1 Non-point Pollution Loadings

1.1 Objectives

The objective of the activities related to the non-point pollution sources, i.e. diffuse runoff from land and deposition from the atmosphere were:

- To produce an estimate of all non-point pollution loadings to Lake Victoria from all major rivers and the atmosphere for the period 1950 to the present.

- To identify source distribution in relation to land-use in the catchment for management purposes.

1.2 Methods

The study has until now focused on:

- Overall estimation of loads from catchments to the lake
- Atmospheric deposition by rain on the lake (wet deposition)
- Atmospheric deposition on lake directly from the air (dry deposition)
- Excess of fertilizers from agriculture

The effects of sources such as nitrogen fixation by blue-green algae on the lake and detailed assessments of the effect of landuse changes (population pressure, deforestation etc.) have yet to be made.

The determination of pollution loads from the non-point sources has been limited to nitrogen and phosphorus.

The LVWQ model requires quantified total inputs from rivers of nitrogen and phosphorus. The methodology for this has been to directly measure the concentrations of the pollutants (N and P) in the main rivers and based on flow data from the same rivers calculate the global transports of N and P from each catchment to the lake.

The atmospheric deposition can be divided into wet deposition i.e. the deposition of nutrients washed out by the rain, and dry deposition which is the amount of nutrients deposited onto the water surface from the air during dry weather periods. For wet deposition rainwater has been sampled and analysed for total-nitrogen, ammonia, nitrates, total phosphorus, and phosphates. Due to lack of special sampling equipment for dry deposition, a simple method has been applied implying analysing the increase of nutrients in distilled water exposed in a bucket for a certain time.

To identify the non-point sources within the catchments the methodology has been based on compilation of existing landuse data to be collected from various institutions external to the project. Such data includes:

- Electronic landuse maps
- Agricultural statistics (location and areas of different cultures)
- Application rates of fertilisers for different cultures

1.3 River Water Quality Sampling

The planned river water quality sampling programmes comprised the major rivers of the Lake Victoria catchments and emphasis was laid on having simultaneous water quality and flow measurements allowing calculation of transports of the pollutants through the river systems and, in particular, the discharges to the lake.

At the beginning of the study the Kenyan water quality network consisted of approximately 100 stations distributed throughout the Kenyan parts of the catchments and samples were sent to different existing laboratories for analysis since the Kisumu laboratory was not yet functioning at that time. During validation of data it became clear from the levels measured that most of the “old” data had been analysed by methods for drinking water control purposes, which did not have the required sensitivity for calculating transports. Moreover, information on the analytical methods used for particular data sets was not recorded. Overall, this created too much doubt about the reliability of the data and it was decided to discard formerly collected data from use in the load calculations. For capacity reasons it was also decided to reduce the number of sampling stations to approximately 50.

During the project period the Kisumu laboratory became equipped with adequate instruments and the staff was trained in adequate methods for analysing nutrients. Thus, a full campaign on the reduced river water quality network (43 stations) was executed in September 2001 (the data are available on the CD-ROM). An example (Total Nitrogen) is given in Figure 1.1.

For the Ugandan catchments, measurements have been made during the whole study period on Sio, Katonga, Bukora and Kagera in collaboration between KARI and DWD. Moreover, the proper inland water quality programme of

DWD has provided nutrient data to the LVEMP project. Consequently 236 data records from 13 river stations, sampled from 1998 to the end of the year 2001 are available to the study (available on the CD-ROM). An example of a time series of Total Phosphorus and Total Nitrogen are given in Figure 1.2 and Figure 1.3 (Bukora River).

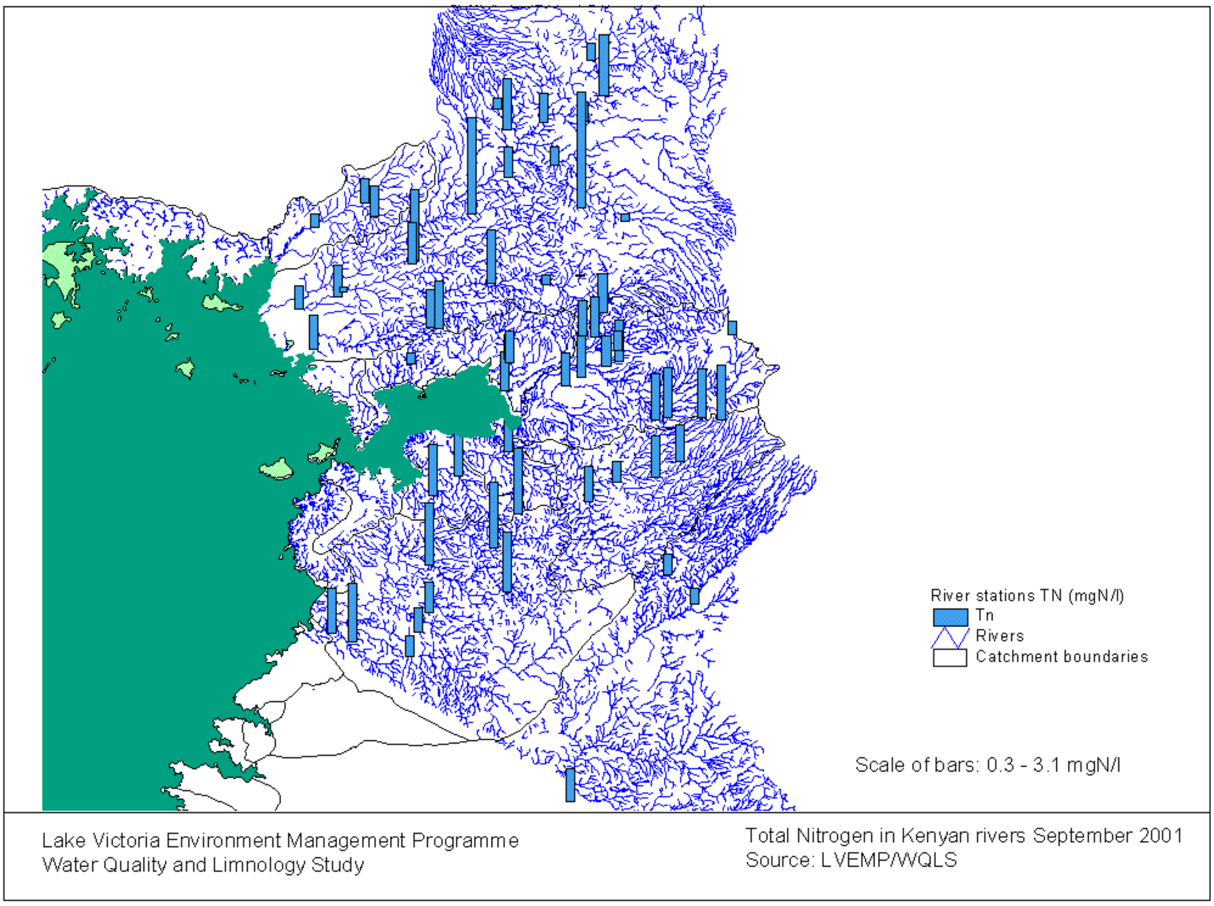

Figure 1.1 Total Nitrogen measured in the Kenyan rivers September 2001

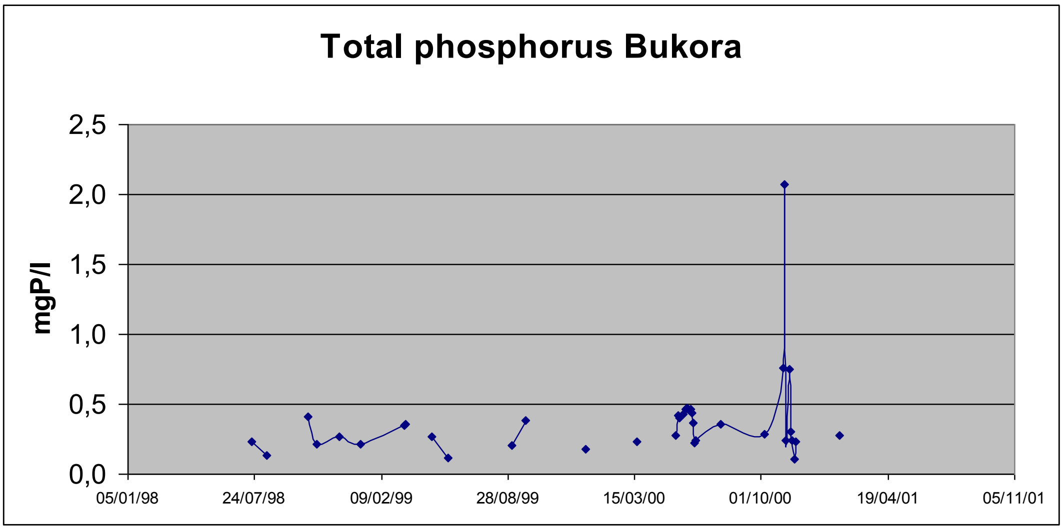

Figure 1.2 Time series of Total Phosphorus in Bukora River, Uganda.

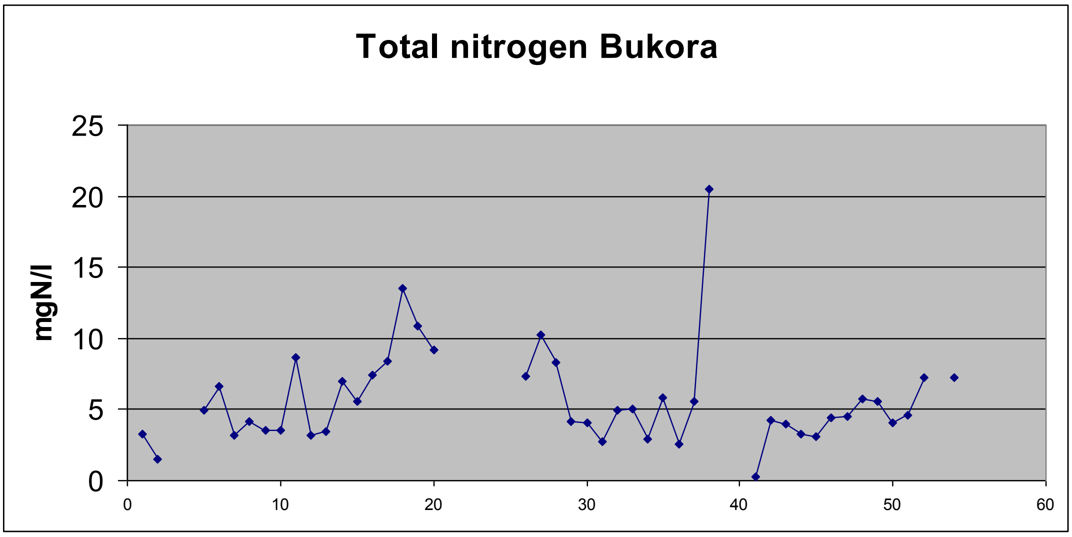

Figure 1.3 Time series of Total Nitrogen in Bukora River, Uganda.

In the Tanzanian part of the catchments, up to 15 water quality sampling stations were planned. However, The Mwanza laboratory suffered, as did the Kisumu laboratory, from lack of adequate equipment and training in low level nutrient analysis for a long time of the project period. Moreover, budget release problems has in some cases been an obstacle to executing the programme. This, combined with fact that most of the Tanzanian rivers are dry during a substantial part of the year explains why only very few river water quality data has been collected yet. As it was the case for the Kisumu laboratory, the laboratory in Mwanza is now capable of performing the required analysis, and the Tanzanian river water quality programme must be considered to be in its starting phase by the end of the year 2001.

It appears from above that the situation regarding river water quality monitoring can be summarised as follows:

- Ugandan catchments are reasonably well covered by time series of nutrient measurements.
- Kenyan catchments are covered spatially with a very high resolution, but only one campaign of valid data is available yet.
- Tanzania river water quality monitoring is at its starting point.

Proceeding on this basis to estimating discharges of N and P to the lake may be considered questionable from a lake management point of view. However, the fundamental approach of the study has been to produce best estimates based on available data, to recognise the weaknesses, and to improve estimations through continued monitoring. Consequently "typical values" for the concentrations of nutrients have been extracted from the data (averages of down stream stations) for use in the first total load estimates:

Table 1.1 Typical concentrations of TN and TP

No.	Sub-catchment	Nutrient concentration TN, mg/l	TP, mg/l
1	Sio	0,65	0,124
2	Nzoia	0,90	0,254
3	Yala	1,16	0,118
4	North Awach	0,94	0,127
5	Nyando	1,12	0,377
6	Sondu	1,08	-
7	South Awach	1,70	0,207
8	Gucha-Migori	1,44	0,143
9	Eastern Shore Streams	-	-
10	Mara	-	-
11	Grumeti	-	0,461
12	Mbarageti	-	0,461
13	Simiyu	-	0,405
14	Nyashishi	-	-
15	Magogo	-	-
16	Isanga	-	-
17	Southern Shore Streams	-	-
18	Biharamulo	-	-
19	Western Shore Streams	-	-
20	Kagera	3,50	0,226
21	Bukora	6,28	0,330
22	Katonga	6,90	0,320
23	Northern Shore Streams	-	-

1.4 Atmospheric Deposition

Data on the deposition of nutrients from the atmosphere as dry or wet deposition has been collected from analysis of a total of 16 samples (dry deposition) and 69 samples (wet deposition). Due to the late start of the Kisumu laboratory sampling started as late as August 2001 and results from six samples from Kisumu are available from Kenya (only wet deposition).

From Uganda time series of wet deposition data are available from Entebbe and Kampala from the period April – July 2001 (35 samples). The reliability of results from additional samples collected at the islands within the lake were questioned due to preservation problems and the fact that neither total nitrogen nor ammonia (the most important nitrogen component in the air) had been measured made it impossible to exploit these data for estimating general deposition of nitrogen. The data set from Uganda comprised, moreover, results from six samples from Kampala on dry deposition.

In Tanzania six samples for dry deposition have been analysed from Itumbili (Simiyu) and wet deposition results are available from Bukoba (5 samples), Itumbili (3 samples), and Mwanza (15 samples). Only the latter have been analysed for nitrogen as the Bukoba and Musoma laboratories were not equipped for adequate analytical methods for nitrogen analyses.

All above mentioned data has been collected from land-based stations and represent as such the deposition as it would appear in the near shore areas of the lake. However, with a lake area of 68,800 km^2 the atmospheric deposition would be expected to decrease with the distance to land. Especially nitrogen enters the air from manure from cattle or as NO_x from industry emissions. Rainfall will normally soon wash out these components and rain generated at the lake itself would be expected to be of low nitrogen content. Unfortunately only few measurements of atmospheric deposition have been made in the offshore parts of the lake. In total there are results (wet deposition) from three samples: UP2 and UP10 from November 2000 and TP9 from May 2001.

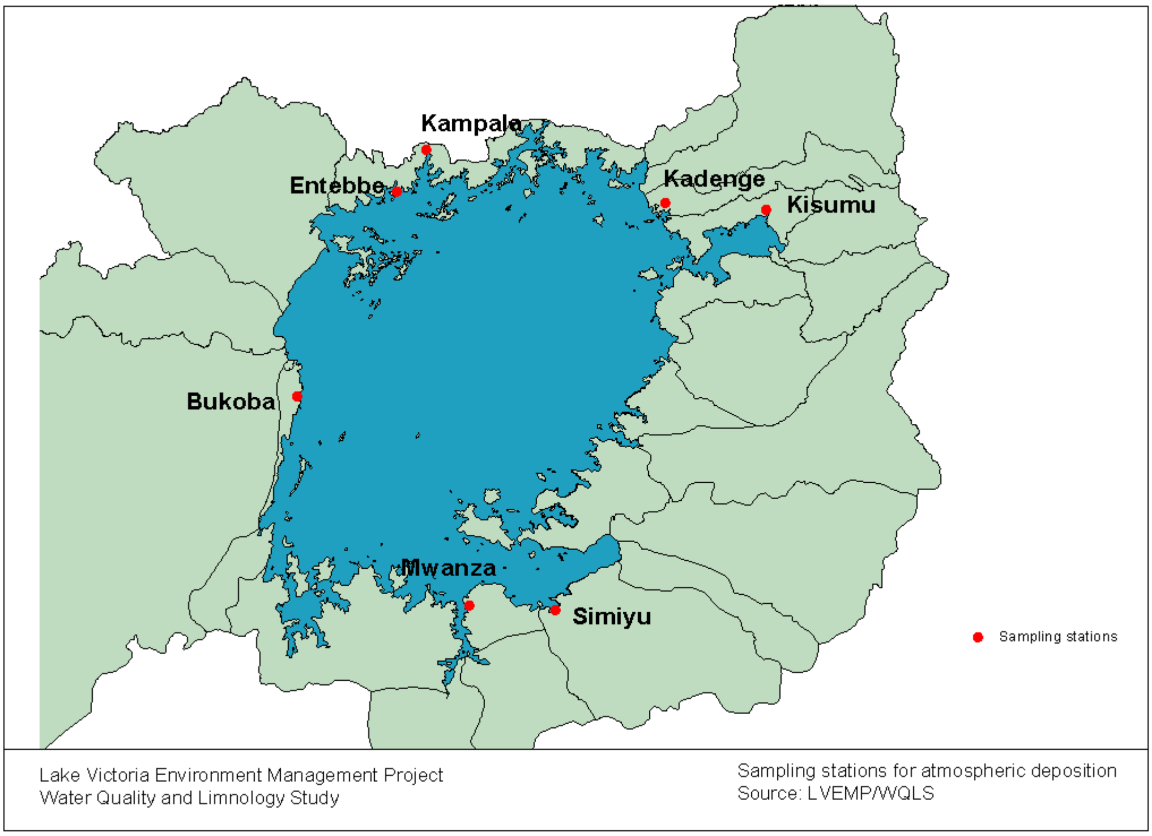

Figure 1.4 Land based stations for measuring atmospheric deposition.

Table 1.2 gives an overview of the data collected and their typical values (averages).

Table 1.2 Sampling and average concentration of nitrogen and phosphorus for estimation of wet and dry deposition.

Dry deposition					**Average deposition (mg/m2/d)**								
Sampling site	*Samplings*	*TN*	*TDN*	*TPN*	*NO2*	*NO3*	*NH4*	*TP*	*TDP*	*TPP*	*PO4*	*SIO3*	*IN*
Itumbili (Simuyi)	10 samples Feb. 01 - Jun. 01							0,866			0,567		
Kampala	6 samples May 01				0,057	0,612	1,594				0,127	0,20	2,148
Wet deposition					**Average concentrations (mg/l)**								
Sampling site	*Samplings*	*TN*	*TDN*	*TPN*	*NO2*	*NO3*	*NH4*	*TP*	*TDP*	*TPP*	*PO4*	*SIO3*	*IN*
Bukoba	5 samples Jan. 01 - May 01				0,007	0,217	0,881	0,031			0,014		1,061
Entebbe	15 samples Apr. 01 - Jul. 01				0,009	0,085	0,862				0,471		0,917
Kampala	20 samples Apr. 01 - Jun. 01				0,008	0,079	0,374				0,160	0,03	0,447
Kisumu	5 samples Aug. 01- Sep. 01	0,965	0,637					0,038	0,077				
Itumbili	3 samples Mar. 01 - Jul. 01							0,026			0,018		
Mwanza	18 samples Jan. 01 - Jul. 01				0,010	0,076	1,155	0,038			0,016	0,47	1,143
Offshore (UP2)	1 sample Nov. 00				0,003	0,011	0,186			0,041	0,014		0,200
Offshore (UP10)	1 sample Nov. 00				0,003	0,1	0,19				0,014		0,293
Offshore (TP9)	1 sample May 01				0,209	0,042		0,079		0,037	0,031		

It should be noted that the measured concentration of phosphorus in rainwater from Uganda (Kampala and Entebbe) is significantly higher than what has been measured in both Kenya and Tanzania and may be questionable[1]. However, the data validation gave no obvious reason to discard these data sets and they have therefore been used in the overall load estimates.

1.5 Landuse Data

Exploitation of landuse data has been part of the approach to assess the significance of different non-point pollution sources. Having estimated total loads to the lake from river water quality measurements, the relative importance of activities related to landuse could be assessed through identifying the location and magnitude of the activity. The most important activities in the context of non-point pollution is alteration of the soils due to deforestation and agricultural practices and the use of agrochemicals whereof a fraction leaches from the soils and enters the water courses.

It was recognised early that an assessment of the effects of deforestation and alteration of soils with respect to leaching of nutrients would be difficult, say impossible within the scope of the present study due to lack of historical data or comparative studies with sufficient generalisation value. The Ugandan team has started comparative studies on pilot plots, a task that will contribute to such assessments in the future.

As a consequence, emphasis has been put on assessing the relative importance of the use of fertilisers in the catchments based on a combination of landuse map information, and agricultural statistics from the ministries of agriculture. Such data are always given by administrative units such as districts, counties etc. and distributing this information to the catchments requires the use of GIS (Geographical Information Systems) where overlays of, eg. district maps and catchment maps can be made for distribution of area specific information from the one to the other.

It must be said that this work has not been finished during the study period for different reasons in the different countries. However, an overall reason is that the collection of this type of information requires a, sometimes substantial, effort from people outside the project (in other ministries) and it is often difficult to obtain priority within the respective institutions for such an effort.

The status of the activities can be summarised as follows:

Achievements

- GIS (ArcView) is installed in all three countries and a number of team members from all three countries have received basic (limited but focused) training in the use of ArcView

[1] See also Chapter 10 on nutrient mass balance

- A large number of basic electronic maps have been identified and are available to all countries (lake boundaries, catchments, districts, rivers, roads, elevation, etc.)

- Existing landuse maps have been identified and are available to all countries.

- Distribution of different cultures within the lake catchments are available in Kenya and Tanzania (by district in Kenya and by ward in Tanzania)

- A spreadsheet based tool for distributing area specific information such as hectares of a certain culture from adminstrative units to sub-catchments has been developed and is available on the CD-ROM. The tool can also calculate runoff of nitrogen and phosphorus based on inputs such as application rates on a particular culture and a runoff factor (%).

Based on the available information a preliminary assessment of the potential contribution of N and P from fertilisers from each of the three countries have been made.

Outstanding issues

The landuse maps from the different countries are not directly comparable especially due to different definitions of landuse classes. The maps from Tanzania and Uganda have been harmonised and thus a general map of cultured land can be produced for these two countries. A harmonisation of the Kenyan map has shown not to be straight forward.

The agricultural statistics from Uganda are normally given at the district level. Unfortunately the districts in Uganda are too large compared to the lake catchments to give a reasonable distribution of data. Consequently, the information has been sought at county level. It has only been possible to obtain the statistics at county level for one district. Moreover, some clarification is needed regarding statistics on mixed cultures, it appears that these are often counted twice. On the other hand, the landuse maps of Uganda are very precise and indicates all major estates of commercial agricultural production (which may be the only significant users of agrochemicals in the country).

The Kenyan agricultural statistics require clarification with respect to changed delimitations of the districts within the catchments. Thus, estimates of the distribution of crops can only be made for the entire Kenyan part of the lake catchments.

Tanzania has provided a very precise administrative map (ward level) with corresponding statistics on crops, livestock etc. The outstanding matter is the practise of application of agrochemicals on the different crops.

1.6 Summary of Non-point Pollution Loads

The estimates of pollution loads of nitrogen and phosphorus from rivers to the lake are given in Table 1.3. Typical concentration values from the river water quality sampling programme (see section 1.3) have been used together with annual discharges as calculated by the hydrology team (see Chapter 3). Where no data was available concentrations have been estimated based on typical values from neighbour or similar catchments. Referring to the discussion in section 1.3, the present estimate must be considered a very first attempt to quantify the loads of nutrients to the lake from the rivers.

However, the total loads of Nitrogen and phosphorus adding up to 49,500 tons of N and 5,700 tons of P per year respectively, corresponds reasonably well to what was found by IHE in 1996. As no water quality data or hydrological compilation were available at that time, IHE used a rapid assessment method at the country level to estimate total loads to the lake. Thus, their global figures for runoff from land were 48,600 tons N and 5,900 tons of P respectively.

Table 1.3 Annual loads of nitrogen and phosphorus to Lake Victoria by sub-catchment.

River discharge from Lake Victoria sub-catchments

No.	Sub-catchment	Area	Discharge	Nutrient concentration		Nutrient loading		Nutrient loading	
		km2	m3/s	TN, mg/l	TP, mg/l	N, t/yr	P, t/yr	N, kg/km2/y	P, kg/km2/y
1	Sio	1450	12,10	0,65	0,124	248	47	171	33
2	Nzoia	12676	118,00	0,90	0,254	3.340	946	264	75
3	Yala	3351	27,40	1,16	0,118	999	102	298	30
4	North Awach	1985	3,80	0,94	0,127	112	15	56	8
5	Nyando	3652	14,70	1,12	0,377	520	175	142	48
6	Sondu	3508	40,30	1,08	*0,25	1.374	318	392	91
7	South Awach	3156	6,00	1,70	0,207	322	39	102	12
8	Gucha-Migori	6600	62,70	1,44	0,143	2.849	283	432	43
9	Eastern Shore Streams	6644	20,20	*1,4	*0,25	892	159	134	24
10	Mara	13393	38,50	*1,4	*0,25	1.701	304	127	23
11	Grumeti	13363	12,70	*1,4	0,461	561	185	42	14
12	Mbarageti	3591	4,90	*1,4	0,461	216	50	60	14
13	Simiyu	11577	34,10	*1,4	0,405	1.507	435	130	38
14	Nyashishi	1565	1,40	*1,4	*0,25	62	11	40	7
15	Magogo	5207	6,30	*1,4	*0,25	278	50	53	10
16	Isanga	6812	5,10	*1,4	*0,25	225	40	33	6
17	Southern Shore Streams	8681	27,00	*1,4	*0,25	1.193	213	137	25
18	Biharamulo	1928	21,50	*1,4	*0,25	950	170	493	88
19	Western Shore Streams	733	21,10	*1,4	*0,25	932	166	1.272	227
20	Kagera	59682	265,30	3,50	0,226	29.303	1.892	491	32
21	Bukora	8392	2,90	6,28	0,330	575	30	68	4
22	Katonga	15244	4,70	6,90	0,320	1.023	47	67	3
23	Northern Shore Streams	4288	1,50	*6,9	*0,32	327	15	76	4
	Entire terrestrial catchment	197.478	752,20			**49.509**	**5.693**	**251**	**29**

* indicate that the figures are estimated from neighbour catchments or literature

It should be noted that the load estimates given in the table covers all nutrients discharged by the rivers and include therefore the contribution from up stream point sources, which have not been degraded before it reaches the shoreline. However, as it will appear from Chapter 5, the total load of nitrogen and phosphorus from all point sources to the catchments is estimated at approximately 4,000 and 2,000 tons per year respectively. This implies that nitrogen from up stream point sources must be regarded at as minor contribution to the final river load whereas the phosphorus discharges from these sources may form a significant part of the land based loads.

The maps (Figure 1.5 and Figure 1.6) show the distribution of loads among the catchments.

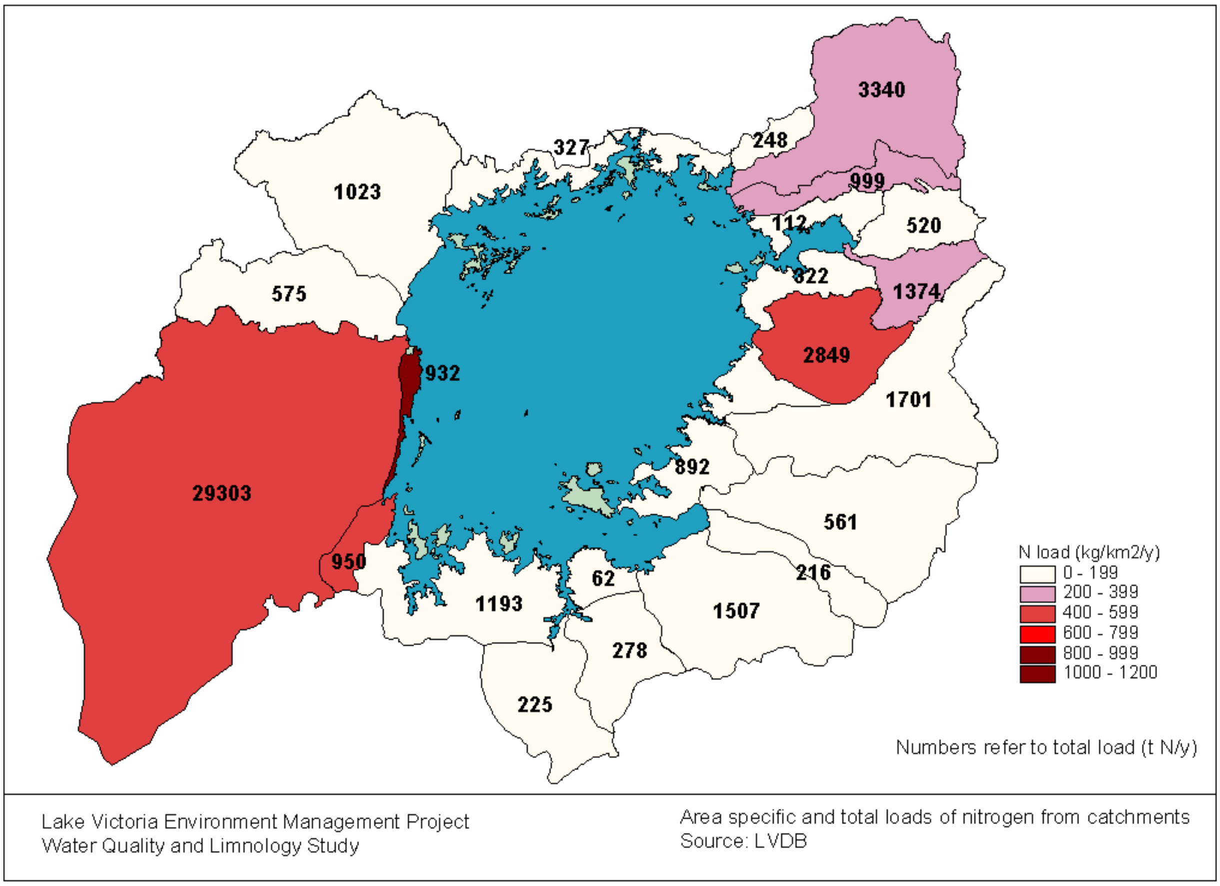

Figure 1.5 Loads of nitrogen from the Lake Victoria catchments.

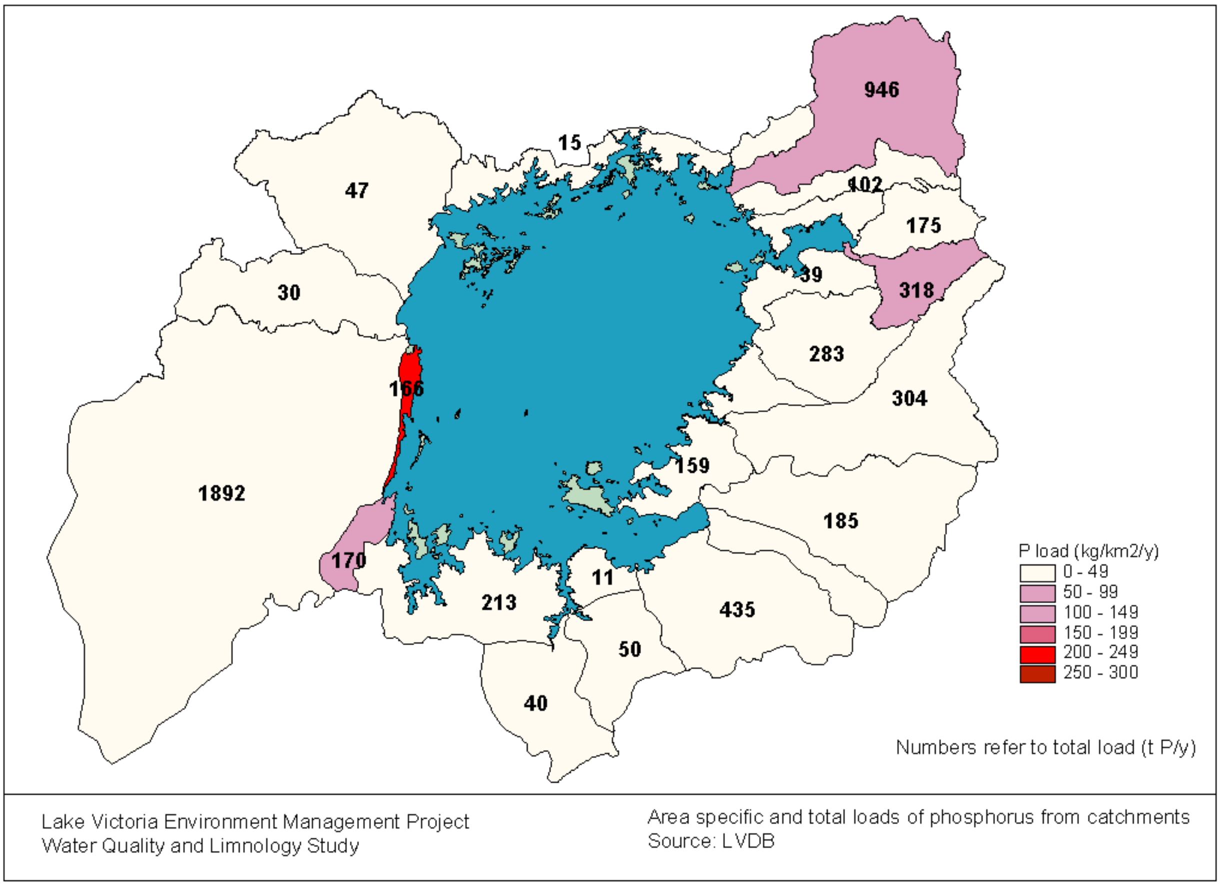

Figure 1.6 Loads of phosphorus from the Lake Victoria catchments.

For the estimation of atmospheric deposition the lake was divided into 17 rain boxes for which the annual average rainfall could be calculated individually (see Figure 1.7). From the measured data (see section 1.4) typical concentrations of N and P from adjacent measuring stations were assigned to each box and together with the average rainfall the average deposition of nutrients was calculated for each box. For the central parts of the lake, the levels found in the offshore samples were used. The results are given in Table 1.4. It is seen that total loads from atmospheric deposition by this method has been estimated at 102,000 tons of nitrogen and 24,000[2] tons of phosphorus. These figures are close to what was initially estimated by the model study, and indicate that the atmospheric deposition is far the most significant contribution to the overall nutrient budget of the lake.

[2] Ugandan data on wet deposition of phosphorus (Kampala and Entebbe) are much higher than found in Kenya and Tanzania

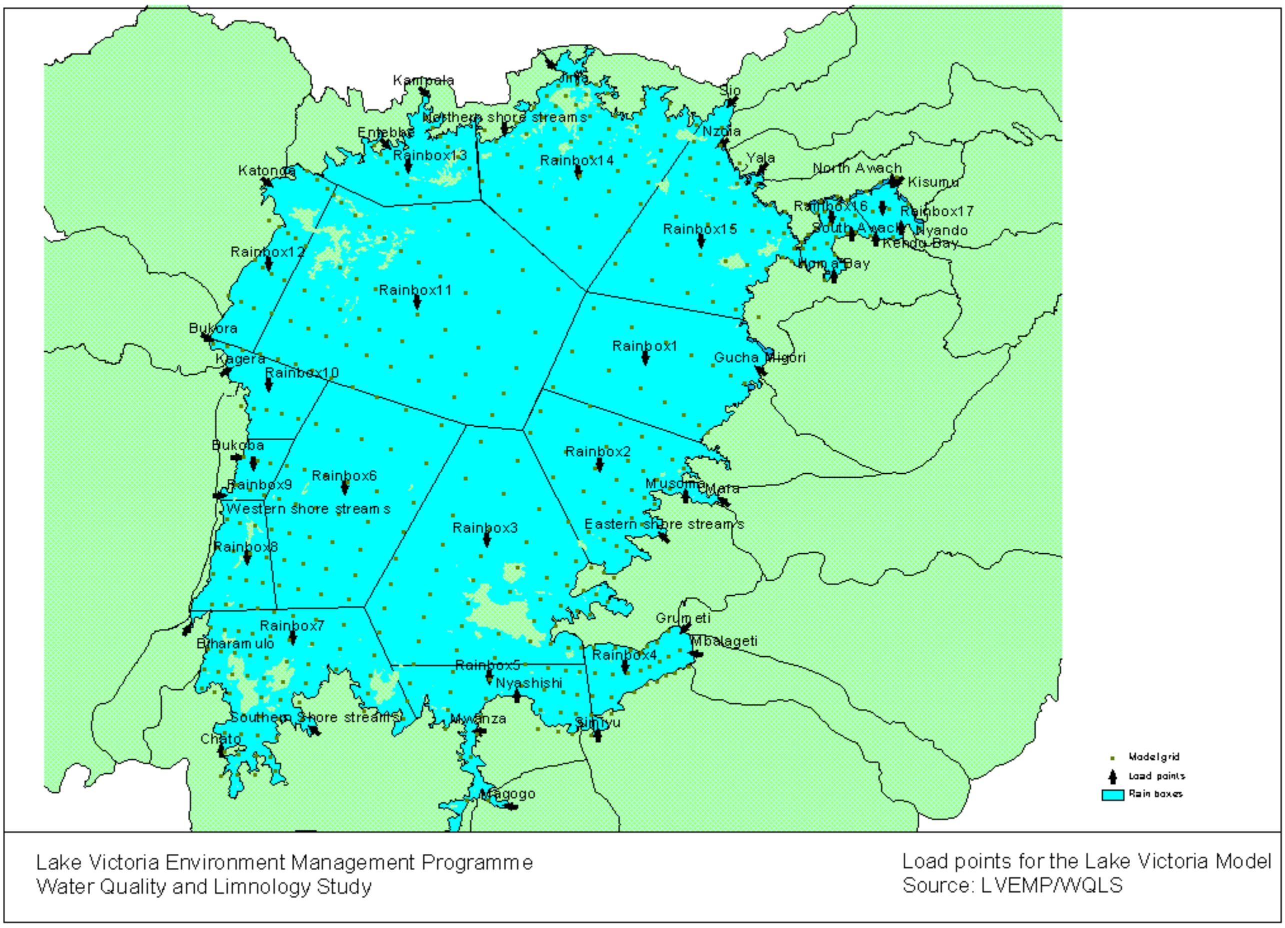

Figure 1.7 Location of rain boxes and load points (as used in the model)

Table 1.4 Estimated annual atmospheric deposition of N and P to the lake

Box no.	Area of box (km2)	Average rain (mm)	Conc. Rain N-mg/l	Conc. Rain P-mg/l	Wet deposition kgN/d	Wet deposition kgP/d	Dry deposition mgN/m2/d	Dry deposition mgP/m2/d	Dry deposition kgN/d	Dry deposition kgP/d	Total deposition kgN/d	Total deposition kgP/d
1	5247	1250	1	0,03	17970	539	2,2	0,9	10390	4250	28360	4789
2	4491	1300	1	0,03	15994	480	2,2	0,9	8892	3637	24886	4117
3	9300	1600	0,25	0,02	10192	815	1,1	0,3	9207	2511	19400	3326
4	1287	886	1	0,03	3123	94	2,2	0,9	2548	1042	5671	1136
5	2706	1000	1,1	0,04	8156	297	2,2	0,9	5359	2192	13515	2489
6	7028	2400	0,25	0,02	11553	924	1,1	0,3	6958	1898	18511	2822
7	5009	1450	1,1	0,04	21889	796	2,2	0,9	9918	4057	31807	4853
8	1553	1450	1	0,03	6171	185	2,2	0,9	3076	1258	9247	1443
9	635	2400	1	0,03	4176	125	2,2	0,9	1257	514	5434	640
10	1413	2300	1	0,03	8904	267	2,2	0,9	2798	1145	11702	1412
11	12846	2100	0,25	0,02	3225	258	1,1	0,3	12718	3469	15943	3727
12	2063	1800	0,7	0,5	7121	5086	2,2	0,3	4084	557	11205	5643
13	2307	1950	0,7	0,5	8628	6163	2,2	0,3	4568	623	13196	6786
14	6666	1696	0,7	0,5	21683	15488	2,2	0,3	13199	1800	34882	17287
15	5423	1230	1	0,04	18276	731	2,2	0,9	10738	4393	29014	5124
16	694	1204	1	0,04	2289	92	2,2	0,9	1374	562	3663	654
17	643	1220	1	0,04	2150	86	2,2	0,9	1273	521	3423	607
Total atmospheric deposition (kg/d):											279856	66855
Total atmospheric deposition (t/y)											102148	24402

As mentioned in Section 1.5 a preliminary assessment of the potential loads of nitrogen and phosphorus originating from use of fertilisers has been made. For this assessment the statistics on crop distribution (hectares within the catchments), typical application rates of artificial fertilisers on the different crops, and a runoff coefficient of 0.1 have been used.

Table ?? shows the calculated potential load[3] from fertilisers in the catchments of the three countries in t/y and as percentage of the total load from land (as calculated from downstream river measurements) and the total load to the lake (including atmospheric deposition). The potential load from fertilisers to Ugandan catchments has been set to zero since fertilisers only are used in commercial estates situated near the lakeshore and therefore mainly drain directly into the lake rather than contributing to the calculated catchment runoffs.

Table 1.5 Potential load from fertilizers to the water courses

	Potential load		Total Load		%	
	N	P	N	P	N	P
Kenya catchments	4314	2007	11000	2200	39%	91%
Tanzania catchments*	890	458	36500	3400	2%	13%
Uganda catchments**	0	0	1900	100	0%	0%
Total all catchments	5203	2465	49400	5700	11%	43%
Total catchments + atm. Dep.	5203	2465	151400	29700	3%	8%

*The total Tanzanian load includes Burundi and Rwanda parts of Kagera catchment

**Loads from Ugandan Estates (270 t N/y and 90 t P/y) drain mainly directly to the lake

It appears from the table that artificial fertilisers may contribute significantly to the total loads of the Kenyan catchments whereas this source is unlikely to be important in Uganda and Tanzania.

1.7 Recommendations

It must be said that the estimation of non-point pollution sources is at an initial stage and consequently it is strongly recommended to continue the work and improve the load estimates both from land and from the atmosphere. The following particular recommendations and outstanding issues are given:

River water quality

- Time series are needed and if capacity for field work is a constraint there should be emphasis on down stream stations. The Kagera river may account for more than half of the land based nutrient loads and should be given overall priority

- If capacity is a constraint in the laboratories, priority should be given to analysing total nitrogen and total phosphorus allowing total estimates.

[3] Here potential load refers to the calculated runoff directly to the rivers without taking into account reduction of the nuitrient levels throughout the river system

Atmospheric deposition

- In addition to the stations located on land, emphasis should be laid on collection of offshore samples, on islands and onboard the ships when sampling for the Lake Water Quality programme.

Landuse information

- In Uganda, agrochemicals are almost only used in the tea, sugar, and flower estates. These are indicated on the general landuse map, and information about their individual cropping and application of agrochemicals should be collected.

- Kenyan agriculture statistics should be clarified with respect to new delimitation of districts

- In Tanzania practises of application of agrochemicals on different crops should be identified.

As mentioned in section 1.5 a major issue has been omitted from the assessment work, namely the quantification of nutrient runoff due to deforestation and alteration of soils caused by agriculture. A way of estimating such effects in the future would be to use an integrated river basin model with water quality module. When reliable time series of water quality measurements are available, as well as distribution of agrochemical inputs, the nutrient balance of such a model would indicate where major runoff of nutrients takes place from sources other than agrochemical runoff.

Finally, the study has not included an assessment of the importance of nitrogen fixing blue-green algae which may contribute significantly to the nitrogen budget (see Chapter 10).