 (25)	2.5 ± 1.1 (25)	3.1 ± 0.9 (13)
Far Station	1.1 ± 1.2 (14)	1.7 ± 1.2 (4)	2.6 ± 1.3 (2)
Itome Bay	1.5 ± 1.5 (14)	1.5 ± 1.2 (6)	2.3 ± 1.0 (6)
Uvula Channel	0.8 ± 0.9 (13)	2.5 ± 0.1 (15)	3.1 ± 0.7 (7)
Napoleon Gulf	0.8 ± 1.3 (20)	1.4 ± 2.5 (14)	2.9 ± 2.1 (9)
Pilkington Bay	0.5 ± 0.8 (11)	0.5 ± 0.8 (11)	2.3 ± 0.9 (7)

Table 8.5 Total nitrogen to total phosphorus ratios from the inshore and offshore regions of Lake Victoria

	Inshore	Offshore
Minimum	14.4	8.1
Average	14.5	14.5
Maximum	43.2	27.2

8.2.5 Spatio-temporal patterns of algal biomass

Given that Lake Victoria is enriched with phosphorus and nitrogen, both nutrients, in particular P loads, have to be reduced through watershed management including management of the wetlands if eutrophication is to be controlled. Phosphorus reduction is the most feasible way of controlling eutrophication as nitrogen has a gaseous phase.

Chlorophyll-a (chl-a) concentrations range from 2.5 mg.m^{-3} to 657.0 mg.m^{-3}, mean of 41.2 mg m^{-3} in the surface waters of Lake Victoria. Average chlorophyll-a concentrations were 3 to 5-fold higher in inshore than in offshore Lake Victoria. In the surface waters of Lake Victoria, chlorophyll-a was lowest when the lake was deeply mixing around July and highest during the stratified phase.

A temporal algal biomass plot shows major chlorophyll-a maximum in September at the onset of thermal stratification and when the lake is rapidly warming up. The present light extinction coefficients vary throughout the year and exhibit similar temporal trends as chlorophyll-a. High algal biomasses contribute to reduced lake transparency. Secchi transparency has reduced by a factor of 3 to 4 and is generally in the range of 0.5 m to 2.0 m and occasionally as high as 4.6 m in offshore deep waters of Lake Victoria.

8.2.6 Chlorophyll-a, total P and total N relationships

TP and chlorophyll-a concentrations exhibited fundamental differences. The coefficient of determination for the relationship of chlorophyll-a to TP for inshore was higher ($r^2 = 0.52$, n = 26) and significant ($p = < 0.01$) compared to offshore where the relationship was very weak ($r^2 = 0.11$, n = 20) and not significant ($p > 0.05$). Offshore, chlorophyll-a did not increase with increases in TP concentrations indicating that phytoplankton in offshore regions of Lake Victoria are insensitive to P enrichment. The negative chlorophyll-a to TP relationship implies that further P loading may not increase algal biomass offshore, but could stimulate larger cyanobacterial blooms inshore.

8.2.7 Nitrogen fixation

Rates of biological N-fixation measured from 1994 to 1998 were high and often exceeded 0.5 μg N l^{-1} h^{-1}. Maximum rates of volumetric N-fixation were orders of magnitude higher and average rates were approximately 8 times higher in inshore than in offshore regions of Lake Victoria. In both inshore and offshore stations, minimum rates of N-fixation were consistent with low light availability and algal biomass. Rates of annual N-fixation in the range of 1.0 N m^{-2} y^{-1} to 24 g N m^{-2} y^{-1} did not differ significantly ($p>0.05$) among inshore stations, Napoleon Gulf, Buvuma Channel and Pilkington Bay. However, Itome Bay, the deepest inshore station, did have lower average and maximum rates than the other inshore stations, being intermediate between inshore and offshore rates. There were significant differences ($p<0.01$) in average N-fixation among offshore stations near Bugaia, at XL9, XL12 and farther offshore stations.

Although N-fixation contributed a small fraction on average to the daily N demand of the phytoplankton community, it is important in the N-budget of Lake Victoria and contributed $\geq$ 60% of the total annual N input into the lake. Biological N-fixation is the largest input of fixed N to Lake Victoria

8.2.8 Status of phytoplankton primary production

Algal photosynthesis now occurs in a euphotic depth of 4 m to 10 m. 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 twice higher than the values recorded in the 1960s. 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. Currently Lake Victoria is inefficient in using nutrients, as algal primary productivity is light limited over most of the time.

8.2.9 Status of algal and zooplankton species composition

The very fertile conditions support elevated algal wet biomass which are in the range 5 to 250 mg l^{-1} and have risen by a factor of 4 to 5 since the 1960s. Lake Victoria has had a shift in dominance from the historical algal communities dominated by diatoms such as *Aulacoseira* and green algae to blue-green algae in response to increased P loading and high N-demand and increasing N-demand by phytoplankton. The high N-demand favour dominance of blue-green algae, dominated by *Cylindrospermopsis, Anabaena* and *Microcystis* species. In Lake Victoria, 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 later in the stratified period and during the deepest mixing period in June-July.

Presently in Lake Victoria, the large green algae such as *Pediastrum* are rare and /or absent in part due to a 10 -fold reduction in soluble reactive silica. Silica concentrations are now in the range of 5 to 60 μM, with an average of 17.3 ± 13.6 μM. This silica draw down is possibly due to eutrophication effects of high P loads into Lake Victoria.

The shift in diatom dominance from *Aulacosiera* (*Melosira*) to *Nitszchia,* which formed the main food of the native commercially important *tilapiine Oreochromis esculentus,* and its reduction might have affected stocks of this species. The dominance of cyanobacteria including toxic forms, could have led to a reduction of available food for the native fish species. Besides, cyanobacteria are less digestible and provide poor quality food that may have contributed to the reduction or loss of planktivorous haplochromines and tilapiines that once flourished in Lake Victoria. It is therefore reasonable that changes in the fishery may have resulted, in part, from dramatic shifts in phytoplankton species composition in Lake Victoria.

The zooplankton community is made up of copepods, cladocerans, rotifers and other minor organisms (Table 8.6 and Table 8.7). Rotifera was the most diverse group containing several genera and numerous species. The macro-invertebrate community was made up of several broad taxonomic groups including Diptera, Anisoptera, Ephemeroptera, Gastropoda, Bivalvia, Oligochaeta and other minor organisms. Gastropoda and Bivalves were the most diverse groups.

8.3 Conclusions and Recommendations

8.3.1 Conclusions

The high nutrient load in Lake Victoria is a characteristic of a disturbed watershed where extensive agriculture and land clearing are common. In Lake Victoria, phosphorus loads are dominated by external sources that include rainfall, dry–fall, rivers, industrial and municipal inputs.

Total N loads income through rainfall contributes approximately 83-kilo tonnes year^{-1} and half as much enters through rivers. The magnitude of nutrient loads through precipitation is magnified because rainfall accounts for >80% of water budget of Lake Victoria. *In situ* biological nitrogen fixation is an extremely important source of nitrogen as it brings in approximately 480 kilo tonnes per year of TN, which accounts for ≥ 60 % of the total N budget of Lake Victoria.

Present studies indicate that atmospheric loads are a large source of P and N to Lake Victoria and are consistent with past observations. Changes in phytoplankton biomass and species composition have been attributed to general increases in P and N loading, changes in fish communities and climate change in Lake Victoria. Management strategies to protect water quality of the lake should therefore give high priority to actions that control nutrient loads and stimulate growth of algal blooms and other aquatic plants. OECD boundaries values for fixed trophic classification (Table 8.8) indicate that Lake Victoria is a typical eutrophic system basing on total phosphorus concentrations and Secchi depth.

Table 8.6 Checklist of zooplankton species at littoral (UL) and pelagic (UP) stations.

	UL01	UL02	UL03	UL04	UL05	UL07	UL08	UL09	UP01	UP02	UP03	UP06	UP07	UP08	UP09
Cladocera:															
Bosmina longirostris				+	++		++				+	++	+	++	+
Ceriodaphnia cornuta			+						+	++	+++	++	+	+	+
Daphnia longispina			+							+	++	++	+		
Daphnia lumholtzi										+	++	++	+		+
D. lumholtzi (helmeted)				+	+			+							
Diaphanosoma excisum	++	++	++	++	++		++	+	+	++	++	++	++	++	++
Macrothrix sp.		+													+
Moina micrura			+	++	++	++	++	+	+	+	+		+	++	
Chydorid sp.		+	+							+					
Copepoda:															
Eucyclops sp.							+								
Harpacticoida				+											
Mesocyclops sp.	+	+		+						+		+			
Thermocyclops decipiens															
T. emini	+++	++	++	++	+++	++	++	++	++	++	++	+++	++	++	+++
T. incisus			+	+	+		+			+					
T. neglectus	+++	+++	+++	+++	++	++	+++	+++	++	+++	+++	+++	+++	+++	+++
T. oblongatus							++			+					++
Tropocyclops confinnis	+++	+++	++	+++	++	++	++	+	++	++	++	++	+	++	+
T. tenellus	+++	+++	+++	+++	+++	+++	++	+++	+	++	+++	+++	+	++	+
Tropodiaptomus stuhlmanni			+												+
Thermodiaptomus galeboides	++	++	++	++	++		+++	+++	++	+++	+++	+++	++	+++	+++
Rotifera:															
Asplanchna sp.			+			+++	++				+		+	+	
Brachionus angularis	++	++	++	+++	+++	+++	++		++	+	+	+	+		+
B. bidentatus															
B. calyciflorus	++	+	+	+	+	++	++		+	+					
B. caudatus											+				
B. falcatus			+	+	+	++	+		+				+		
B. forficula		++	+	+					+	+	+	+	+	+	+
B. patulus			+			++		+			+				
Euclanis sp.		+	++	+	++	+++	++			+		+	+		
Filinia longiseta	++	++	+	++	++	++		+	+	+	+	+	+		+
F. opoliensis		+++	++	++	++		+	+		+		+	+	+	+
Hexathra sp.		+	+	+	+				+				+		
Keratella cochlearis	++	++	++	++	++	+++	++	++	++	++	+++	++	++	++	++
K. tropica	+++	+++	+++	+++	+++	+++	++	++	+++	+++	+++	++	++	+++	++
Lecane bulla			+					+	+	+	++				
Polyarthra sp.	+	+		+	+					+	+++				
Polyarthra vulgaris.		++	+	+		++	+		+	+	+		+		
Synchaeta pectinata			+												
Synchaeta sp.	++	+++	++	++	++	+++	+++	+++	++	+++	++	+++	++	+++	+++
Trichocerca cylindrica	++	++	+++	+++	++	+++	++	++	+	++	++	+	+	+	

Table 8.7 Checklist and frequency of occurrence of macro-invertebrate taxa from littoral (UL) and Pelagic (UP) stations.

	UL01	**UL02**	**UL03**	**UL04**	**UL05**	**UL08**	**UL09**	**UP02**	**UP06**	**UP07**	**UP10**
Anisoptera	+			++	++						
Bivalves:											
Byssanodo		++		++		++	++	++	+++		
Caelatura	+					+++	+++				
Corbicula	+++	+++	++	+++	++	+++	+++	++	++	+	
Sphaerium						+++	+++		++		
Conchostraca		++	++		++						
Decapoda:											
Caridina		++	++	+++	++			++			
Diptera:											
Ceratopogonidae	+					+					
Chaoborus	++	+++	+++	++	++	++	++	+++	+++	++	++
Chironomid	+++	++	+++	+++	++	+++	+++		+++	++	+++
Ephemeroptera:											
Caenis sp.						++					
Povilla			+			+++	++				
Gastropoda:											
Bellamya	+++	+++		+++					++		
Biomphalaria				++							
Bulinus sp.	+	++		++							
Gabbia sp.	+++	++		++							
Melanoides	+++	++		+++	++	+++	+++		++		
Hirudinea						++					
Nematods							++				
Oligochaetes	++	++	+	++	++	++	+++		++		
Ostracods	++	+	++	++	++	++					

Table 8.8. OECD boundaries values for fixed trophic classification system.

	Lake Victoria	**Typical Eutrophic system**
Total P (μg L^{-1})	46-372	35 -100
Mean chlorophyll-a (μg L^{-1})	2.5 -70	8 – 25
Maximum chlorophyll-a (μg L^{-1})	8-675	25 – 75
Mean Secchi (m)	2 – 1.0	3 - 1.5
Minimum Secchi (m)	1- 0.5	1.5– 0.7

Nutrient reduction in Lake Victoria requires reductions of direct and indirect anthropogenic loads that contribute to enrichment of rivers and modification of the precipitation chemistry of Lake Victoria. Reduction of nutrient loads require watershed management and good soil conservation practices aimed at reducing extensive vegetation clearing, soil erosion and vegetation burning. In addition, municipal and industrial effluents should be of acceptable nutrient concentrations and ratios so as to reduce proliferation algal biomass and weeds, such as water hyacinth

Zooplankton community composition in Lake Victoria is dominated by cyclopoid copepods, which exhibit ubiquitous distribution and occurs in relatively high volumetric abundance in both littoral and pelagic areas. This has implications to the production and sustainability of fishes (i.e. *R. argentea, some* haplochromines and larval fishes) that utilize these organisms as a food source.

Macro-invertebrate composition is dominated by dipteran larvae and mollusks, which occur in relatively high abundance around littoral areas. This too has implications to the production of fishes (i.e. juvenile fishes and the lungfish, *Protopterus aethiopicus*) that use these organisms as a food source.

Vertical dispersion of zooplankton is inhibited by oxygen depletion in the deepest part of the water column during spells of thermal stratification at most pelagic stations. Such displacement is tantamount to habitat loss and the resulting concentration of zooplankton in mid- to-surface waters may lead to unlimited consumption by pelagic planktivores (fishes and invertebrate predators), with implications to the sustainability of pelagic fisheries.

Macro-invertebrates that have high tolerance to low-oxygen conditions such as some dipteran larvae (chironomid bloodworms, chaoborids) and *Caridina nilotica* utilize the low-oxygen hypolimnion water mass as refugia against excessive consumption by fish predators including the Nile perch.

The occurrence of relatively high abundance of low-oxygen taxa at littoral stations is an indication of deteriorating water quality conditions due to eutrophication and pollution processes especially around near-shore areas of the lake.

8.3.2 Recommendations

There is need for reduction of nutrient loads and pollutant input in the near shore through treatment of municipal and industrial effluents.

We further recommend reduction of waste into the lake through promotion of cleaner production practices, promotion of good land-use practices in the catchment area, and conservation of the natural wetlands as well as promotion of constructed wetlands (CWs) as tertiary treatment systems for industrial and municipal effluents to include management of sources of nutrients contributing to atmospheric deposition.

The riparian communities should be sensitized on benefits of sound environmental management, harmonization of policies and laws on environmental protection and management as well as enhancement of analytical capability necessary to address emerging issues such as algal toxins, monitoring atmospheric deposition particularly phosphorus to establish the amount that originate outside the basin boundaries, monitoring atmospheric and riverine loadings of potential toxic contaminants. There is need for improvement of sanitary conditions in shoreline settlements, enhancement of capacity for water quality management with the aim to enhance co-management of the lake waters.

9.0 Agro-chemicals and metal contaminants in Lake Victoria, Uganda

Use of agricultural chemicals in the Lake Victoria catchment has increased in recent years. The increasing level of environmental degradation reflected in loss of vegetation cover, biomass burning, encroachment on protected areas, and accelerated soil erosion pose a serious environmental concern. Studies have revealed gross abuse and misuse of agricultural chemicals in Uganda. Many restricted chemicals are being used by untrained persons while adulteration of some is common.

A number of banned organochlorinated pesticides (e.g. DDT, endosulfan, dieldrin and lindane) were detected in air showing that they may still be in use in the Lake Victoria basin. However, these pesticides were not detected in sediments, water or fish tissue. Studies also showed that herbicides Touch Down (48% Glyophosate trimesium) and Gasepax (2,4-D and Ametryne) used in sugarcane cultivation pose no environmental threat in runoff water, soil and fish four months after field application. Elevated metal concentrations (Mn, Zn and Cr) detected in some rivers were, related to industrial activities or runoff from urban areas, therefore calling for controlled waste disposal.

Total Hg concentrations were higher in recently deposited lake sediments than older ones, indicating increased environmental degradation. Nevertheless, Hg concentrations in sediment, water and fish from Lake Victoria were below the WHO and international environmental guidelines. The results call for more stringent measures to control the types of agricultural chemicals used in the catchment coupled with massive sensitisation of communities on safe handling and use of agrochemicals.

9.1 Conclusions and Recommendations

Presences of banned organochlorinated pesticides such as DDT in the Lake Victoria catchment pose a serious environmental risk to the population. Bans on agricultural use of organochlorine pesticides should be enforced to protect applicators, the aquatic environment and the valuable export fishery. Use of ‘restricted use’ chemicals by incompetent users and the chances for adulteration of some of the chemicals pose another concern over improper use and management of many chemicals, with serious environmental consequences. More trained applicators are required to ensure appropriate use of registered pesticides, and farmers should continue to be targeted for dissemination of information on best practices and uses of agrochemicals.

The elevated metal concentrations call for improved catchment management including controlled industrial and municipal waste disposal to minimise metal pollution. More stringent enforcement measures and regular monitoring should be put in place to control disposal of industrial waste material especially where Cd, Pb and Hg that may be components of the wastes, coupled with better municipal waste management. Open burning of unsorted trash can lead to undesirable exposure to toxic fumes.

Efforts to promote better land management activities to control biomass burning, soil erosion and atmospheric pollution should be ensured. Physical planning for better utilisation of land resources, especially in the identified erosion ‘pollution hot spots’ within the catchment, should be emphasised.

More studies and monitoring of pesticide and metal contamination in the atmosphere, water, sediments, flora and fauna should be carried out. Capacity (human, equipment) should be built for carrying out such studies.

10.0 Water quality and health conditions in Lake Victoria region, Uganda

Studies to examine the prevalence of water-related diseases and other health risks in the Lake Victoria region of Uganda indicate faecal contamination of Lake Victoria waters at the shores. The riparian communities source their water for domestic consumption mainly from the lake. The wet seasons had significantly higher coliform counts than the dry seasons for all lakeshore sites. This seasonal variation in coliform counts correlated positively with waterborne disease incidences that were higher in the wet season.

The most prevalent diseases in the landing sites included malaria, dysentery, diarrhoea and bilharzia. Many people in the catchment disposed their wastes in bushes or in polythene bags, contaminating water sources with faecal material and leading to waterborne diseases. Lakeside communities' vulnerability to water-related diseases was further aggravated by low accessibility to health facilities and personnel.

In Lake Victoria, cyanobacteria (potentially toxic to humans and animals) dominate other algal species and contribute a larger fraction (>50%) of the biomass. Algal blooms were found to be frequent in Murchison Bay, a source of drinking water for Kampala and the surrounding urban centres. Algal blooms cause unpleasant odours and tastes in domestic water supplies, clog filters on pumps and machinery, increase chlorine demand, requiring a more complex and expensive treatment process. Findings suggest that improvements in water quality, sanitation and hygiene behaviour change can significantly reduce prevalence of water-related diseases, as indicated by some success stories elsewhere.

10.1 Conclusions and recommendations

10.1.1 Conclusions

Malaria continues to be the most prevalent water related / waterborne disease followed by dysentery in the riparian districts. Lowest prevalence of malaria and bilharzia was on the south western shoreline close to Tanzanian boarder, and increased towards the east and Kenyan boarder. Malaria prevalence was highest in Bugiri, followed by Iganga and Busia while the incidence was lowest is in Ntungamo. Highest bilharzia prevalence was in Bugiri, followed by Mukono and Kalangala. Of all the waterborne diseases, dysentery was the most common, followed by typhoid fever and cholera respectively. The most affected districts included Wakiso, Kampala and Kalangala.

Highly toxic blue-green scum consisting of *Microcystis* and *Anabaena* spp. congregate along the shore of Gaba water intake sites. In the inner Murchison Bay, microcystin levels observed were higher than the WHO guideline, posing a threat to human and other animal health.

AIDS and STDs were reportedly common at landing sites due to high rates of prostitution, lack of safe sex, and existence of migrant HIV infected persons. Kampala, Masaka, Jinja and Rakai were observed to have the highest numbers of AIDS cases. High mobility and high rates of immigration to landing sites, together with increased cash flow because of the fishery makes landing sites focal centers for HIV-AIDS and STD transmission.

The 2002 Uganda census report shows that 17 percent of Uganda's population had no access to toilets or latrines; and only 55 and 62 percent of the rural and urban populations respectively had access to safe water (UBOS 2005). Some riparian districts have low water and sanitation coverage, for example, the district water coverage for Rakai is 42.6%.

10.1.2 Recommendations

Efforts should be geared towards reduction of water-borne and water-related diseases. This will largely contribute to improved standard of living for the riparian communities. There should be increased sensitisation / health education, combined with improvement of sanitary structures, as the main focus. Improved quality of domestic water supply in a number of selected locations could be included in such programmes. Low-cost locally initiated infrastructure development (latrines, and small water supplies) should be the starting and focal point.

- Such interventions should be focused towards changing peoples' hygiene habits and behaviour patterns and must take a long-term approach, as changing peoples' minds needs time.

- Use of cheap, sustainable home-based methods of purifying / treating water in particular should be embarked upon, for example, the potential use of plants such as moringa (*Moringa oleifera* Lam).
- Attendance of compulsory Universal Primary Education (UPE) for all school-age children must be ensured to improve literacy level, which will in turn improve better hygienic and sanitary practices.
- Exposure to algal toxins has increased because of eutrophication and is an increasingly important but understudied risk factor for the health of lakeshore populations.

11.0 Impacts of water quality change on beneficial uses of Lake Victoria

Most of the problems facing Lake Victoria have escalated as a result of weak enforcement institutional mechanisms. Additionally, the aspect of "Common Property" implies the sense of ownership hence property right has negatively affected implementing management measures.

i. Loss of biodiversity has been attributed in part, to over exploitation of natural resources, alien species introductions, and deterioration in environmental quality.
ii. Loss of fish habitats is attributed to anthropogenic activities that have resulted into sedimentation, turbidity, eutrophication, deoxygenation and proliferation of aquatic weeds.
iii. Inefficiency in food webs are due to predation by the introduced Nile perch that has altered the food web structure by preying especially on haplochromines of various trophic levels, thus creating energy flow gaps.
iv. Contamination of the food web was attributed to discharge of pollutants from some industries (e.g. leather tanneries), faecal contamination, in addition to methylation.
v. Proliferation of aquatic weeds especially water hyacinth was partly due to the rich nutrient base that fosters plant growth.

11.1 Recommendations

The main objective of management intervention should be to regulate human activity impacts on the beneficial uses of the Lake Victoria basin resources in order to ensure their stability in a healthy environment. The approach should involve measures including:

1. For lake shores, there is a law that protects 100 to 200 m buffer zones between the shore line and towards dry land. This law should be enforced.
2. A similar distance (200m) from the shoreline towards open water should be gazetted as a "no fishing zone" and enforced by BMUs.
3. Sandy and rocky shores should be regarded as part of critical habitats and protected under appropriate legislation.
4. Beach Management Units (BMUs) and conservation management units (CMUs) should include diverse stake holders to avoid sectoral conflicts.
5. Interventions by policy makers and managers should place emphasis on closed areas, closed seasons, and bans to fishing in critical habitats.
6. Selected habitats with high fish diversity should designated as "Marine Parks" or Reservoirs and protected as provided for in existing legislation.
7. The established conservation management units on some satellite lakes should be reinforced and extended to other lakes.
8. Reclamation of swamps and clearing of macrophytes surrounding the lake for agriculture should be avoided to stop the spread of Nile perch and other human impacts.

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