1 Executive Summary

The Integrated Water Quality / Limnology Study for Lake Victoria is a consultancy contract between the Lake Victoria Environment Management Project (LVEMP) and COWI Consulting Engineers and Planners AS, in association with DHI Water and Environment. The contract was signed on 23 June 2000 in Nairobi, and is financed by credits from the International Development Association (IDA) and grants from the Global Environment Facility (GEF) to the three countries, Tanzania, Kenya and Uganda.

The overall objective of the study is to provide advice and assistance to the Water Quality and Ecosystem Management Component (WQ Component) of LVEMP in the three riparian countries over a period of 18 months from 1 August 2000.

The contract requires that the Consultant prepares a Final Report detailing the progress achieved in the execution of the assignment, the results of the study and recommendations for future work. The report has been divided into two parts:

Part I: Administrative Report, with a description of the Consultant's activities and methods used in advising and assisting the WQ Components.

Part II: Technical Report, with a description of the technical methods applied in the study and the scientific results of the work of the WQ Components.

1.1 Overall Objectives

The overall objectives of the Water Quality and Ecosystem Management Components of LVEMP are defined in the TOR for the present study:

1. Define ongoing changes in lake limnology and water quality, model and predict their short and long term consequences.

2. Provide quantitative information on nutrient loading and recycling within the lake.

3. Define sources of micro/macro nutrients promoting eutrophication, and contaminants found to be present in the lake, and describe their effect on lake productivity.

4. Define phytoplankton communities and their composition.

5. Define algal bloom dynamics within the lake.

6. Quantify the role of lake consumers e.g. zooplankton, microbes, lake flies in ecosystem dynamics.

7. Quantify primary production.

8. Define the horizontal and vertical circulation of waters and its effect on distribution of nutrients, oxygen and organisms.

9. Define the trophic interrelationships of the lake's biological communities.

10. Provide necessary information on lake circulation and water quality to the Water Quality Management Model, which will guide future water quality management decision within the lake and its catchment.

The Consultant's assignment in relation to the overall objectives was to:

- Plan and advise on the implementation of a regionally integrated, lake-wide study to address common water quality problems confronting the lake and the riparian countries.

- Co-ordinate the activities of LVEMP in the three countries into a coherent lake wide programme.

The Consultant's role was one of co-ordinating, advising and assisting the WQ Components in achieving their overall objectives through improvement of their action plans and staff capabilities.

The TOR defined the detailed duties of the Consultant in terms of three technical disciplines, Eutrophication, Sedimentation and Hydraulic Conditions. Emphasis was placed on assisting the scientific staff in analysing and understanding the physical and biological processes in the lake.

Within each of these disciplines the TOR also required the review and adjustment of on-going programmes of field data collection and laboratory analysis of samples. However, during the Inception Phase it was found that the programmes for collection of field data and laboratory analysis had not progressed as far as was anticipated in the TOR.

This lead to a redefinition of the priorities for the Consultant's scope of work and approach to the study, as reported in the Inception Report (October 2000). Greater effort was required for the field data collection and laboratory analysis, with the consequence that less time and resources was available for the training in the physical and biological processes.

1.2 Technical / Scientific Approach

The integrated study of the water quality of Lake Victoria can be approached using well-established standard sequences of activities for the study of any water body. The general sequence of activities is as follows:

- Formulation of the problem. In the present case, this involves a critical examination of the postulated changes and the data on which the postulates are based, with the purpose of verifying or rejecting the actual existence of the changes.

- Establishment of hypotheses which could explain the cause/effect relationships in the observed changes in the lake. Again, for the present case, a number of hypotheses have already been put forward by local and international scientists.

- Field monitoring for use in analysing and understanding the processes, as input to the WQ model, and as calibration data for the model.

- Collection of data from other sources with the same purpose.

- Calibration of the WQ model and application of it to study the hypotheses, the cause/effect relationships, and the effect of various management scenarios.

- Using the model results in developing practical management policies for the lake.

The application of this technical / scientific approach resulted in the identification of the subjects requiring the specific attention of the Consultant:

1 Lake Monitoring
2 Laboratory analyses
3 Water Quality Database
4 Meteorology / Hydrology
5 Non-Point Pollution Loadings
6 Industrial and Municipal Effluents
7 Hydraulic Conditions
8 Eutrophication
9 Sedimentation

1.3 Task Objectives and Methods

The methods adopted for achieving the objectives can be divided into two groups. The first group concerns the organisational arrangements for the identification of necessary changes and improvements of facilities, equipment and administration, for the training of the WQ Component staff and for promoting co-operation among the staff in the three riparian countries. This group is addressed in Part I: Administrative Report.

The second group concerns the technical methods adopted for achieving the technical and scientific objectives. This group is addressed in this report.

The technical methods are briefly summarised here, with details given in the relevant chapters.

1.3.1 Meteorology / Hydrology

The objective of the meteorology / hydrology task is to produce time series of all inflows and outflows of water to Lake Victoria for the period 1950 to 2000. It is the inflows that convey to the lake some of the nutrients that are responsible for the eutrophication. Since one of the overall objectives is to determine the reasons for the changes observed since the 1950's, it is also necessary to determine the changes in the inflows of water and pollutants. The sum of all inflows and outflows also produces the important water mass balance for the lake.

The technical methods applied to calculate the inflows and outflows were standard meteorological and hydrological methods.

1. Generate continuous **rainfall** records for the period 1950-2000 for selected stations in the catchment and on islands on the basis of measurements, correlations to adjacent stations and insertion of "typical years".

2. Generate continuous **evaporation** records for the period 1950-2000 for selected stations in the catchment and on islands on the basis of measurements, correlations to adjacent stations and insertion of "typical years".

3. Calculate **discharges** in rivers on the basis of rating curves and measured gauge heights.

4. Perform **rainfall-runoff modelling** to extend the river discharge record to the period 1950-2000.

5. Calculate the **final discharges** for each individual river catchment or basin.

6. Calculate the **water mass balance** for the lake as the sum of all inflows and outflows.

1.3.2 Non-Point Pollution Loadings

The non-point pollution loadings are those originating from the catchment, including agricultural and rural population, and from the atmosphere. The loads from the catchment are conveyed to the lake via the rivers and streams, while the atmospheric pollution is absorbed and deposited on the lake surface in dry form (gases and particles) and in wet form carried down by rain.

The non-point pollution loads are estimated by two methods which complement each other; direct and indirect methods.

The direct method consists in measuring the concentration of nutrients in the rivers and in the atmospheric deposition. This work is in its early stages, and only few measurements are presently available. If possible, the estimates can be complemented by the indirect method that consists of estimating the loads from land-use statistics, use of fertilisers in agriculture and population statistics and distribution. Both methods are in common use throughout the world.

Originally it was intended to estimate the non-point loadings from 1950 to the present, but this was not possible due to the lack of historical data. Only estimates for the present were made.

1.3.3 Industrial and Municipal Effluents

The object in this task is to estimate nutrients loads to the lake originating from industrial and municipal sources.

The starting point for the estimates is an inventory of industries and towns with more than 10,000 inhabitants in the lake catchment. The estimates can also be made by direct and indirect methods.

The direct method consists of measurements of concentrations in the effluents from industries, from waste water treatment works and from streams which drain the larger towns. These data are few, and their reliability is low because they are notoriously non-representative of the real discharges.

The indirect methods consist of:

- Standard values for municipal loads ("personal equivalents").
- Industrial loads based on production figures.
- Rough estimates where neither waste water production nor industrial production figures are available.

The basic loads are then reduced to account for the loss of nutrients due to natural biological processes depending on the method of discharge (direct to a stream, to a municipal sewer system, to septic tanks or pit latrines, to waste water treatment plants, or to wetlands).

As with the methods for non-point loads, these are standard and in common use in developing countries.

1.3.4 Lake Monitoring

The purpose to the lake monitoring is of course to obtain data on the hydraulic conditions, eutrophication and sedimentation in the lake.

The monitoring programme consisted of monthly cruises to make measurements at 54 stations covering both inshore and offshore areas of the lake. At each station, measurements are made of:

- Position, depth, wind speed and direction, wave height, period and direction and air temperature.
- Secchi depth.
- Vertical profiles of water temperature, dissolved oxygen, conductivity, pH, light and current speeds and directions.
- Water samples taken at a number of depths for later laboratory analysis for nutrient concentrations (nitrogen, phosphorus, carbon and silicate), chlorophyll-a, and for phytoplankton and zooplankton.
- Sediment trap samples for determining sedimentation rates of organic detritus.
- Grab samples of the bed for analysis for benthos.
- Sediment core samples for determining sediment fluxes at the bed.

Internationally standard field instruments and marine survey methods are applied.

Unfortunately none of the countries could carry out a full programme of monthly cruises due to technical, funding and logistical problems with the survey vessels. Lack of equipment also prevented the measurement of currents in Kenya and Tanzania, and the taking of sediment cores in all countries.

1.3.5 Laboratory Analyses

All the water and sediment samples taken in the field (from the lake, rivers and atmospheric deposition) were to be analysed by the laboratories in Kisumu, Mwanza, Musoma, Bukoba and Entebbe.

The analyses are to be made following Standard Methods 18th and 19th editions with a few local variations depending on the equipment available.

A total of 1500 samples and 20,000 analyses were planned for the 1 year programme. Only 40-50% of the analyses was carried out partly due to the lack of equipment, chemicals and filters. However the main reason was the lack of training and routine of the laboratory staff, particularly in Kisumu and Mwanza. Some training was carried out by the Consultant, but more is required.

1.3.6 Hydraulic Conditions

The objective of the Hydraulic Conditions task was to collect data and develop models of the vertical and horizontal circulation patterns in Lake Victoria and in the focus areas of Winam Gulf, Mwanza Gulf and Napoleon Bay.

The data required consisted of the monthly measurements of vertical profiles of water temperature and currents at all the lake monitoring stations. Apart from the detailed analysis of the data, the most important tool in developing the circulation patterns was the 3-dimensional hydraulic model which is part of the Lake Victoria Framework Model. Unfortunately there were no current measurements from Kenya and Tanzania due to lack of equipment, and it was not possible to use the model as planned due to lack of training of the WQ Component staff. The preliminary nature of the model also made its application cumbersome.

The methods applied in the study were thus limited to a detailed analysis of the temperature profiles from the whole lake and the current profiles from Uganda. The analysis consisted of plotting and interpreting:

- The time series of the temperature profiles at selected stations.
- Transects of temperature profiles across the lake and in focus areas.
- Currents at selected depths during each cruise and correlation with wind.

The data was compared with that of previous studies.

1.3.7 Sedimentation

The principal objectives of the Sedimentation task was to obtain data on the fluxes of particulate and dissolved nutrients between the water phase and the sediment, and to monitor vertical sediment profiles of dissolved and particulate nutrients (organic detritus settling to the bed). Such data is an important part input to the understanding of the eutrophication of the lake.

The determination of the dissolved nutrient fluxes between the water and the bed should be measured in the laboratory using undisturbed cores of the surface sediment in the bed of the lake. Unfortunately, sediment coring equipment was not available, and no measurements could be made. More success was achieved with the measurement of the sedimentation even although 50% of the measurements were lost, probably due to theft of the sediment traps.

The samples from the sediment traps were analysed in the laboratories for particulate nutrients (nitrogen, phosphorus, carbon and silicate). The results were further used for calculations of sedimentation rates, sinking velocities and resuspension.

1.3.8 Eutrophication

The objectives of the eutrophication studies were to assess the state of eutrophication in the lake, to assess the mechanisms by which the lake responds to increased nutrient loadings, and to provide data for the water quality model.

The collection of data has been based on monthly and quarterly lake monitoring programmes (see Chapter 6 for details) including standard variables such as nitrogen and phosphorus fractions (inorganic, pariculate, organic dissolved, and total), chlorophyll-a, algae species, zooplankton species, light conditions (measured as secchi depths or light), and oxygen conditions (see Chapter 12 on analyses).

After validation, spatial variability has been examined through calculated statistics such as minimum, maximum, average, median, and upper and lower quartiles by station and presented in tables and by using horizontal contour plots and vertical profile plots.

Where the data collection starts to be sufficient, temporal variability has been examined by various time series plots.

The quantitative relation between different parameters have been assessed through regression analysis (light to Chlorophyll-a, particulate N to particulate P, Chlorophyll-a to N and P etc.) and a global ratio of C:N:P:Si has been estimated to preliminarily assess the regime of nutrient limitation of the primary production.

1.3.9 Lake Victoria Framework Model Application

It was the original intention to use the model for the study of the hydraulic conditions and the eutrophication. The model should first be calibrated and verified using the data collected during the past year and then applied to the studies.

A prerequisite for the application of the model is that the staff of the WQ Components should be thoroughly trained in the use of the model as well as its scientific background. The training was planned to occur during 2001, but was postponed until the next phase of LVEMP.

Another prerequisite is the existence of all the necessary data. As already pointed out, there is little data on currents and sediment nutrient fluxes. Further, there are gaps in the water quality data, eg. some lake stations were only monitored once or twice during the year.

These constraints made it not possible to make effective use of the model. Another constraint was the lack of a data input pre-processor which made the preparation of input data cumbersome and time consuming.

Despite intensive efforts, the application of the model was limited to some sensitivity tests of the influence of wind speed on the current patterns. These tests showed that much more accurate data on the wind speeds and directions at the lake surface is required.

1.3.10 Regional Quality Assurance Mechanism

The TOR for the present assignment simply specify that the Consultant should

"Be responsible for instituting a Regional Quality Assurance Mechanism".

A clarification during the proposal preparation period indicated that LVEMP was referring to the quality of field data.

World-wide experience with all quality assurance systems has shown that quality is not achieved by a top-down control process alone. It requires, most of all, the motivation, engagement and commitment of the staff. Certain tools must be provided to assist and guide the staff, but without the encouragement of the management and the commitment of the staff, the tools are of little use. In the present case, the "tools" are essentially the manuals with instructions for field data collection procedures and laboratory analyses.

The methods applied by the Consultant in instituting a QA mechanism were as follows:

- Preparation of a set of field forms with instructions for field data collection and for recording both field data and laboratory analysis results.
- On-board training of field staff in monitoring procedures, methods and routines.
- Checking and adjustment of the laboratory analysis methods.
- Preparation of methods manuals specifically adapted to local conditions in Kisumu and Mwanza.
- Training of laboratory managers in international QA/QC standards and procedures (Kisumu and Mwanza).
- Training of laboratory staff in analyses of water samples for nutrients.
- Comprehensive hands-on training in data validation.
- The first inter-laboratory comparison of precision and accuracy of analyses of nutrient concentrations.

1.4 Conclusions and Recommendations for Tasks

1.4.1 Meteorology / Hydrology

Conclusions

In short it can be concluded that a successful method has been developed for computing the water mass balance for Lake Victoria.

- A very large amount of data on rainfall, evaporation and river discharges has been collected, collated, analysed, quality controlled, and distributed to the WQ Components in the three riparian countries.
- Data gap filling techniques with a solid physical basis have been developed and applied with success to rainfall, evaporation and river discharges.
- New mean annual rainfall and evaporation maps for Lake Victoria have been developed.
- An accurate water mass balance for Lake Victoria for the period 1950-2000 had been developed.
- The resulting time series of basin discharges and rain/evaporation distribution over the lake provide an excellent basis for the water quality studies.

The long-term average discharges from the individual river basins around the lake are shown in Table 1.1 with the average inflows and out flows to Lake Victoria in

Table 1.2. See also Figure 1.1.

Table 1.1 Long term average discharges from river basins.

Country	Basin	Discharge (m^3/s)	Percent
KENYA	Sio	11.4	1.5
	Nzoia	115.3	14.8
	Yala	37.6	4.8
	Nyando	18.0	2.3
	North Awach	3.7	0.5
	South Awach	5.9	0.8
	Sondu	42.2	5.4
	Gucha-Migori	58.0	7.5
TANZANIA	Mara	37.5	4.8
	Grumeti	11.5	1.5
	Mbalageti	4.3	0.5
	E. Shore Streams	18.6	2.4
	Simyu	39.0	5.0
	Magogo-Moame	8.3	1.1
	Nyashishi	1.6	0.2
	Issanga	30.6	3.9
	S. Shore Streams	25.6	3.3
	Biharamulo	17.8	2.3
	W. Shore Streams	20.7	2.7
	Kagera	260.9	33.5
UGANDA	Bukora	3.2	0.4
	Katonga	5.1	0.7
	N. Shore Streams	1.5	0.2
	Total	778.3	100.0

Table 1.2 Average inflows to and outflows from Lake Victoria

Average 1950-2000	Flows m^3/s	Percent %
Inflows		
Rain over lake	3631	82
Basin discharges	778	18
Outflows		
Evaporation from lake	-3330	76
Victoria Nile	-1046	24
Sum	33	

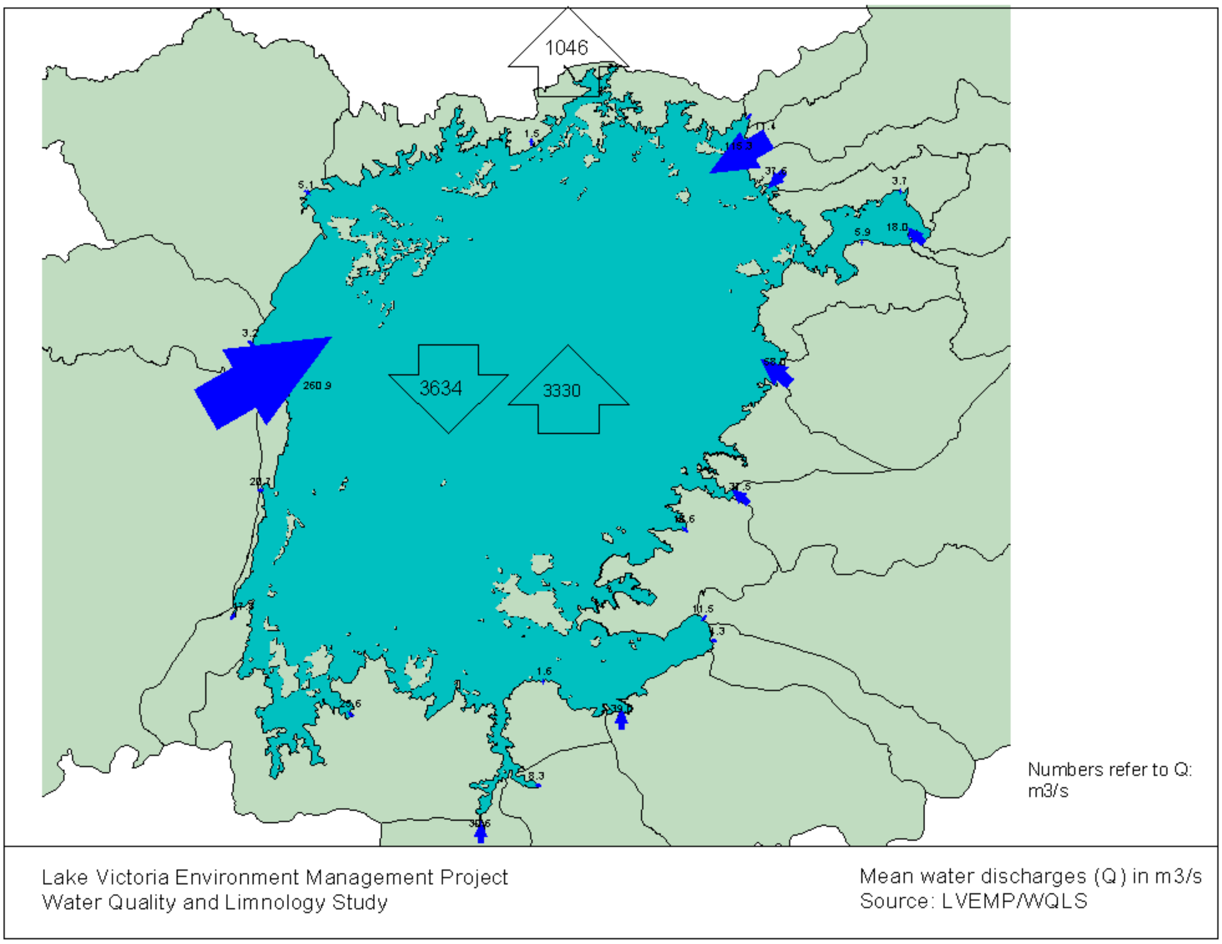

Figure 1.1 Mean annual inflows to and outflows from Lake Victoria.

The inflows and outflows are dominated by the rain and evaporation, with the rain being slightly larger than the evaporation. The outflow in the Victoria Nile is correspondingly larger than the inflow from the catchment. The sum of the inflows and outflows gives a small positive inflow of 33 m^3/s which accounts for the rise in the lake water level of 0.98 m between Jan 1950 and Dec 2001.

Recommendations

The following recommendations are given for the future activities:

- Efforts should be continued in all countries to fill the data gaps with real data instead of the approximations.
- Particular attention should be given to the obtaininmg more data for the important Kagera catchment where there is a rather poor data coverage.
- Gauging stations for ungauged catchments should be established as soon as possible.
- In general, rating curves should be updated for all rivers in all countries.
- Detailed quality control of all the data is required.

- Finally, it is recommended that the mass balance should be continuously updated as additional historical data is collected, and extended each year as new data becomes available.

1.4.2 Non-Point Pollution Loadings and Industrial and Municipal Effluents

The non-point and point source pollution loadings are considered together since they represent all the nutrient loadings to lake Victoria.

Total loads

Revised estimates of the nutrient loadings have been made during the study. The estimates are based on few measurements and the use of indirect methods. They are therefore relatively uncertain, but the orders of magnitude are correct, and this is sufficient to draw the required conclusions.

Table 1.3 shows the total loads to the lake. It is clear that the loads of nutrients are dominated by the contribution from the atmosphere. The contributions from industrial and municipal sources are negligible for the lake as a whole. They are, however, important for local inshore areas. See also F and F for the distribution of the loads.

Table 1.3 Nutrient pollution loads to Lake Victoria

Source	BOD (tons/year)	Total Nitrogen (tons/year)	Total Phosphorus (tons/year)
Catchment	0	49,510	5,690
Atmosphere	0	102,150	24,400
Industrial	5,610	410	340
Municipal	17,940	3,510	1,620
Totals	**23,550**	**155,580**	**32,050**

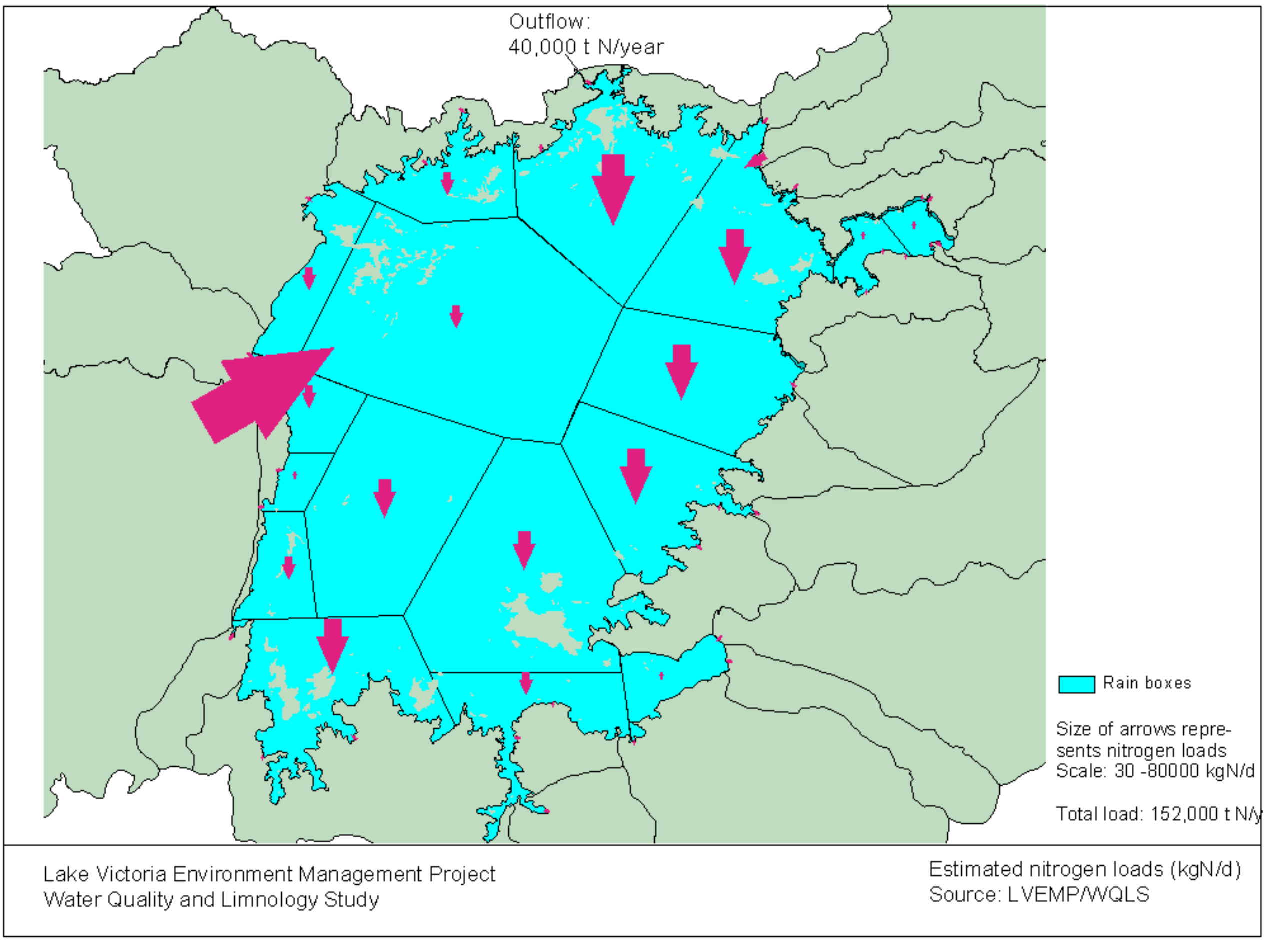

Figure 1.2 Loads of Total Nitrogen (TN) to Lake Victoria.

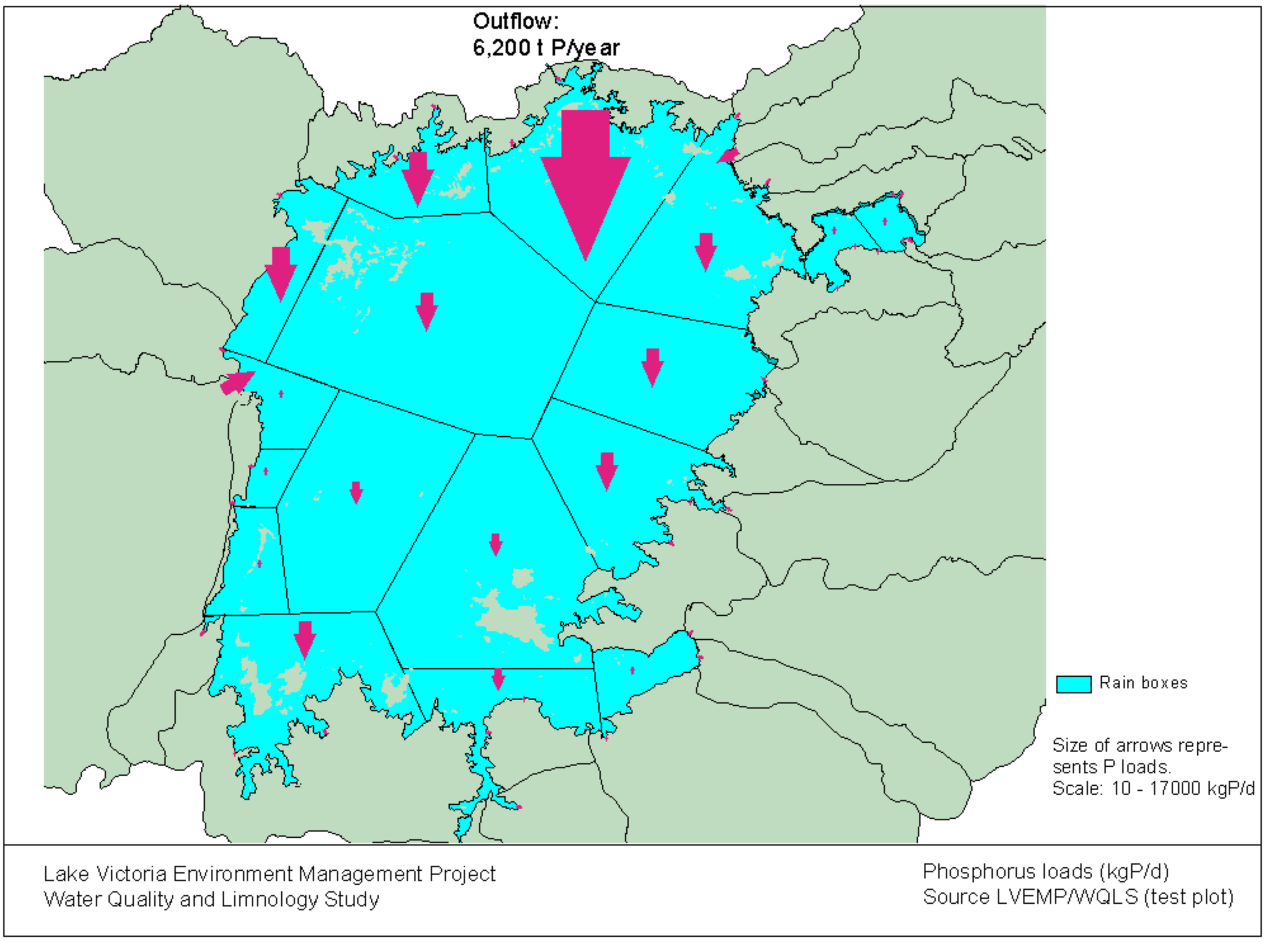

Figure 1.3 Loads of Total Phosphorous (TP) to Lake Victoria.

Focus areas

Table 1.4 shows the loadings for three focus areas which are the three most eutrophied areas around the lake.

Table 1.4 Nutrient loads for Winam Gulf, Mwanza Gulf and Murchison Bay

Focus Area	Source	BOD (tons/year)	Total Nitrogen (tons/year)	Total Phosphorus (tons/year)
Winam Gulf	Catchment	-	2,327	547
	Atmos. dep.			
	Industrial	455	3	1
	Municipal	3,908	664	294
	Total	**4,363**	**2,994**	**842**
Mwanza Gulf	Catchment	-	566	101
	Atmos. dep.			
	Industrial	2,838	289	185
	Municipal	3,815	520	208
	Total	**6,653**	**1,375**	**494**
Murchison Bay	Catchment	-	-	-
	Atmos. dep.			
	Industrial	781	53	45
	Municipal	1,512	389	267
	Total	**2,293**	**442**	**312**

Together, these three areas receive 57% of the total BOD load to Lake Victoria, 9% of the total nitrogen and 22% of the total phosphorous (atmospheric deposition excluded).

Conclusions

The nutrient loadings to the lake are dominated by the atmospheric deposition. The relative loadings ratios atmospheric:catchment:industrial+municipal for total nitrogen and phosphorus are 102:50:4 and 24:6:2 respectively.

The detailed data in Chapter 5 shows that the main point sources (industrial and municipal) are concentrated at a few major cities in Uganda and Tanzania, while in Kenya the main point sources are distributed at several larger towns.

The loads from the catchment, industrial and municipal sources are not critical for the lake as a whole, but they give rise to serious eutrophication in a few local coastal gulfs and bays.

Recommendations

Non-point

- The estimation of non-point pollution sources is at an initial stage and consequently it is strongly recommended to continue the work.
- The efforts for the determination of atmospheric deposition should be greatly intensified.
- If capacity is a problem, priority should be given to sampling and analysing at river stations closest to the mouth. High priority should be given to Kagera River since it may account for half the land-based loads.
- The missing details in the landuse data must be collected before the information can be effectively utilised.
- For use in management of the lake catchment, methods must be developed in the next phase of LVEMP for the estimation of nutrient runoff due to deforestation and alteration of soils caused by agriculture.

Industrial and Municipal

- Gross or "rapid" estimations of industrial and municipal pollution loads should be carried out at regular (annual) intervals.
- Field measurements should be made over longer periods to verify estimates of standard figures such person equivalent loads, reduction efficiency of discharge system, industrial production related load figures etc.
- Concentrate future measurements of industrial pollution loads on industries with significant wastewater production, sites with significant local problems and on studies to determine production/load factors.

Historical

The objective of developing historical loads back to 1950 was not accomplished due to lack of data. Such data is still important if the main reasons for the eutrophication of Lake Victoria are to be found. The next phase of LVEMP should include a task to develop the historical data.

1.4.3 Lake Monitoring

In the period 20 November 2000 to 9 October 2001, each of the countries accomplished 6 lake monitoring cruises with measurements at both near shore and offshore stations (Uganda 8 at near shore stations). Following the original plan, there should have been 10 cruises, but this was not possible for reasons explained above. Based on the temporal changes observed in the hydraulic conditions, water quality and eutrophication, it is recommended that the frequency of monthly cruises be retained as the goal.

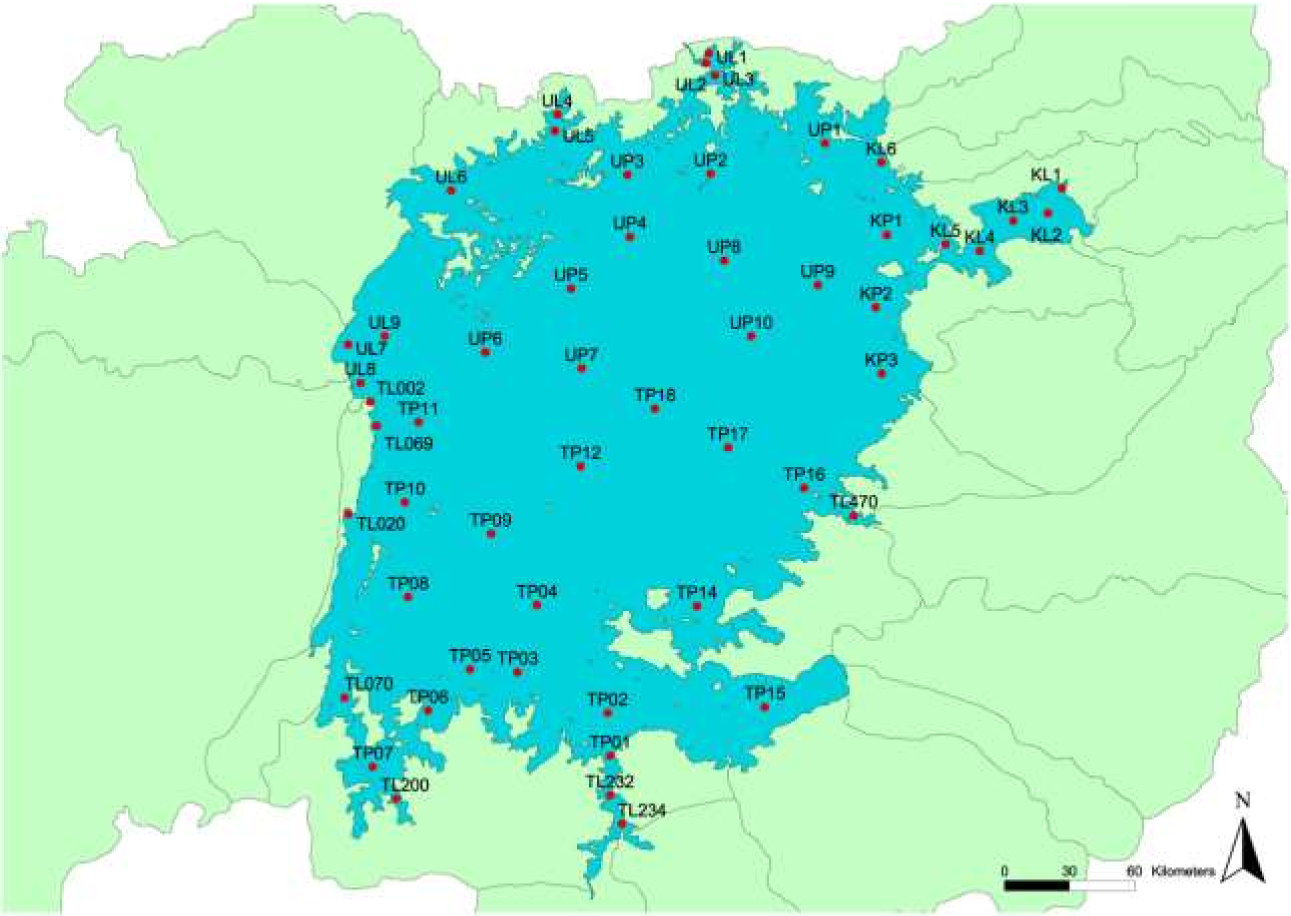

Figure 1.4 Locations of lake monitoring stations.

The locations of the stations are shown in Figure 1.4 and a summary of the stations sampled in the lake monitoring programme is shown in Table 1.5. The total number of stations was increased from the planned 54 to 61 mainly because of the addition of some near shore stations in Tanzania. The study so far has shown that the lake is spatially inhomogeneous, and it is therefore recommended to retain the original 54 stations in order to resolve the spatial variations in the lake. Initially it was expected that the number could be reduced after some time, but this has proved not to be the case.

A total of 244 profiles out of a planned 512 (for 12 months) were measured. This gave a total of 1516 water samples to be analysed in the laboratory for nutrients etc.

Table 1.5 Summary of stations sampled in lake monitoring programme.

	Kenya	*Uganda*	*Tanzania*	*Total*
Number of near shore stations	6	9	14	31
Number of offshore stations	3	10	17	30
Total number of stations	9	19	31	61
Number of near shore profiles	36	48	50	122
Number of offshore profiles	18	33	59	110
Total number of profiles	**54**	**81**	**109**	**244**
Total number of samples	**155**	**650**	**711**	**1516**

Recommendations

For the immediate future, it is recommended that planning and co-ordination with FIRI, KEMFRI and TAFIRI should be improved to accomplish more frequent cruises. It is further recommended that, in the next phase of LVEMP, fast survey vessels be purchased for each country so that the cruises can be completed in much shorter time. This would reduce the cost of the cruises and release the laboratory staff who participate in the cruises for more work in the laboratories.

Prior to the fast vessels becoming available, it is recommended that the present vessels in Kenya and Tanzania be made suitable for on-board accommodation and arrangement made for continuous cruising. The need to stop at night and to over-night on land more than doubles the duration of the cruises.

Regarding equipment, it is recommended that larger water samplers (all countries), Acoustic Doppler Current Meters and sediment corers (Kenya and Tanzania) and more reliable communication and navigation instruments (all countries) be purchased as soon as possible.

1.4.4 Laboratory Analyses

The main conclusions and recommendations regarding the laboratories are as follows:

- All the laboratories are, in principle, capable of making all the analyses that are necessary for the study. However, the full capabilities of the laboratories in Kisumu and Mwanza have not yet been realised.
- The lack of a proper laboratory in Kisumu is a serious constraint on all their work.
- The efficiency in the laboratories (ie. the ability to handle large numbers of samples) can be improved by more automatisation (autoanalyzers in Kisumu and Mwanza, a silicate module in Entebbe, zipper systems on all spectrophotometers and general use of syringe dispensers).
- A more reliable supply of purified water in all three laboratories (reverse osmosis systems) is required.

- Improved management and planning of daily laboratory work is necessary.
- The purchase of consumables such as chemicals, filters and glassware as well as equipment should be possible on a day-to-day basis.
- Long-term training of the laboratory staff in Kisumu and Mwanza as described in Chapter 12 is required.

1.4.5 Hydraulic Conditions

Lake Victoria temperature profiles

Previous descriptions of the hydraulic conditions in Lake Victoria are partially confirmed by the measurements made during the study. A thermocline at 50 m depth forms in February-May, and total vertical mixing accompanied by cooling occurs in July-August. However the previously reported gradual warming of the water column in September-December is less obvious and almost total mixing occurs in December-January at some stations.

Other general conclusions are:

- Lake Victoria is spatially inhomogeneous. At any instant there are large differences in temperature and stratification from north to south and east to west. The profile at UP2 (Bugaia Is) cannot be used as an indicator of the conditions everywhere in the lake as has been assumed by previous researchers.

- In general, there is less mixing on the eastern side of the lake, including the southeastern corner. A possible explanation is that the global winds that cause the mixing come from east and southeast, and the adjacent lake areas are more protected than the western side.

- The stratification of the water column is more pronounced in the north and central areas than in the south.

- There is a tendency for the entire water column to be slightly warmer in the north than in the south.

It is recommended that the planned monitoring programme for the hydraulic conditions be continued in the next phase of LVEMP. It is important that the monitoring occurs at monthly intervals and that currents and wind are also measured.

Winam Gulf

The measured temperature profiles show a very irregular variation from Kisumu out to Rusinga Channel. This could be explained by the discharges from the various rivers and streams into the gulf, particularly from the Nyando and Sondu Rivers.

The flushing of Winam Gulf is caused by three factors:

- Discharges from the rivers that give a net outflow through the gulf.

- Diurnal onshore-offshore winds that cause strong currents in Rusinga Channel into, and out of the gulf.
- Thermal stratification, the importance of which is uncertain.

The field monitoring should continue in the next phase of LVEMP and be extended with current profiling in Rusinga Channel and temperature measurements in the rivers. A detailed model of the gulf is required to obtain a full understanding of the flushing mechanisms.

Mwanza Gulf

The measured temperature profiles show that thermal stratification seems to exist most of the time in Mwanza Gulf. The stratification is likely to cause a vertical circulation with cooler water flowing out at the bed and warmer water flowing in from the lake at the surface.

The flushing of Mwanza Gulf appears to be mainly due to:

- Vertical circulations caused by the thermal stratification.
- Periodic discharges from the rivers and streams into the upper gulf.

These phenomena should be investigated further in the next phase of LVEMP, together with the source of the cooler water at the bed of the gulf. Current profiles should be made to test the hypothesis of vertical circulation.

Napoleon Bay

There seems to be two typical conditions in Napoleon Gulf. For about 50% of the time the vertical temperature profiles throughout the gulf are similar without any strong thermocline and only small temperature differences between surface and bed. The second conditions has much warmer water at the upper end of the gulf (UL1) than in the central and lower gulf, probably due to the fact that the upper gulf is a quiet, shallow bay near Jinja harbour which can be heated more by the sun.

The flushing of the gulf is probably entirely due to the outflow to the Victoria Nile.

Napoleon Gulf is not interesting as a focus area for further study.

Lake Victoria currents

The analysis of the currents measured in Ugandan waters shows that there is rarely any recognisable large scale horizontal circulation. The currents are weak at all depths (less than 0.1 m/s) and frequently in opposite directions at adjacent stations.

Similarly, the winds rarely show any consistency in speed and direction from station to station and there is no obvious correlation to the water surface current speeds and directions.

A preliminary conclusion is that the spreading of pollutants from the coast to the centre of the lake is caused by dispersion rather than advection (large scale circulations) for most of the year. The dispersion is caused by local turbulence generated by wind and solar heating.

It is strongly recommended that the field measurement campaign with ADCPs should be continued for several years to confirm or reject the preliminary conclusion. The measurements should be made over the whole lake within a short period each month, say maximum 1 week. The campaign should include both measurements from the survey vessels during the monthly lake cruises and continuous measurements a 1-2 stations in each country by bottom deployed ADCPs.

Annual updating

It is strongly recommended that regional working sessions be held annually to distribute the data among countries, to analyse the data, to calibrate, verify and apply the model of the hydraulic conditions and to update the understanding and conclusions about the hydraulic processes in the lake and focus areas.

1.4.6 Eutrophication

Nutrients

Water samples were analysed for 13 different nutrient parameters and a total of 8,600 nutrient analyses are now available in the database. These showed that, as expected, there are generally higher nutrient concentrations in the nearshore areas, and particularly in Winam Gulf, Mwanza Gulf, Murchison Bay and Napoleon Gulf.

Chlorophyll-a / light

The investigations of chlorophyll-a concentrations and light penetration showed an excellent correlation between the two parameters. The measurements showed low secchi depths and high chlorophyll-a concentrations in the eutrophied nearshore areas, see Figure 1.5.

Oxygen

There was a good coverage of oxygen measurement during the year, and some tendencies regarding the oxygen conditions start to appear. For example, Figure 1.6 shows the areas where half of the measurements at the bed were below 2 and 1 mg/l. It was generally found that the main period of oxygen deficit at offshore stations was Jan/Feb to Jun/Jul. However, the length and timing of the periods with oxygen deficit are not the same at all stations (lake inhomogeneity) and the Bugaia station is not representative of offshore conditions. There is an area in Tanzanian waters which suffers oxygen deficiency most of the time (Figure 1.6). Oxygen deficits are rare in the top 40 m at offshore stations, but in nearshore areas total oxygen depletion occurs from time to time.

Phytoplankton

The phytoplankton analyses shows that there is an increase in algal biomass in near shore areas, both blue-greens and diatoms. Offshore, the algal biomass concentrations are quite low. In both areas blue-green algae has become the dominating species. In the diatoms, there has been a shift from *Melosira* to *Nitzchia* dominance.

Zooplankton

Approximately 1500 samples were taken for analysis for zooplankton composition, but not all have been treated yet. The investigation showed some 30 Rotifer species which were also more associated with nearshore than offshore stations. The macrozooplankton was completely dominated by copepods during the whole period of study whereas Cladocera species occurred in low numbers. The copepods contributed most towards the total zooplankton biomass.

Nutrient mass balance

A mass balance for phosphorus and nitrogen for the lake as a whole has been made. The loadings to the lake include those from the catchment (non-point sources), industrial and municipal effluents (point sources), atmospheric deposition and nitrogen fixation by blue-green algae. The losses are those to the Victoria Nile, by burial in the lake bed, by denitrification and by removal from the lake in the fish catch. The difference between loadings and losses is an increase in the concentration in the lake water. The calculations showed that the processes of nitrogen fixation and denitrification are major elements in the mass balance, accounting for somewhere between 37,000 and 127,000 tons of nitrogen annually (the difference is due to the assumptions about the magnitude of the atmospheric deposition). The magnitude of the two processes is unknown, and should be investigated in the immediate future.

Historical development of eutrophication

Measurements of eutrophication effects since 1960-61 have been collected in an historical water quality database. These measurements have enabled an analysis of the changes in the eutrophication of Lake Victoria since Talling's time. There is data from 1960-61, and then there is a long gap until 1990 after which there is data from 9 campaigns up until the present study. The general result is that there is a significant increase in the level of eutrophication effects in the near shore areas, but not offshore. More details are given in section 1.6 in this chapter, and in Chapter 10.

Conclusions

The inlake monitoring of water quality is now operational, but a proper assessment of the state of eutrophication of the lake requires at least one full year of measurements, which has not been obtained during the project period for various reasons. However, the data set available at the end of the project is much more comprehensive regarding combined spatial and temporal extent than what has been the basis of former “conclusions” on the lake and gives some indications regarding future conclusions.

Overall, the data indicates that due to combination of a large surface area and relatively shallow depth, the lake does not react homogenously. Thus, mixing occurs at different times and to different degrees in different parts of the lake (see Chapter 8) and e.g. oxygen deficits do the same. Generally, the offshore part of the lake (60 – 70% of the lake area) has relatively low chlorophyll-a concentrations and often measurable nutrient concentrations indicating that the primary production offshore may not be limited by nutrients but rather by light due to the mixing regime. This implies that the ecological turn-over in the offshore parts of the lake may not be significantly affected by inputs of nutrients to the lake.

Oxygen deficits occur in the offshore parts of the lake, but the data from the study indicates that lesser parts of the lake are affected, and for a shorter time than was expected based on former studies.

On the other hand, the data shows clearly that near shore areas may be highly affected by eutrophication, especially the hot-spot areas such as Winham Gulf, Murchison Bay, Napoleon Gulf, and Mwanza Gulf. In these areas chlorophyll-a concentrations today rise far beyond what has been measured previously. Thus, the present study has measured 170 ug/l of chlorophyll-a in Mwanza Gulf and a study on Murchison Bay in 1997 measured up to 300 ug/l. For comparison, Talling (1965, 1966) reported maximum values of chlorophyll-a of 70 ug/l in near shore areas of the lake.

It is likewise evident, that strong oxygen deficits occur in the hot-spot areas independently of the general oxygen regime of the lake. Thus, several meters of oxygen free water column has been registered both in Mwanza Gulf and Napoleon Gulf, and in Murchison Bay the whole water column was deoxygenated in November 1997. Such events are related to local conditions such as high nutrient input, high algae production and, at the same time low wind mixing.

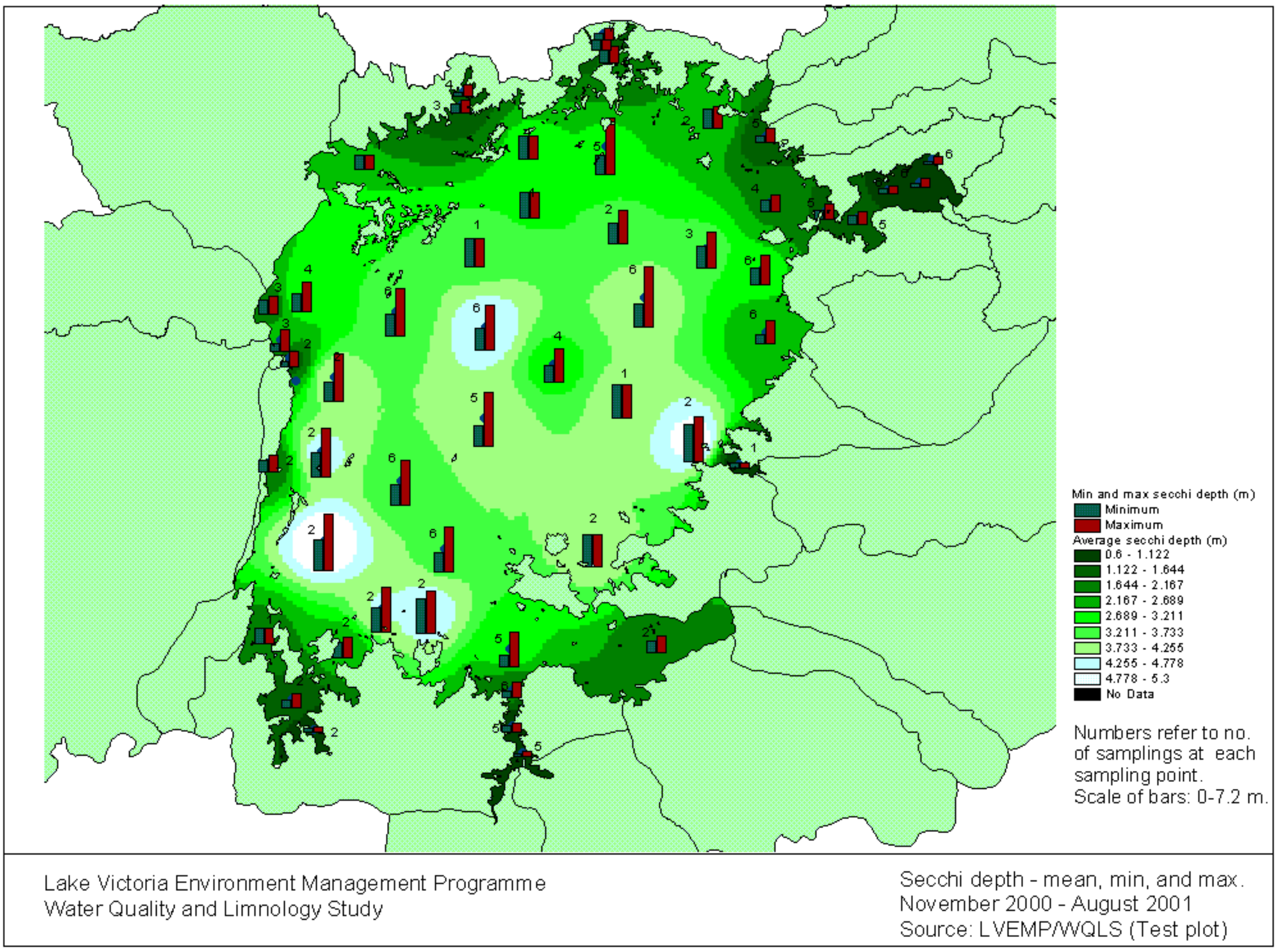

Figure 1.5 Secchi depths November 2000 - August 2001.

Recommendations

The basic recommendation is to finalise outstanding data compilation (especially phytoplankton and zooplankton) and to continue with the data collection to obtain at least two full years data. At the inception workshop, the proposed monitoring programme was meant to evaluate the variability of the various eutrophication indicators within the lake with the intention to propose a reduced future monitoring programme. The collected data has shown that the ongoing monitoring programme must be considered a minimum for the next years to obtain more knowledge of the spatial and temporal variability of the eutrophication indicators within the lake.

The lake monitoring programme should be extended to include measurements of nitrogen fixing by blue-green algae and denitrification.

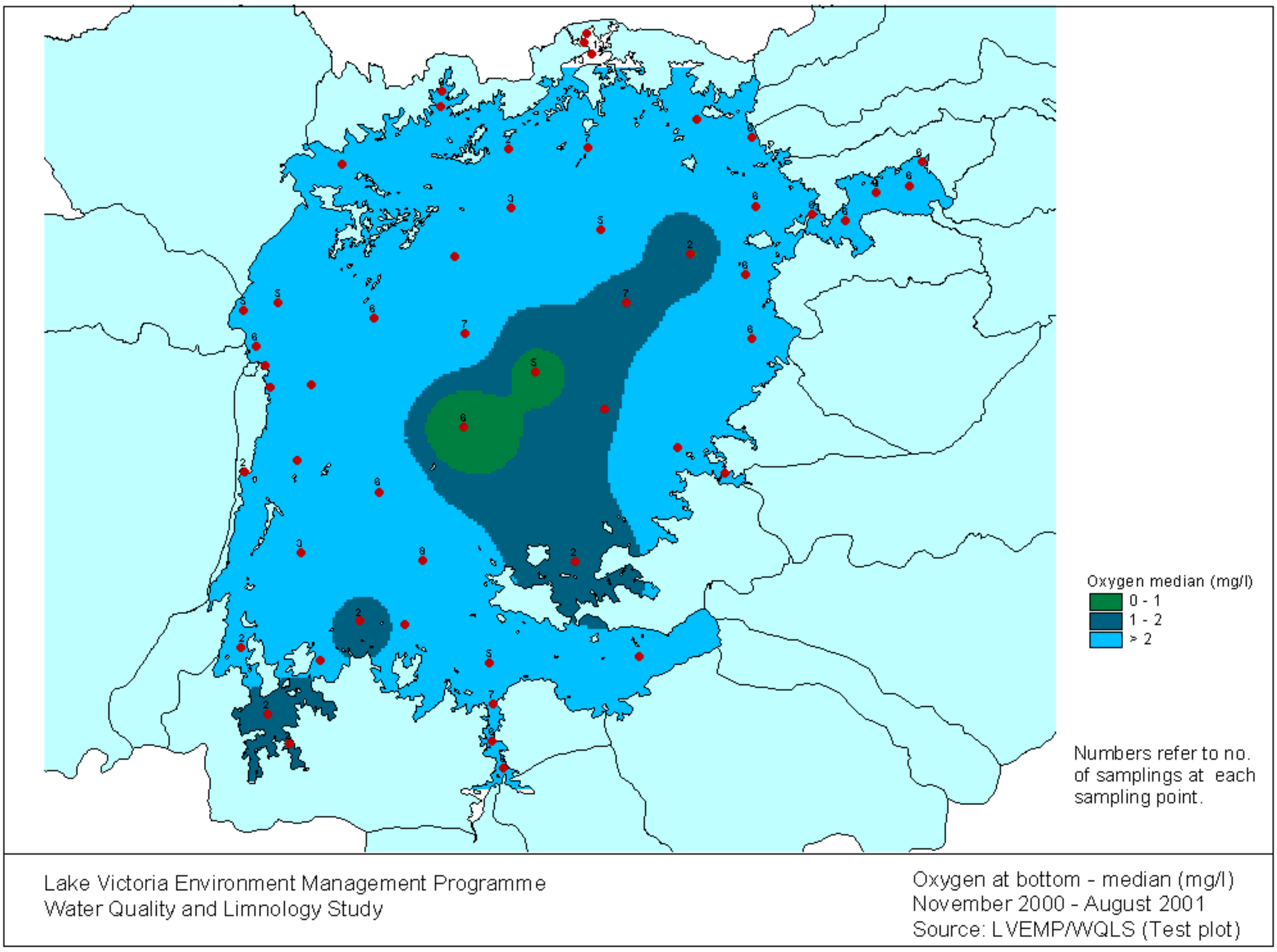

Figure 1.6 Oxygen concentrations at bed of lake - median.

1.4.7 Lake Victoria Framework Model

The tests with the Lake Victoria Framework Model resulted in the following conclusions and recommendations:

- The model is well-suited to the purpose of analysing management practices and remedial measures for Lake Victoria.

- The model should be extended with the full facilities for analysing and pre-processing of input data, and for analysing and post-processing of model results.

- The WQ Component staff should receive extensive and comprehensive training in the use of the model and the scientific background.

- The model should be extended with detailed local models of focus areas in the three countries, eg. Winam Gulf, Mwanza Gulf and Murchison Bay.

- The global winds applied to the model are not representative of the actual wind patterns that occur at the surface of the lake. The global winds cause large scale horizontal and vertical circulations in the lake that are not observed in the measurements. The winds at the lake surface are much weaker and irregular, and are dominated by the diurnal onshore-offshore winds near the coast for most of the year. A new, important, and major task in the next phase of LVEMP will be to measure and develop wind patterns over the lake surface.

1.4.8 Regional Quality Assurance Mechanism

The Consultant's work on establishing the basis for a Regional Quality Assurance Mechanism covered a range of activities and revealed specific areas where improvements are necessary. A summary of the observations, conclusions and recommendations for each of the activities follows:

Field forms

When properly used, the field forms prepared for the recording of all data and laboratory analysis results are the record of the raw data for the project. They are thus very important documents and it is recommended that they should be used consistently by all field parties, both on the lake and in the catchment, and by the laboratories.

Laboratory analysis methods

The laboratory analysis methods are well-known and agreed by the laboratories. Documentation of most of the methods has been prepared, and it is recommended that it be completed in connection with the proposed long-term training.

Training of laboratory managers and staff

Basic training in eutrophication laboratory analyses and QA for staff from Kisumu and Mwanza has been carried out. The observations and recommendations of the Consultant's laboratory specialists during the hands-on training in Kisumu and Mwanza were:

- The laboratory technicians knew the analysis methods to use, but lacked confidence and practice. Long-term hands-on training is required.
- There is little internal sharing of knowledge and experience in the laboratories, eg. the techniques learnt by the staff trained in Denmark were not passed on to all the laboratory technicians.

Laboratory manuals

A well-recognised fact is that laboratory manuals are most useful when they are prepared by the laboratory staff themselves, so that they take account of local conditions. The preparation of QA/QC manuals consisting of the analysis methods and QA/QC procedures was started during the training courses. It is recommended that this work be completed as soon as possible and probably in connection with the proposed long-term training.

Data validation

The working sessions revealed a myriad of errors in the data from the field and the laboratory, and data validation became a major part of the work at each session. Most of the errors relate to trivial mistakes and not, for example, to poor laboratory analyses. Fortunately, the serious mistakes were infrequent, and after the trivial mistakes had been corrected, most of the data was accepted.

The techniques used for data validation consisted of:

- Visual examination for "reasonableness".
- Statistical analysis.
- Inter-parameter relations.

Inter-laboratory comparison

Preliminary results indicate that both analytical precision and accuracy should be improved in all three laboratories.

Recommendations

The Consultant strongly recommends the inclusion of additional training in the bridging phase and in Phase II of LVEMP. Training should cover both the field and the laboratory.

The field staff require training in actual field techniques with the various instruments and the immediate, on-board analysis of data to reveal measurements errors and the need for repetition of the profiles and sampling. Training on three lake cruises is expected to be sufficient to build up the necessary routine.

Long-term, hands-on training of the laboratory staff is required, particularly in Kisumu and Mwanza. The staff need continuous on-the-job training and practice to build up confidence and routine before they can produce quality data. The laboratory training should continue over at least 2 years, with visits by specialists for 3 to 4 months each year. The training should include not only analysis methods and post-processing of data, but also completion of the methods and QA/QC manuals.

The inter-laboratory comparisons should be repeated and more parameters should be included. The use of control charts and certified reference material should be implemented at the laboratories.

1.5 Recommendations for the next Phase of the Project

A summary of the recommendation for the continuation of the project is given in this section. The recommendations apply to the bridging phase up until 2004 and to Phase II of LVEMP. Reference is made to other parts of this report for the details of the recommendations.

1. Continue monitoring to collect data for the model, to identify trends and for future management purposes. This applies to meteorological, hydrological, pollution loadings and water quality monitoring in both the catchment and the lake. The present number of stations and frequency of monitoring (monthly) should be retained for at least 2 years after which the programme can be reconsidered on the basis of the results obtained.

2. Improve monitoring facilities in the catchment (rainfall, evaporation and river discharge measurements).

3. Purchase missing field and laboratory equipment (e.g. Acoustic Doppler Current Profilers, sediment corers, water purifiers, laboratory automatisation equipment).

4. Start sediment and lake current studies as soon as possible.

5. Purchase suitably equipped fast survey vessels for all three countries.

6. Complete the Kisumu laboratory as soon as possible. Even although the urgency of this action is obvious to all, there has been almost no progress in the construction in the 20 months of the consultancy. The lack of a proper laboratory is a serious constraint for the Kenyan team.

7. Speed up procurement procedures for equipment and consumables. For example, it is not acceptable that laboratory analysis work has to stop due to lack of filters which cannot be purchased until permission and funds are received from the main LVEMP office. Budgets should be available for immediate and local purchase of such consumable items. Another example is that even now at the end of Phase I, the WQ Components still do not have equipment which, in reality, was essential for them to achieve their goals.

8. Speed up the flow of funds for allowances for staff on field work and at working sessions etc. This applies particularly to Kenya.

9. More training is required in a number of fields:

   Limnology: A selection of staff from the three WQ Components should participate in a full course in Limnology. At present there is only one person who has such training.

   Field data collection: It is recommended that a field data collection specialist from a consultant should participate in 2-3 lake cruises in each country to give more on-the-job training in the use of instruments, particularly the ADCPs, on board analysis, and improvement of routines and efficiency. Similarly some assistance is needed in water quality sampling in the catchments.

Laboratory analyes: A long-term on-the-job training programme is required for the laboratories in Kenya and Tanzania with the purpose of improving the efficiency, precision, accuracy and to develop routines to avoid data processing errors. The training should continue for at least two years with visits by specialists for 3-4 months each year.

Plankton analyses: There is a lack of specialists in the analysis of phytoplankton and zooplankton samples. Suitably qualified staff should be employed and trained.

Modelling: Comprehensive training of the staff with responsibility for the Lake Victoria Water Quality Model is required. At least 2 hydraulic specialists and 2 biologists from each country should receive an estimated 6 weeks of training from the model vendor in the scientific background of the model, its calibration and practical application.

10. More resources should be allocated to the upgrading of the Lake Victoria Water Quality Model from a demonstration model (its present form) to a full management tool. This includes the purchase of the model input data pre-processor, the grid generator, development of new wind data which correctly represents the annual wind patterns over the lake (the winds are the main driving force for the circulations and mixing), and extension of the model with detailed sub-models of focus areas (e.g. Winam Gulf, Mwanza Gulf, Murchison Bay and Napoleon Gulf).

11. Hold annual working sessions in all disciplines to update databases, extend records, perform data validation, analyse new data, refine the model, and to revise the conclusions, the recommendations for environmental protection and the proposals for remedial measures. It is recommended that a consultant be engaged to assist in the working sessions. The consultant's input should include:

    Mid-year progress visit: A few specialists covering all the disciplines should visit each of the countries for 2-3 weeks at mid year to check progress and to give advice and assistance as necessary.

    Annual working sessions: The consultant's discipline specialists should participate in the annual working sessions with the purpose described above.

1.6 Preliminary Conclusions about Hypotheses for Changes in Lake Victoria

The work described in this report is the result of the first lake-wide study with a duration of one year. It has shown that Lake Victoria is spatially inhomogeneous and there is a large seasonal and inter-annual variability. While previous studies have indicated the possibility of spatial and temporal inhomogeneity, it has not been demonstrated clearly until now.

Earlier studies were based either on regular measurements at Bugaia Is., or a single lake-wide cruise, or even just a few sporadic measurements, and they could therefore not reveal the magnitude of the inhomogeneity and the state of the lake as a whole. It is characteristic that all the recent studies in the 1990's have compared their results with those of Talling (1965,1966) who carried out a very comprehensive study at Bugaia Is. for one year in 1960-61. The inter-annual variability that has now been proven implies that the year 1960-61 is not necessarily representative of the conditions in the 1950's and 60's. The conditions could have been worse or better in the years immediately before and after.

The comparisons of the studies in the 1990´s with Talling's results have formed the basis for many statements about the deteriorating state of the lake, and the reasons - often contradictory - for the observed changes. The new knowledge about the lake gained through the present study indicates that the basis for the statements and reasons needs to be reconsidered.

The various reasons for the changes can be grouped into three main hypotheses which can be subjected to a first test of validity using the preliminary conclusions of the present study.

Hypothesis no. 1:
Increased nutrient loading from the catchment and atmosphere due to population growth and changes in agricultural practices.

Preliminary conclusions:
The nutrient loadings have certainly increased, both from the catchment and atmosphere. There are higher concentrations of inorganic phosphorus and nitrogen in both near shore and offshore areas.

The only station where there are enough historical measurements to be able to make statements about the effect on the increased nutrients on the eutrophication is Bugaia Is, which is in the transition zone between near shore and offshore. Some preliminary conclusions for the near shore and offshore areas are also put forward on the basis of the few available measurements and qualitative statements about conditions in earlier years.

Near shore:
- Inorganic nitrogen and phosphorus concentrations increased.
- Silicate concentrations decreased.
- Chlorophyll increased (corresponding to increased algal biomass and decreased secchi depth.
- Phytoplankton composition changed from diatom to blue-green dominance.
- Zooplankton composition unchanged.
- Oxygen deficits increased in the most eutrophied bays and gulfs.

Transition zone (Bugaia Is.):

- Inorganic nitrogen and phosphorus concentrations increased.
- Silicate concentrations decreased.
- Chlorophyll increased (corresponding to increased algal biomass and decreased secchi depth.
- Phytoplankton composition changed from diatom to blue-green dominance.
- Zooplankton composition unchanged.
- Oxygen deficits unchanged.

Offshore:

- Inorganic nitrogen and phosphorus concentrations increased.
- Silicate concentrations decreased.
- Chlorophyll unchanged (corresponding to unchanged algal biomass and decreased secchi depth.
- Phytoplankton composition changed from diatom to blue-green dominance.
- Zooplankton composition unchanged.
- Oxygen deficits unchanged.

The effect is clearly seen in the near shore areas which have increased algal biomass, and is due to the increased phosphorus loading. There are a number of highly eutrophied "hot spots".

In the offshore areas the increased nutrients (N and P) do not appear to have had a significant effect on the eutrophication, possibly due to light limitation of algal growth.

The anoxic area of the lake bed is also less in extent, both spatially and temporally, than predicted in previous studies and as frequently speculated in the media.

In general, the offshore areas are not seriously eutrophied.

Hypothesis no. 2:
Predation by Nile Perch on native planktivorous fish species and changes in fishery practices.

Preliminary conclusion:
The studies of fish and fisheries come under the fisheries components of LVEMP and have not been addressed in the present study. However, the WQ Components have now a large amount of data available that should assist the fisheries components in reaching their conclusions.

Hypothesis no. 3:
Climate changes towards warmer, more humid and less windy weather reducing mixing depth and frequency of total mixing.

Preliminary conclusions:
Meteorologists are still debating the magnitude of the climate changes during the last 50 years. For East Africa there is no clear trend in the rainfall and temperature changes are likely to be less than 0.5° C. The inter-annual variability is so large that it would also effectively disguise any trend over the last 50 years.

Any temperature increases could have an effect on stratification and mixing. However, contrary to the hypothesis, there was less stratification and more total mixing in 2001 than in 1960-61.

1.7 Management Considerations

The results of the present study enable some considerations about the future management and protection of the water quality and ecosystem of Lake Victoria. The considerations include some suggestions for remedial measures that address the eutrophied near shore areas which are seen as the most serious problem for the water quality.

The suggestions concern the reduction of nutrient loadings, but not how to implement the reductions, which is outside the scope of work for the present study.

However, the first management consideration concerns the continuation of monitoring.

1.7.1 Monitoring

Management of any kind is based on information. For the management of Lake Victoria the source of information is monitoring of the conditions and inputs in both the catchment and lake. Monitoring is thus an integral part of management and all management programmes include continuous monitoring.

It is therefore imperative that all monitoring programmes in the catchment and the lake are continuous. It is normal that the monitoring is more intensive at the start of a project and reduces with time to fewer representative stations and parameters. For example, after two more years of monitoring (which is enough for proper calibration and verification of the water quality model) the density of stations and number of parameters can be revised. However, it is proposed that the frequency of measurements (monthly) should not reduced. If anything, the frequency should be increased.

1.7.2 Remedial measures in near shore areas

Sio, Nzoia, Yala and Gucha-Migori Rivers
The phosphate discharges from the Sio, Nzoia, Yala and Gucha-Migori Rivers cause high chlorophyll and low secchi depths in the near shore areas at the river mouths (see Figure 1.5). The origin of the phosphate is agriculture and perhaps a few point sources in the catchment, and the remedial measure is clearly to reduce the magnitude of the discharges.

With regard to agriculture, it is not suggested that the use of fertilisers should be reduced as this would result in a reduction of food production, which is clearly undesirable. Rather, it is suggested that agricultural practices should be altered to avoid soil loss from the fields, since the phosphate is adsorbed to the soil particles.

Note that "soil loss" should not be confused with "soil erosion". "Soil loss" refers to the loss of surface soil from cultivated fields, especially when they are bare. "Soil erosion" refers to the spectacular erosion which occurs on steep slopes in the upper catchment of rivers.

Winam Gulf
Winam Gulf is highly eutrophied due to nutrient discharges from point sources (Kisumu city and industries) and from the catchments of the Nyando, Sondu, North Awach and South Awach. The suggested remedial measure is to reduce the phosphate loadings from point sources and by soil loss control in the catchments.

Musoma Gulf and Speke Gulf
Musoma Gulf receives discharges from Musoma town and the Mara River. Speke Gulf receives discharges from the Grumeti, Mbalageti and Simiyu Rivers. Both gulfs show elevated levels of algae biomass.

The suggested remedial measure is, once again, to reduce the phosphate discharges. However, more study of the catchments is needed before a recommendation on how to reduce the discharges can be given. It may prove not feasible to reduce the phosphate discharges in these catchments with low intensity agriculture.

Mwanza Gulf
Mwanza Gulf receives nutrient loadings from many sources - Mwanza city, industries, and Nyashishi, Magogo-Moame, Issanga and Southern Shore Streams catchments.

Here again it is suggested that phosphate discharges should be reduced. First priority should be given to the collection and treatment of the municipal and industrial effluents in Mwanza city. More study is required to determine how to reduce the phosphate discharges from the catchments.

Emin Pasha Gulf and Western Shore Streams
There are only a few measurements in these areas and more are required before definite conclusions can be reached about the state of the eutrophication. Further, more study of the catchments (Southern Shore Streams, Biharamulo and Western Shore Streams) is required to determine the origin of the nutrient discharges.

Kagera River
There are large nutrient loadings to the lake from the Kagera River but, compared with other rivers, the relative proportions of nitrogen and phosphorus are

different. The Kagera has a higher proportion of nitrogen and a correspondingly lower proportion of phosphorus.

It is suggested that the main source of the nutrients is actually the high population density in the catchment (including Rwanda and Burundi) and all the associated human and small scale agricultural activity. For this reason, it is not possible at this stage to suggest any realistic remedial measure.

Murchison Bay
Murchison Bay is highly eutrophied, and the solution is quite clear. The municipal and industrial waste waters from Kampala should be collected and treated, including removal of phosphorus.

Napoleon Gulf
Napoleon Gulf also shows a high level of eutrophication due to the point sources that discharge into the gulf, e.g. Jijna Njeru, Kakira Sugar etc. It has previously been suggested that the effluents were quickly flushed directly into the Victoria Nile, but the high level of eutrophication shows that this is not the case. The effluents are dispersed in the gulf by local wind-driven water movements and general dispersion before entering the Victoria Nile.

As with Murchison Bay, the effluents should be collected and treated, including the removal of phosphorus.

1.7.3 Why reduce Phosphorus loadings?

The remedial measures suggested above for the near shore areas all involve the reduction of the phosphorus loadings from the catchments and the point sources. However, the near shore areas have been shown to be nitrogen or light limited, which means that a more immediate effect on the eutrophication could be achieved by reducing nitrogen or light rather than phosphorus. It also means that a large reduction in phosphorus will be required before it becomes the limiting factor and has an effect on the eutrophication level. So, why choose phosphorus?

The short answer is that it is not possible to change the light, and it will be too expensive, and in many cases not feasible to reduce the nitrogen loads.

In the catchments the loss of soil from cultivated fields (the phosphorus is mainly adsorbed to soil particles) can be reduced by soil conservation practices. Nitrogen on the other hand is dissolved in the water and there are limited possibilities of reducing it. The cost of reducing the phosphorus discharges is mainly connected to the cost of educating farmers to use soil conservation measures.

For the point sources it will be less expensive to remove phosphorus than nitrogen from the wastewater. 70% - 80% of the phosphorus can be removed by chemical precipitation in connection with pond systems at the wastewater treatment plants, which is a relatively simple method. The cost of removal of the first 60% - 70% of the phosphorus is relatively low, but increases for higher percentages. Removal of nitrogen would require expensive upgrading of treatment plants to another level of technology, and such a solution cannot be recommended at this stage for reasons of cost and difficulties with sustainability. A necessary condition for this remedial measure is of course the establishment of sewage collection systems in the main cities.

The percentage removal of phosphorus and nitrogen can be increased even more by passing the effluents from treatment plants through natural or constructed wetlands.

It is emphasised that the required degree of reduction of phosphorus loads can only be determined through the use of the Lake Victoria Water Quality Model. The model can be used to make sensitivity tests to determine the percentage of reduction which is necessary to achieve acceptable water quality conditions in the near shore areas. The degree of reduction may be different for the individual catchments and point sources.

As already noted, the cost of reduction of the loads increases with the degree of reduction. Therefore it has yet to be proved if it is economically, practically and politically feasible to achieve the necessary degree of reduction. Here again, the model can play a central role as an optimisation tool.

1.7.4 Rehabilitation of wetlands

The wetlands at the mouths of many of the rivers entering Lake Victoria act as a buffering zone for the nutrients. Phosphorus is partially retained in the wetlands and some removal of nitrogen occurs by denitrification. The magnitudes of these processes are being studied by the Wetlands Management Components of LVEMP.

Some increase in the removal of nutrients from the river discharges could be achieved by rehabilitation of the wetlands. Rehabilitation should involve increasing the area by recovery of encroached areas and improving the spreading of the river water in the wetlands.

Estimates of the effectiveness of the wetlands in reducing the nutrient loads to the lake must await the results of the Wetlands Management Components.

1.7.5 Remedial measures for offshore and lake-wide

The major source of nutrients to the lake as a whole is the atmospheric deposition. The increased deposition since 1960-61 has resulted in increased nutrient concentrations. The increase, in general terms, is the result of the increased population and human activity in the region. However, some of the increase may be due to nutrients transported in the atmosphere from areas outside the region. At this stage there is no data and no possibility to determine the geographical origins of all the atmospheric deposition.

NH_4 and PO_4 are mainly attached to particles which enter the lake through both wet and dry deposition. NO_3 is dissolved in the rain.

NH_4 comes from livestock, burning of grasslands and use of wood for fuel and charcoal, while PO_4 comes with the dust from bare agricultural land. NO_3 comes from burning of coal and oil and from oxidation of NH_4 in the atmosphere. NH_4 and PO_4 originate more from local sources whereas NO_3 originates from regional sources.

The immediate remedial measure is to improve agricultural practices and prevent soil losses to the atmosphere and runoff. Here again, the model will play an essential role in determining the degree of reduction of the loads which is necessary to achieve acceptable water quality.

On the other hand, the offshore area of the lake is not eutrophied and is not in need of immediate improvement. Therefore it is recommended that priority should be given to improving the conditions in the near shore "hot spots".