



Education and Culture

Erasmus Mundus



UNIVERSITY OF ALGARVE

FACULTY OF SCIENCES AND TECHNOLOGY

“THE ROLE OF PAPYRUS PLANTS (*Cyperus papyrus*) AND INTERNAL WAVES
IN THE NUTRIENT BALANCE OF LAKE VICTORIA, EAST AFRICA”

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O PAPEL DAS ZONAS HÚMIDAS DE PAPIRO (CYPERUS PAPYRUS) E DAS ONDAS INTERNAS NO BALANÇO DOS NUTRIENTES NO LAGO VICTORIA, ESTE DE ÁFRICA.

RESUMO

Quantidades de azoto e fósforo removidos pelo papiro dominante nas zonas húmidas do bacia do Lago Victoria foram quantificados. Os níveis no lago e a frequência das suas resurgências foram avaliados, porque estes dois compostos contribuem para a Eutrofização. Numa área de 10,235.17 km² de papiro nas zonas húmidas, a desnitrificação remove anualmente 53% de azoto que entra no sistema, enquanto que a biomassa das plantas (acima do solo) pode remover 26% e 19% por ano de azoto e fósforo, respectivamente. Para remover as descargas existentes de azoto com a desnitrificação são necessários 1.3 anos enquanto que com a produção de biomassa (acima do solo) existente são necessários 3.8 e 5.2 anos para o azoto e fósforo, respectivamente. A exploração excessiva de água ao longo do canal de Jinja causou uma diminuição do nível do lago de 2.5 m de 2004 a 2006. Porque estavam expostas ao ar (acima do nível da água) as zonas húmidas de papiro perderam 80% das suas funcionalidades, como refugio e como campos de reprodução para tilapia. Quando as plantas de papiro morrem, secam e ardem, o azoto nelas armazenado é reciclado e entra novamente na água. Quando isto ocorre, o equivalente de 17- 18,500 anos de azoto pode entrar no sistema durante o ano corrente, aumentando as cargas normais de azoto para o lago, e emitem $5.2 * 10^7$ toneladas de CO₂ para a atmosfera. A aplicação do número de Wedderburn mostra que a resurgência ocorre quando significativos ventos sopram no lago durante 6 dias consecutivos com uma velocidade de pelo menos 5 m/s sem a brisa do lago para a terra. A temperatura da água de superfície registada todas as horas à volta da ilha de Rubondo indica que o mais baixo valor de temperatura é de 21.79°C e mostra-se irregular; a ilha dá origem a ondas internas que provocam resurgência. A diminuição do nível do lago e o aumento da eutrofização por resurgência, realça a necessidade de conservação das zonas húmidas de papiro para a saúde futura da bacia do lago Victoria.

Palavras Chave: zonas húmidas de papiro, ondas internas, azoto, fósforo, eutrofização, diminuição do nível da água.

ABSTRACT

THE ROLE OF PAPYRUS (*Cyperus papyrus*) WETLANDS AND INTERNAL WAVES IN THE NUTRIENT BALANCE OF LAKE VICTORIA, EAST AFRICA.

Amounts of nitrogen and phosphorus removed by the papyrus dominated wetlands of Lake Victoria basin were quantified. Lake levels and frequency of upwelling were assessed because they contribute to eutrophication. In the 10,235.17 km² area of papyrus dominated wetlands, denitrification removes 53% annual nitrogen input, while above-ground biomass harvest can remove 26% and 19% annual nitrogen and phosphorus input per year respectively. To remove the existing load of nitrogen, it requires 1.3 years by denitrification alone while through above-ground biomass harvest; it requires 3.8 and 5.2 years for nitrogen and phosphorus respectively. Overdrawing of water through Jinja outlet caused a lake level decrease of 2.5 m from 2004 to 2006. Because they were out of water, papyrus wetlands lost 80% of their functionality as refuge and breeding grounds for tilapia. Because dried out papyrus die, burn, and are returned into the water, they can add 17 to 18,500 years in one year of current levels of nitrogen input into the lake, and emit $5.2 * 10^7$ tonnes of CO₂ to the atmosphere. Wedderburn number application shows upwell occurs when mean winds over the lake blows for 6 consecutive days by a speed of at least 5 m/s without the lake-land breeze. Surface water temperature recorded at hourly basis around Rubondo Island gives a lowest temperature value of 21.79°C, and shows patchy; island generated internal waves causing upwelling. Both lake level decrease and upwelling enhance eutrophication, emphasizing the need to conserve papyrus wetlands for the future health of Lake Victoria basin.

Key words: papyrus wetlands, internal waves, nitrogen, phosphorus, eutrophication, lake level decrease.

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1.0 INTRODUCTION

1.1 Lake Victoria; Location and general features

Lake Victoria in East Africa ($3^{\circ} 00'S$, $0^{\circ} 30'N$; $31^{\circ} 40''$ and $34^{\circ} 50'E$) is the second largest freshwater lake in the world by surface area occupying about $68,800 \text{ km}^2$ (Newell, 1960; Okaronon & Wadanya, 1991; Kassenga, 1997). Most of the lake lies in Tanzania (51%), while 43% lies in Kenya and 6% in Uganda (Figure 1). The length of the shoreline is more than 3200 km^2 . With a volume estimated at $2,760 \text{ km}^3$, the deepest point of the lake is

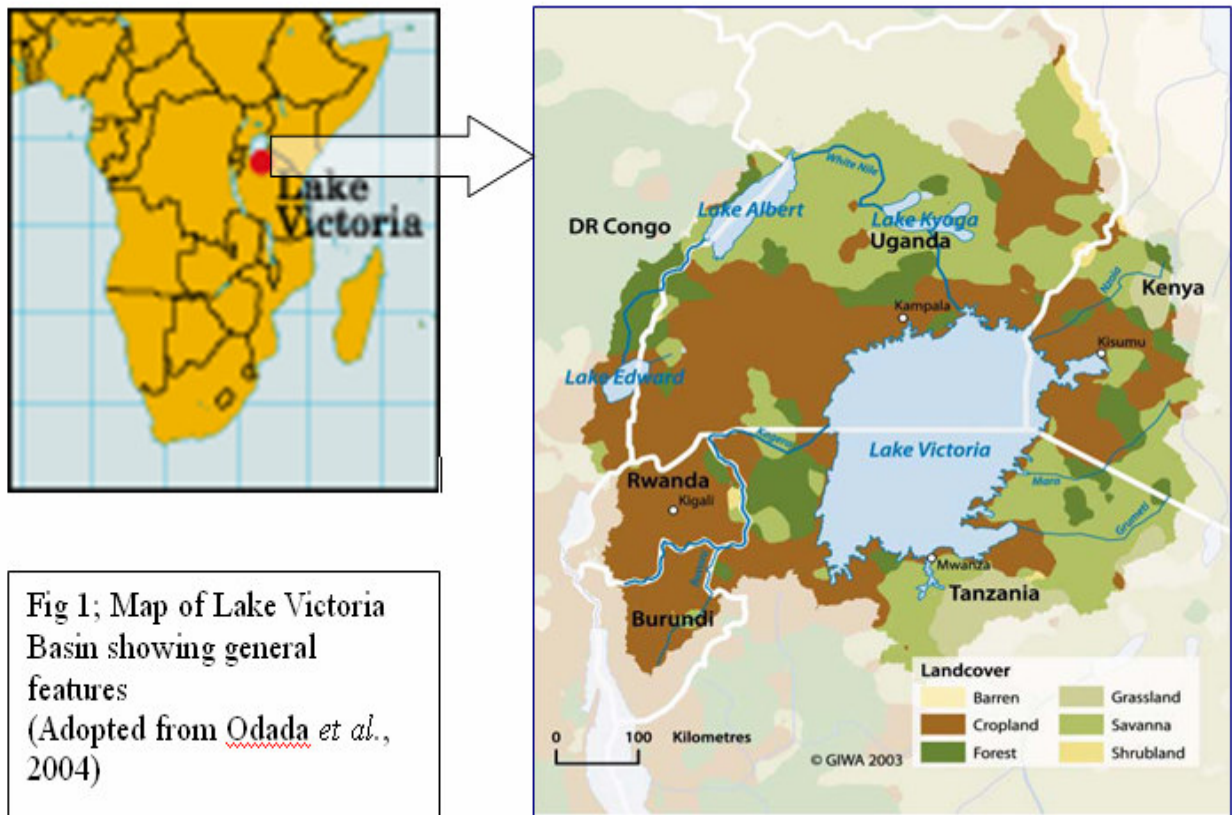


Figure 1. Map of Lake Victoria Basin showing general features (Source; *Odada et al.*, 2004)

82 m and the average depth is 40 m. It is 337 km long and 240 km wide. The lake has about 3,000 islands, the biggest ones including Ukerewe and Rubondo in Tanzania, Ssesse in Uganda and Rusinga in Kenya. Lake Victoria is the source of the White Nile through its only outflow at Jinja.

Lake Victoria is surrounded by a number of small satellite lakes, including Bisini, Kanyaboli and Nabugabo (Darwall *et al.*, 2005). Rivers and lakes in the catchments of Lake Victoria are important as they are source of nutrients and contain vast expanses of wetlands (Kansiime & Nalubega, 1999; Scheren *et al.*, 2000; ARCADIS, 2001; Mwanuzi *et al.*, 2003; Mdamo, 2001).

1.2 The hydrology of Lake Victoria

The lake receives most of its water, about 82%, from rainfall directly on its huge surface. An average of 1315 mm of rain is received annually. The rest (18%) is contributed from rivers of which Kagera is the largest tributary. About 24 other streams feed the lake (Lindenschmit *et al.*, 1998; COWI, 2002) as shown in Figure 2 and as summarized in Table 1. Water loss through evaporation from the lake basin is about 76 % of all outflow, the rest being the outflow at Jinja, the only tributary from the lake, about 24 % (COWI, 2002), and which can amount to 23.5 km³/year (Scheren *et al.*, 2000). Table 2 gives the average inflows and outflows from Lake Victoria. Rain and evaporation are the main players of the lake water balance, with the rain being slightly higher than the evaporation. Likewise, the outflow at Jinja is slightly higher than catchment inflow. Therefore the

sum of the inflows and outflows gives a small positive inflow of 33 m³s which accounts for the rise in the lake level of 0.98 m between Jan 1950 and Dec 2001 (COWI, 2002).

Table 1. Rivers discharging into Lake Victoria (Source; COWI, 2002).

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
	Eastern Shore Streams	18.6	2.4
	Simiyu	39.0	5.0
	Magogo-Maome	8.3	1.1
	Nyashishi	1.6	0.2
	Issanga	30.6	3.9
	Southern Shore Streams	25.6	3.3
	Biharamulo	17.8	2.3
	Western Shore Streams	20.7	2.7
	Kagera	260.9	33.5
	Uganda	Bukora	3.2
Katonga		5.1	0.7
Northern Shore Streams		1.5	0.2
	Total	778.3	100.0

Due to its small volume relative to its huge surface area, the lake is vulnerable to climatic changes such as rainfall fluctuations and increased evaporation due to stronger winds and heat.

Table 2. Average inflows to and outflows from Lake Victoria (Source; COWI, 2002)

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

Jinja outlet through Ripon Falls in Uganda, which is the only outflow from the lake, was replaced by a hydroelectricity power plant, the Owen Falls, later renamed Nalubaale



Figure 2. Location of the Nalubaale and Kiira existing dams, and the proposed Bujagali dam in Uganda (Adopted from Burnside, 2006)

Dam, in 1957. In 1999, another dam was constructed at Kiira, and three turbines were operating by 2003 (Kull, 2006). The two dams together, now control the amount of outflow from the lake. Due to power crisis in Uganda (Waweru, 2006), there is a proposal to build another dam, Bujagali, which is to be located further down the Nile as Figure 2 shows.

1.3 Physical processes of the lake

Lake Victoria is density stratified, with warm, oxygenated water at the surface and colder, anoxic waters at the bottom (Newell, 1960; Myanza *et al.*, 2006). The upper layer is called the epilimnion while the lower layer is the hypolimnion. These two layers are separated by a transitional layer, the thermocline. The thermocline of Lake Victoria was at 40 m depth in the 1960s (Newell, 1960) but this has been rising (Okaronon & Wadanya, 1991; Myanza *et al.*, 2006). Although the precise reason for this rise is not known, the speculated cause is the change of climate towards warmer, more humid weather hence reducing the mixing layer. The mixing layer is currently always at 20 m depth in pelagic waters (Rutagemwa *et al.*, 2006^a).

1.4 Nutrients (nitrogen and phosphorus) in the lake

Nutrient enrichment of Lake Victoria, especially nitrogen and phosphorus, over the past four decades has been increasing (ARCADIS, 2001; COWI, 2002; Kansiime & Nalubega, 1999; Kansiime *et al.*, 2005; Odada *et al.*, 2004; World Bank, 1996) reaching

three fold from the values for the 1960s (Rutagemwa *et al.*, 2006^b). Concentration of phosphorus has risen markedly in the deeper lake waters and around the edges. Most nitrogen entering the lake basin is due to human activities and comes from agriculture, while phosphorus comes from municipal and industrial sewage, discharge from urban and agricultural drainage channels, and the dumping of untreated sewage from villages and small settlements (UNEP, 2000, Scheren *et al.*, 2000, Odada *et al.*, 2004)).

In Tanzania and Uganda, there are almost no treatment facilities for effluents from industries and factories discharging to the lake system. However, much of the Ugandan industrial effluents drain through wetlands before entering the lake. In Kenya, most big industries and factories have a treatment facility although in poor condition (Scheren *et al.*, 2000). Along the lake's shoreline and especially at river mouths, the problem of nutrient enrichment is thus more serious than in the offshore waters (Kansiime & Nalubega, 1999). This increases the importance of nutrient removal by the fringing wetland in this area.

The average concentration of nitrogen and phosphorus in Lake Victoria waters is estimated to be 0.640 mg/l and 0.074 mg/l respectively. Every year, about 2,276,600 t/N and 502,900 t/y P are released from the sediment layer (COWI, 2002).

basin, Kagera River, Ngoni wetland system in the Kagera, Mori swamp in the Mara River, Masirori, Gurumeti swamp, Ruwana, Mbalageti, Orangi, Simiyu, Duma, Bariadi, Magogo, Mabuki, Maome river wetlands, and Isanga (ARCADIS, 2001). On the Kenyan side of the lake, SMEC (2005), reports wetlands to include Sio, Nzoia, Nyando, Yala, North Awach, South Awach, Sondu and Gucha-Migori. Wetlands on the Kenyan side total up to 2,168.60 km². On the Ugandan side of the lake basin, major wetlands include Bukora, Katonga and the Northern Shore Streams. Kasoma (2006) and Awange & Ong'ang'a (2006) in combination gives us information to determine the total area of Ugandan wetlands in Lake Victoria basin to be 3,846.57 km².

The total area of the wetlands is therefore about 10,235.17 km². Up to 80% of these areas of wetlands in the lake are occupied by papyrus alone (Kansiime & Nalubega, 1999). In fact, much of the permanent swamps consist of monotypic stands of papyrus (Muthuri & Jones, 1997). These papyrus dominated wetlands account for about 5.5% of the total basin area and about 15% of the total area of the lake. This is assumed to be the minimum area because many wetlands in the basin are seasonal and difficult to quantify.

Some wetland areas are small in size, such as Nakivubo which is 2.5 km² (Kansiime & Nalubega, 1999) and Mlaga, 1.41 km² (Mnaya & Wolanski, 2002). There are also large wetland expanses in the basin of which the largest is in western Uganda, in the river Katonga wetland system. Other large wetland expanses are found in river Kagera wetland system in Tanzania and on the Kenyan side important wetlands are at the mouths

of rivers Yala and Nyando (Scheren *et al.*, 2000). The ecosystem services and function of the wetlands is very important to the lake. Whether small or extensive, the wetlands are ecotones separating the lake from the surrounding environment.

Many studies have focused on the role of papyrus plants in removing excess nutrients from water (Gaudet, 1979; Kassenga, 1997; Kansiime & Nalubega, 1999; Azza *et al.*, 2000; UNEP, 2000; ARCADIS, 2001; Mdamo, 2001; Mwanuzi *et al.*, 2003; Kyambadde *et al.*, 2004; Gichuki *et al.*, 2005). Papyrus plants do indeed trap nutrients especially nitrogen and phosphorus (Kassenga, 1997; Kyambadde *et al.*, 2004) reducing the amount of these nutrients in the water. Papyrus plants traditionally acted as a sink for nutrients, as they absorb organic nutrients from both water and sediments because of their high ability to tolerate polluted water (Gaudet, 1979; Azza *et al.*, 2000; Kyambadde *et al.*, 2004). However, it is feared that they may now act as a source of nutrients for Lake Victoria (Kansiime & Nalubega, 1999) because in this tropical wetlands, recruitment, death and growth of papyrus aerial organs occur concurrently in the year round (ARCADIS, 2001). Therefore, as it is the case with other emergent macrophytes, the decaying shoots are major contributing sources to the release of nutrients to the aquatic ecosystem (Asaeda *et al.*, 2002).

Although the functionality of the wetlands and papyrus plants have received their attention, and the nutrient mass balance of the lake has been established, the studies do not quantify the role played by the papyrus wetlands. In fact, most studies conducted on wetlands focused on small areas of the wetlands and not on the basin as a whole.

Therefore, the overall quantification of the wetland total area has been dealt with in segments, and each country, Kenya, Tanzania and Uganda has worked separately. This previous research has provided data for the current overall basin study. Quantification of the wetlands impact on nutrients reduction, which is one part of this study, is important so as to attract appropriate protection policy, promotion and management for sustainable use.

1.5.2 The fisheries

Historically, several hundreds of species of fish thrived in Lake Victoria (Odada *et al.*, 2004). This number has declined down to only 3 dominant species by 2000 (Mnaya & Wolanski, 2002). Several reasons have been linked to this dramatic loss of species, of which the most important one is the introduction of the Nile Perch, which is responsible for extinction of several species of haplochromine cichlid fish. The other reasons for fish loss in Lake Victoria include eutrophication, water hyacinth introduction to the lake, over exploitation, destructive fishing practices and industrial pollution (Odada *et al.*, 2004). Loss of haplochromine cichlid fish in the lake has been followed by the intensification of eutrophication due to disturbance of the food chain.

Wetlands are important as fish larvae nurseries and as refuge for endangered species (Mnaya & Wolanski, 2002; Awange & Ong'ang'a, 2006; Mnaya *et al.*, 2006), and should be protected against unsustainable use such as unplanned and unsustainable harvest, or draining through unsustainable water withdrawal from the lake that lead to water level decrease.

1.5.3 Water hyacinth

Increased eutrophication of Lake Victoria favored growth and spread of water hyacinth (*Eicchornia crassipes*), which reproduce rapidly due to the increased nutrients (Kite, 1981; Mbendo & Thomas, 1988; Ogutu-Ohwayo, 2003). The hyacinth, which is exotic to the lake, was introduced in 1989. Although they absorb nutrients from the water, the exotic plant is harmful to the lake ecosystem because during growth it extracts a lot of oxygen from the water beneath its mat (Odada *et al.*, 2004) especially during the night. It also blocks light penetration into the water beneath it, hindering photosynthetic activities by other aquatic plants. When the water hyacinth mat dies, it releases its nutrients back into the water through decomposition. The process of decomposition itself, consumes a lot of oxygen from the water, depleting further the oxygen content of the water. The decomposed material accumulates on the lake bed, thus decreasing the water level and releasing the nutrients on the lake bed. Water hyacinth, therefore, accelerates the eutrophication of Lake Victoria.

During the peak infestation in 1998, the exotic weed covered a total of 120 km², with 60 km² in the Kenyan waters, 20 km² in Tanzanian side and 40 km² in Uganda (Mallya *et al.*, 2001).

Manual and chemical control of the hyacinth was tried by LVEMP, biological control using beetles (*Neochetina eicchornia*) seemed to yield significant results because the infestation was reduced by 78% by the year 2001 (Mbendo & Thomas, 1998; Ndunguru *et al.*, 2001).

Until 2004, the water hyacinth infestation was substantially reduced, existing primarily at the river mouths and at a few other hotspots. Now, extensive coverage of the weed can be seen around the lake again (Figure 4). Water level decrease has favoured its returned



Figure 4. Proliferation of water hyacinth (*Eicchornia crassipes*) following water level decrease in Lake Victoria. Photo taken on 23.03.2007 near Rubondo Island

proliferation because the seed bank has been exposed with the exposed shores (Awange & Ong'ang'a, 2006), exposing the water hyacinth seeds to light and air, a favourable environment in which they grow easily. Water level decrease can thus accelerate eutrophication of Lake Victoria because it favours rapid reproduction of water hyacinth, which contributes both directly and indirectly to eutrophication.

2.0 BACKGROUND INFORMATION

2.1 Ecosystem function of papyrus wetlands in reducing nutrients

Lake Victoria is home to a vast variety of flora and fauna and has been facing serious environmental problems in the last four decades (Odada *et al.*, 2004). Eutrophication is one of the most serious problems of the lake. Other problems include over fishing, siltation from the erosion of deforested watersheds, industrial pollution and climate change (Odada *et al.*, 2004). Recently, an important problem was rapid water level decrease (Awange and Ong'ang'a, 2006, Kull, 2006). These problems have attracted significant research on the lake, including research on the wetlands functionality.

Papyrus is one of the largest herbaceous reed species with its culm (the name for its stem) growing up to a height of 5 m above the ground (Jones & Muthuri, 1985). Healthy growing papyrus are lush as revealed by thick and tall culms with dark green umbels (Kansiime & Nalubega, 1999). Umbels are the large, spherically shaped, reproductive structures that serve as the main photosynthetic surface as well (Jones & Humphrey, 2002). When papyrus grows as a monoculture, they outcompete the undergrowth leaving the mat surface bare. In some places in Lake Victoria, dense umbels of papyrus prop each other forcing the culms to bend and lean, allowing light penetration. Light penetration favours opportunistic plants such as creepers and scramblers to flourishing in areas where papyrus has been recently harvested or burnt (Kansiime & Nalubega, 1999). Below the ground or water surface, the rhizomes of the papyrus plant occur, followed by hairy-like root extensions, which float freely back and forth beneath the plant with water movement. The two parts of a papyrus plant, culm and umbel, occur above-ground

while the rhizome and roots compose its below-ground parts. Figure 5 below shows the above-ground parts of an average sized papyrus plant in Lake Victoria.

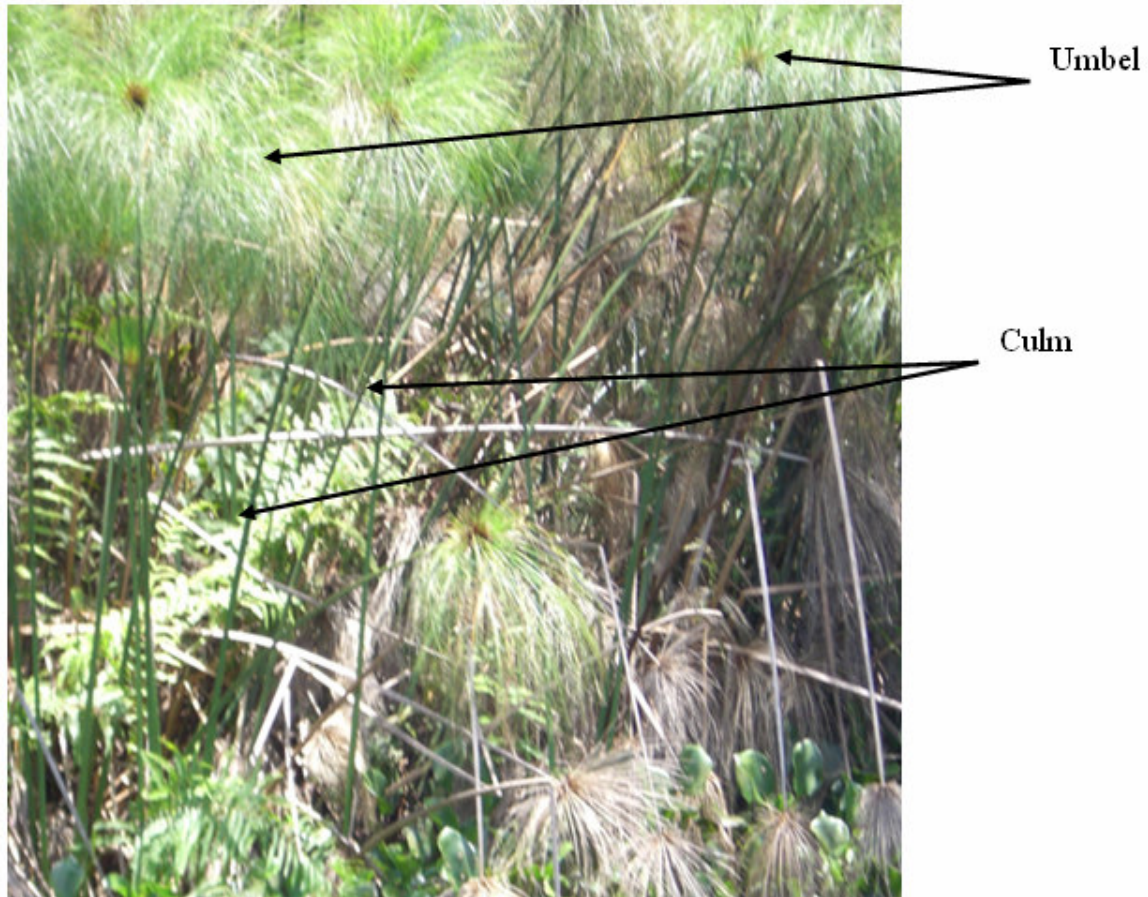


Figure 5. A photo of average-sized papyrus plants in Lake Victoria showing the above-ground plant parts.

Papyrus plants are very effective at nutrients removal because they grow quickly, and in the course of growing they utilize excess nutrients from the waters around them for biomass production. Hence, papyrus thrives well in areas where waste waters are released. The reed has an average life-cycle of 150 days (Clark, 1986), but size, life cycle and vitality varies from one community of papyrus to another. During growth and reproduction, some of the nutrients are returned back into the water. This is through

leaching when the plants are still growing, decomposition after the plants have died and dried, and mineralization. Seiches from the main lake and overflow from the catchments are mechanisms that transport these nutrients from the papyrus wetlands into the main lake. The particulate nitrogen and phosphorus that are returned to the open waters are deposited on the lake bed as sediments. This bottom lake layer stores the nutrients until physical processes such as upwelling bring the deep waters to the surface. The layer can thus be referred to as an active sediment layer. The deep waters bring up with it nutrients buried in the active sediments layer (World Bank, 1996; UNEP, 2000). The nutrients upwelled from the active sediment layer contribute further to eutrophication of the lake.

Some of the nutrients in the water column are buried very deep in the lake bed so that they are not available for biological activities (inactive sediment layer). Sediment burial is the main pathway for phosphorus removal in Lake Victoria (Kansiime & Nalubega, 1999; Scheren *et al.*, 2000). The other pathway for phosphorus removal may be biomass harvest. The percentage of phosphates removed from wetland ecosystem, is less than that of nitrogen removed because there is no equivalent of denitrification for phosphorus (Kansiime & Nalubega, 1999).

Lake Victoria wetlands are mostly found at river mouths (Mdamo, 2001) into the lake, and around Lakes Burigi and Kyoga, as well as other smaller satellite lakes in the basin (ARCADIS, 2001; Kasoma, 2006). Water entering the lake from the catchments by rivers and runoff, is highly polluted by waste waters from industries, factories and homes, which are released into the ecosystem without treatment (Mdamo, 2001; ARCADIS,

2001). However, when the polluted water passes through the wetlands before getting into the main lake, nitrogen and phosphorus are removed (Kansiime & Nalubega, 1999; ARCADIS, 2001). Traditionally, this natural mechanism was effective to reduce Lake Victoria eutrophication due to the vast intact wetlands and natural processes.

The nutrient mass balance of Lake Victoria (COWI, 2002) shows that several processes are responsible as sources and sinks of nutrients into and out of the lake respectively (Figure 6 & Figure 7). Other processes are responsible for internal nutrients cycling within the lake system.

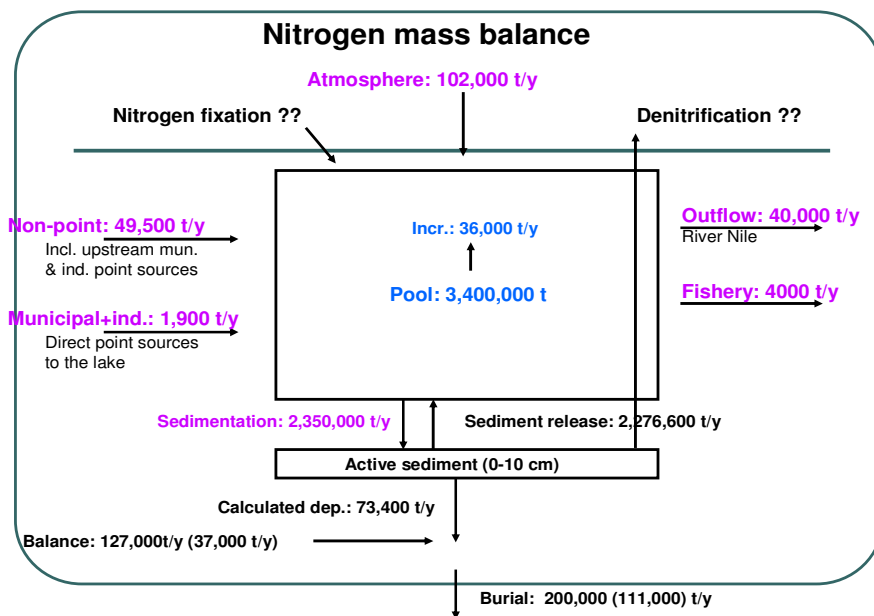


Figure 6. Nitrogen mass balance for Lake Victoria (Source; COWI, 2002)

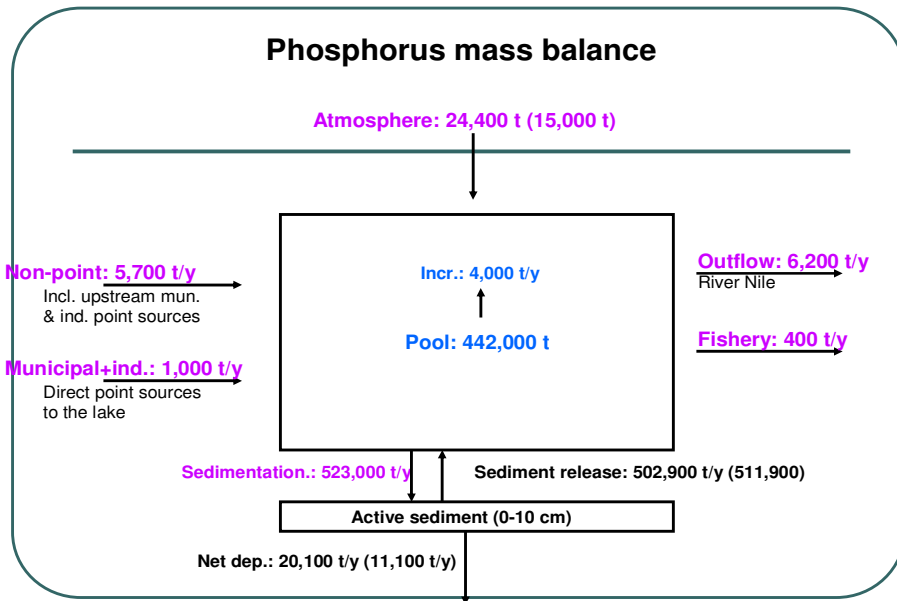


Figure 7. Phosphorus mass balance for Lake Victoria (Source; COWI, 2002)

2.1.1 Internal cycling of nutrients and above-ground biomass harvest

The processes responsible for internal cycling of nutrients within the lake system include macrophyte biomass such as wetland plants mainly papyrus (*Cyperus papyrus*) and water hyacinth (*Eicchornia crassipes*). When these plants die, decomposition releases the nutrients back into the water. During senescence, the wetland plants such as papyrus accumulate nutrients in their root zones and release them back into water (UNEP, 2000). But when the macrophytes are replaced by harvesting, then significant amounts of nutrients can be removed from water systems (Awange & Ong'ng'a, 2006). Studies in the Nakivubo channel demonstrate that, in a papyrus dominated wetland area of 0.92 km², about 5.69×10^4 kgN/yr and 9.38×10^3 kgP/yr can be removed by harvest of the above ground biomass (Kansiime & Nalubega, 1999). Figure 8 illustrates the dynamics of nutrients in a papyrus dominated wetland.

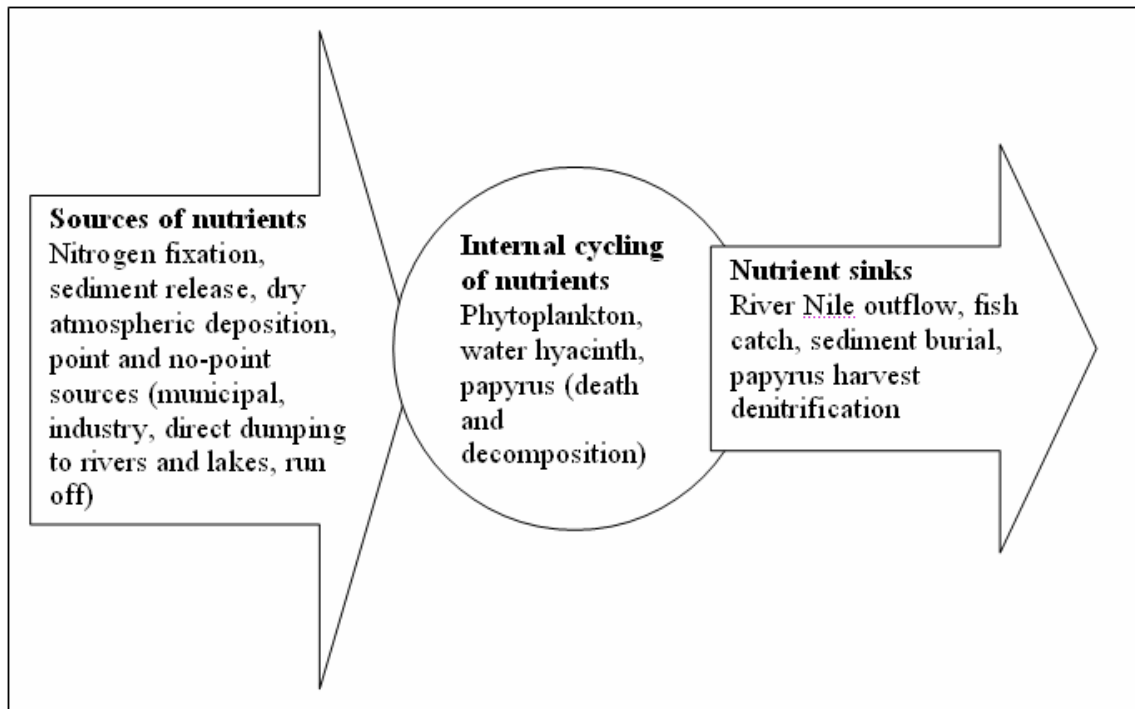


Figure 8. Wetlands – nutrients dynamics in a papyrus dominated ecosystem.

2.1.2 Denitrification in papyrus wetlands

Not all wetlands in Lake Victoria can be harvested. Some wetland sites are very sensitive or difficult to reforest, that they should be totally protected from human intervention. Some of such sites are protected from human use to varying degrees, although it is only Rubondo Island in Tanzania whose wetlands are fully protected. Removal by papyrus in such area is a significant activity brought about through the process of denitrification. Denitrification is a process carried out by bacteria whereby nitrates are reduced into nitrogen gas, which is released into the atmosphere. In the root zone of papyrus plants, significant activity of denitrification takes place whereby up to 0.35 gN/m²/d are removed from the lake system (Sloey *et al.*, 1978). Studies show that wetlands are most important

systems in freshwater systems because they provide sites for microbial activity, where this process of denitrification takes place. In fact, denitrification is the only process in the nutrient cycle of nitrogen in freshwater system that permanently removes nutrients (Kansiime & Nalubega, 1999; UNEP, 2000).

2.2 Internal waves and nutrient cycling

2.2.1 Upwelling in the open waters of Lake Victoria

Studies show that wind is the main agent causing movement in the water column (Wetzel, 1983, Gikuma-Njuru & Hecky, 2005). In lakes, wind causes surface waves, which lose their form and dissipate their energy as they break on the lee shore. Some of the wind energy is transferred indirectly via breaking waves to currents. These currents build up much more slowly than waves but eventually contain most of the lake's kinetic energy. Strong wind induces internal waves in the thermocline (interface), disturbing its position (Wetzel, 1983; Myanza *et al*, 2006). Past researchers have noted the internal waves of Lake Victoria from occasional cross-lake transects (Figure 9). These studies have shown that internal waves can be large scale, covering up to a quarter of the lake width, but that they are not always present. Measurements taken on monthly and quarterly intervals are thus too infrequent to assess the frequency and amplitude of the waves.

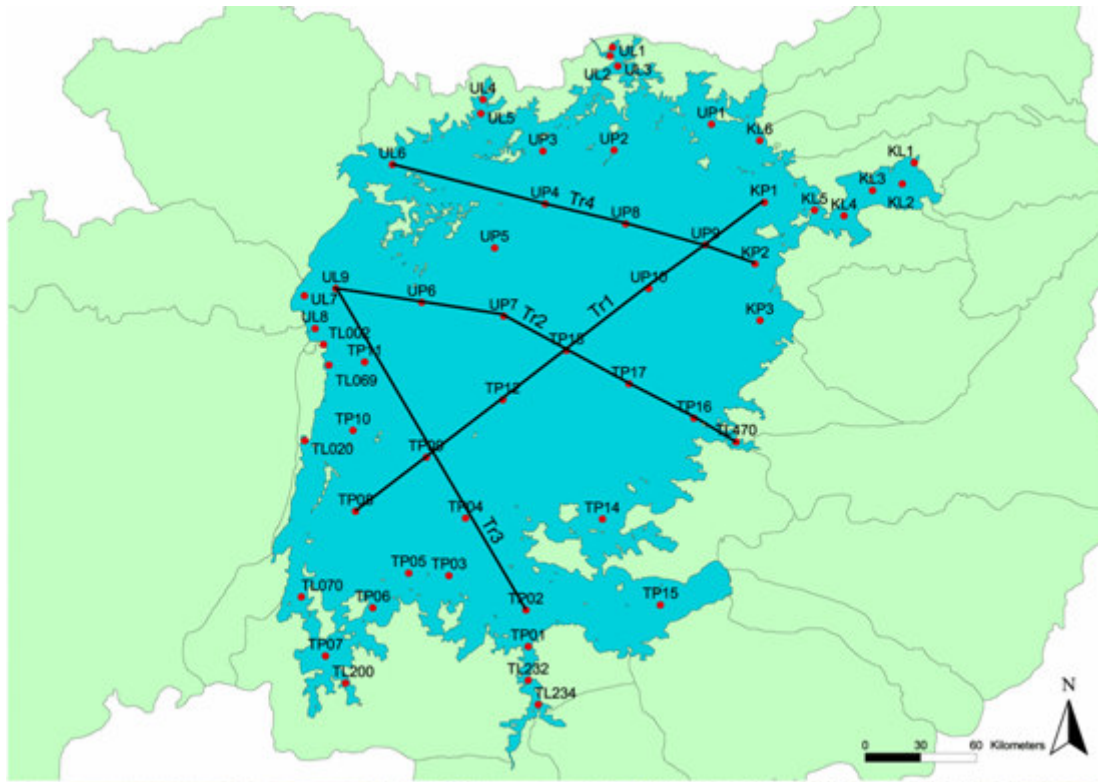


Figure 9. Lake Victoria monitoring stations and transects (COWI, 2002).

The data from the Lake Victoria Environmental Management Project (LVEMP) and from Rubondo show that the internal wave occasionally bring the thermocline to the surface. This brings nutrients and anoxic waters to the surface (COWI, 2002, Gikuma-Njuru & Hecky, 2005). The anoxic waters cause fish kills (Wetzel, 1983; Ochumba & Kibaara, 1989; World Bank, 1996) as was observed at Rubondo.

Wind driven seiches are responsible for the generation of the epilimnion, which is usually well mixed with oxygen (Stevens & Lawrence, 1997; Wetzel, 1983). Apart from mixing into the water column, which is essential for respiration of living organisms in the water including fish, the mixing action stirs nutrients that would otherwise be deposited in the water bed, and make them available for biological activities. When the wind is strong

enough, deep buried sediments and nutrients are stirred and deep buried nutrients are brought to the photic zone. The nutrients are then available for biological activities and contribute to eutrophication of the lake.

In the main part of Lake Victoria (north of the islands in the south zone) the lake is open water and there the wind causes a surface set-up downwind and a surface set-down upwind (Figure 10). Then the interface will fall downwind and will rise upwind. An upwelling will occur at the upwind side of the lake. In the case of Lake Victoria, upwelling in the open lake may occur at the south and eastern parts of the lake, due to the fact that the global winds blow from the east, south east and from south west as Figure 11 shows.

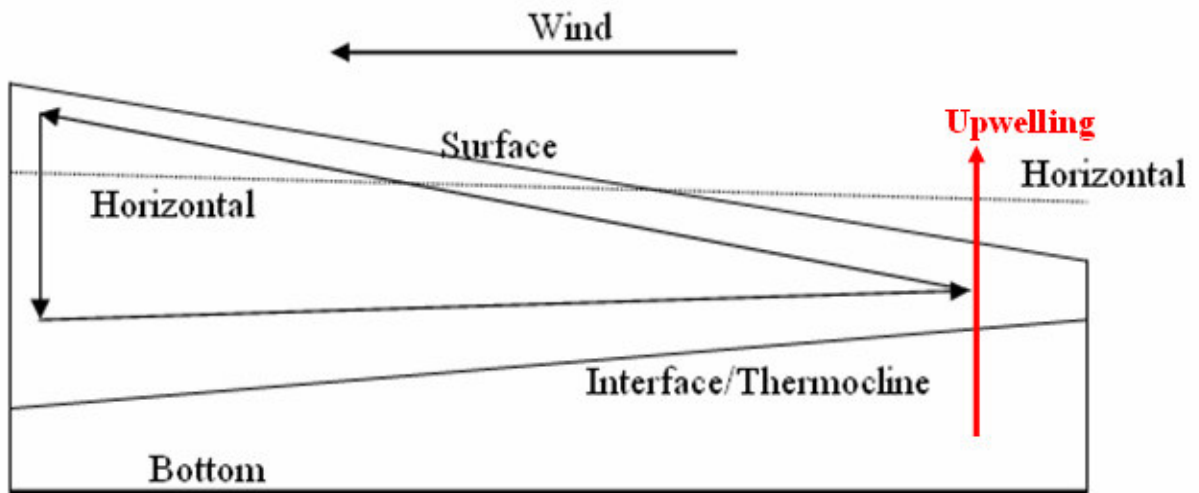


Figure 10. Wind induced water movement in the open waters of a lake.

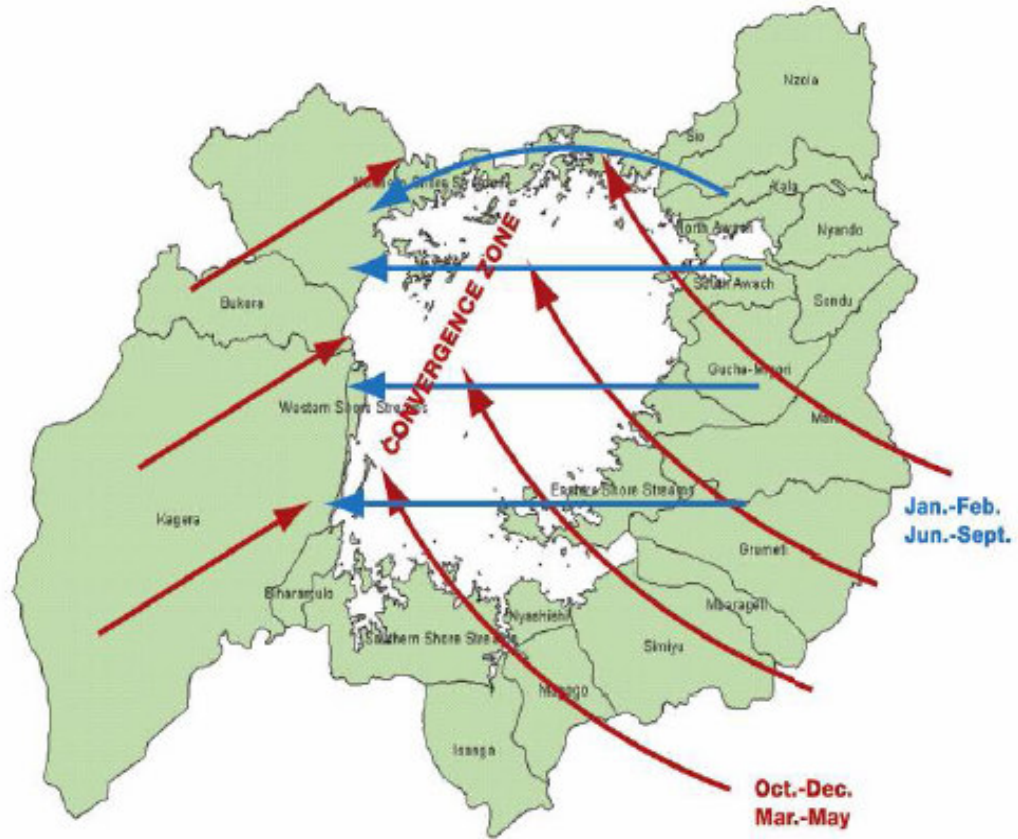


Figure 11. Global wind patterns over Lake Victoria (Source; COWI, 2002).

The Wedderburn number can be used to determine the amplitude of the wind required to generate this force strong enough to mix the whole depth of the lake water (Wolanski *et al.*, 1995).

$$W = g h_1^2 \Delta\rho / L u_*^2 \rho.$$

Where;

W is the Wedderburn number, g is the acceleration due to gravity, h1 is the mixing layer of the lake, L is the length of the lake to the wind direction, u* is the kinematic shear

stress measured in the water, ρ is the density of water and $\Delta\rho$ is the change of density between top and bottom layers.

Upwelling has happened when the calculated Wedderburn number is found to be less than one (Stevens & Lawrence, 1997; Kaplan *et al.*, 2003; Talavera & Richardson, 2004).

Although research over the lake indicates that upwelling occurs at least once annually (COWI, 2002), the Wedderburn number approach has not been used before for Lake Victoria. The Wedderburn number is based on the assumption that the system has reached a steady-state (that the wind has blown long enough). The time to reach that steady state is the time for the interface/thermocline to be tilted, and for the internal wave to have formed (deepening downwind and uplifting upwind). Wedderburn number is a name after the founder of this limnology approach (Stevens & Lawrence, 1997).

2.2.2 Upwelling in small island areas, south west part of Lake Victoria

The Wedderburn number can not be used to determine frequency of upwelling in small islands such as those in the southern part of Lake Victoria, where Rubondo is. The islands block the large-scale flow that occurs in the open lake waters. In these areas of Lake Victoria, a similar situation to that studied in Palau Islands, Micronesia, may apply. In a Palau Islands study, it was found that waves did not travel around the island because there was no coherence between internal waves on either side. The headland at the southern tip of Palau prevented the internal waves from rotating around the island. The

study shows that island generated internal waves may exist and generate localised upwelling events (Wolanski *et al.*, 2004).

Due to solar heating, the upper surface of the lake is warmer than the bottom waters, which are colder, and anoxic (Stevens & Lawrence, 1997). Travelling water masses transport heat energy in the water column. Temperature differences are thus effective method that can be used to determine if there is an upwelling and are useful in these small island regions where the Wedderburn number does not apply. Lehman *et al.* (1998) measured the East African Lakes temperature. He recorded 23.5 °C at a depth of 60 m for Lake Victoria. This water has 1ppm dissolved oxygen concentration. Such water is hypoxic and when internal waves bring it to the surface this water is able to shock, and possibly kill large fish that do not quickly react and swim to the surface to seek oxygen rich water. When the colder, anoxic waters are seen at the surface of the lake, it implies that there has been an upwelling.

Fish kills around Rubondo and the neighbouring south-western part of Lake Victoria have been observed almost every year since the early 1980s (Kaoneka & Mlengeya, 2000; TANAPA, 2004; Rutagemwa *et al.*, 2006^b; Borner, pers. comm.). With no obvious reason, fish die-offs are mostly of Nile Perch. The Nile perch surfaced quickly from deeper water in large numbers and died. Usually the stomach (not the swim bladder) was inverted and pressed out of their mouths. Die-offs in shallow waters were also witnessed, which affected other organisms as well, including tilapia. Poison as a cause of the fish

kills was ruled out by laboratory investigation of the dead fish samples taken to Veterinary Investigation Center in Mwanza (Kaoneka & Mlengeya, 2000).

2.3 Human activities and consequences

During the past forty years, several environmental problems have disturbed the natural conditions of Lake Victoria leading to the disruption of natural ecosystem services, processes and function. Human activity is responsible for the deterioration of the lake ecosystem (UNEP, 2000; COWI, 2002; Odada *et al.*, 2004; Kull, 2006).

2.3.1 Release of untreated effluents and wastes

Increased human dependency on, and misuse of freshwater resources, coupled with mismanagement of riparian areas has resulted in nutrient enrichment of Lake Victoria (Scheren *et al.*, 2000, Odada *et al.*, 2004; Phoon, 2004; Kull, 2006). These human activities include release of untreated waste and effluents into rivers and directly to the lake due to operation of factories and industries (Odada *et al.*, 2004). The result has been increased nutrient load to the lake and eutrophication.

2.3.2 Papyrus harvesting

Unsustainable papyrus harvest is one of the features of wetland destruction in Lake Victoria. Papyrus plants are utilized for construction of domestic tools, such as baskets, mats, fencing materials, roofing and house construction, by the people who live in the lake basin. In many areas, papyrus plants are harvested and the land cleared for

cultivation (Odada *et al.*, 2004). In many such places, replacement of the wetlands is difficult due to specific soil characteristics. Papyrus harvesting is good only when sustainable. Harvesting old papyrus plants removes the above-ground biomass and the nutrients assimilated, replacing the plant so that it can assimilate more nutrients from its new shoots.

In the Nakivubo channel, papyrus harvesting is done after every 6 – 8 months (Kansiime & Nalubega, 1999), but Muthuri *et al.* (1989) and Ndyabarema, (1991) suggests an interval of 12 months or more for papyrus harvest to be done in harvestable areas.

2.3.3 Burning of papyrus wetlands

The areas of papyrus that are left out of water due to water level decrease dry out and form dead organic material, and are subjected to bushfires in the dry season. When the ground is dry enough, the below ground biomass, the peat, also burns. Studies conducted in Sumatra shows that the fires can burn deep to the below ground biomass, if the peat is deep. In Sumatra, the peat was in frequently deeper than 5 m, and sometimes 12 m deep (Roach, 2004). Burning of peat releases carbon dioxide gas to the atmosphere, which contributes to the green house effect and hence global warming. In addition, phosphorus is released into the environment.

Survey of the Lake Victoria shows that burning has often been used for clearing land for cultivation and for sand excavation (ARCADIS, 2001; Awange and Ong'ang'a, 2006). Water level decrease, or otherwise drained wetlands, have been used as pasture grounds

for cattle, further destroying these ecosystems. It is evident that these activities that convert wetland areas to uplands should be avoided, so as to conserve the wetlands of Lake Victoria. According to Kansime *et al.* (2005), papyrus plants are better adapted for effluent purification than agricultural crops; hence they should not be substituted. In the lake basin, proper management of the farming land which is extensive could serve for adequate agricultural needs without invading on the wetlands.

2.3.4 Unsustainable withdrawal of water from the lake

The water level for Lake Victoria has fluctuated in the last century, but no decrease has been as drastic as during 2004 to 2006. Figure 12 and Figure 13 show the water level

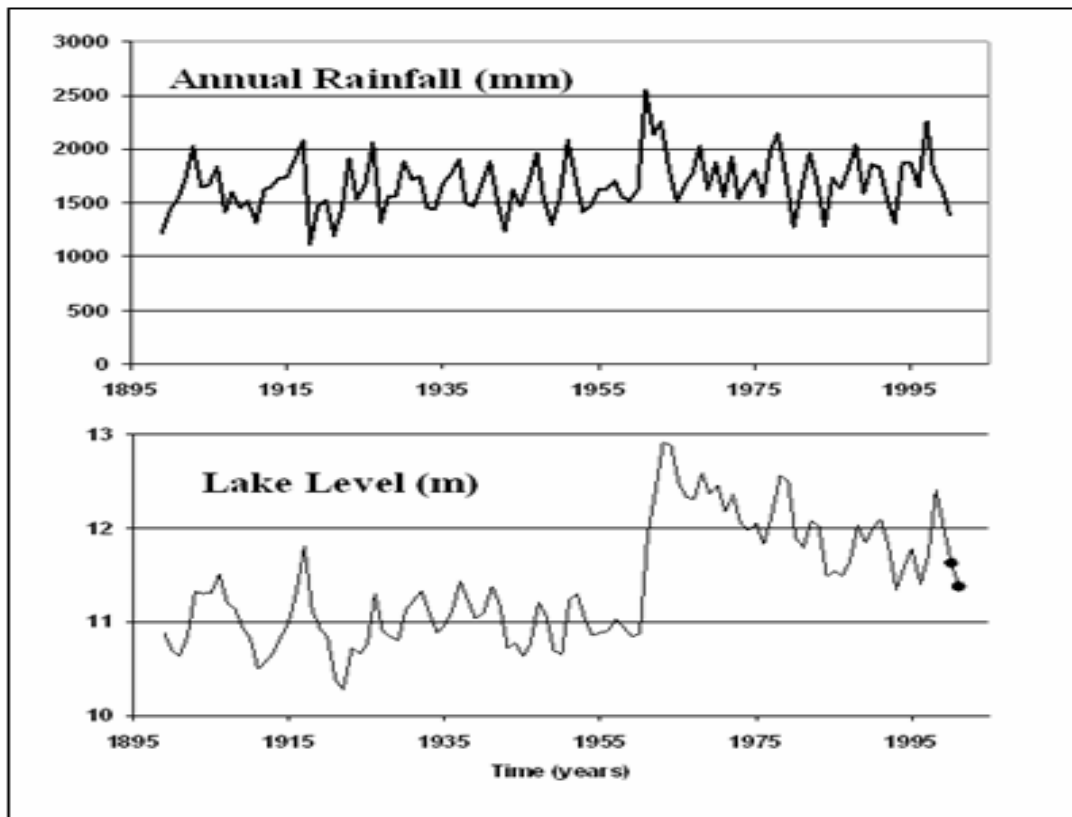


Figure 12. Rainfall and water level fluctuations in Lake Victoria from 1895 to 1996

pattern over this time. The water level shows similar pattern for 1895 to 1961 and another similar pattern for 1961 to 2002 (Figure 13). The two patterns are separated by the El-nino rains of the 1961 which caused floods in many East African areas and a significant lake level rise. After 2002, the lake level has been rapidly returning to the pre 1961 levels, and what is not known is how far this level decline will go if the pattern is not reversed or intersected by conditions that will cause a lake level rise. Furthermore, it is a concern to scientists, politicians as well as the general public that the recent lake level decline is happening when the River Nile outflow is controlled not naturally, as it was in the past critical low levels (the lowest ever recorded level was in March 1923 followed

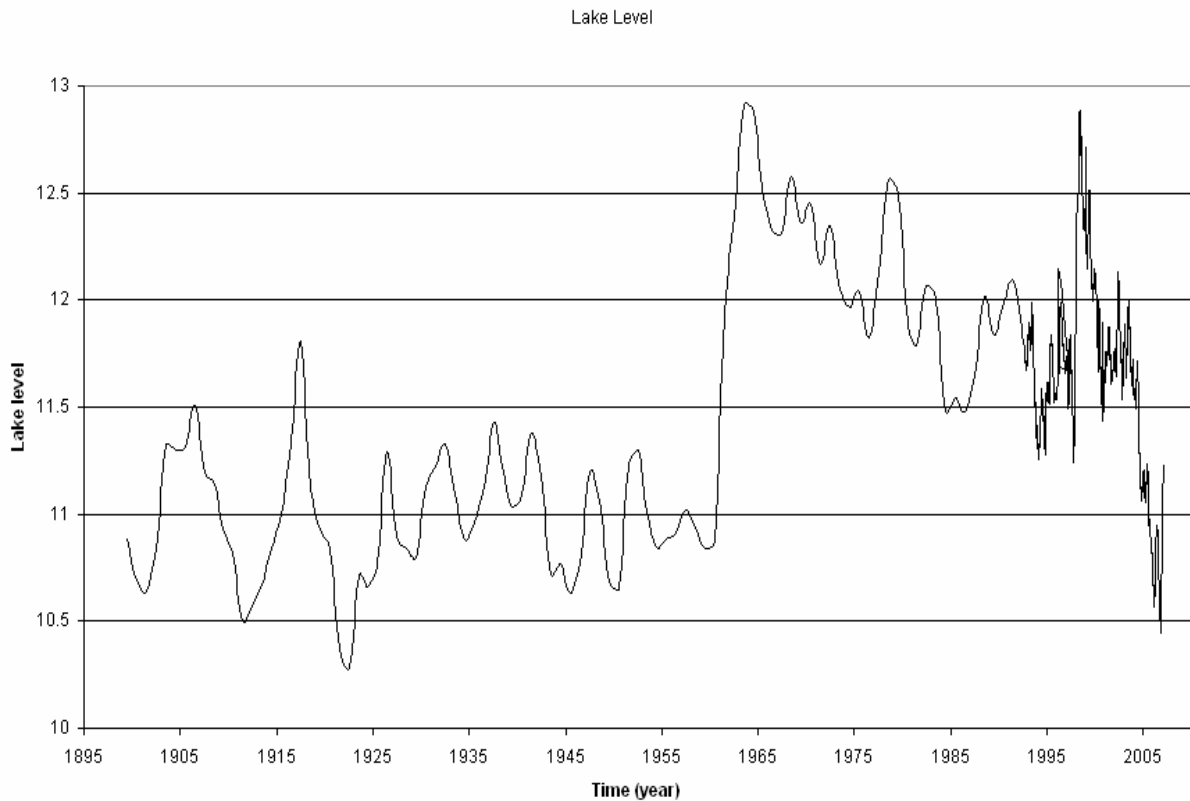


Figure 13. Water level fluctuations of Lake Victoria over the last 104 years

by January 10 2006), but by man through the Nalubaale and Kiira dams (Phoon *et al.*, 2004; Kull, 2006; Waweru, 2006; Mubiru, 2006). It is realized that without water in the lake, we can not talk about fisheries, lake transport, wetland benefits, water for domestic and industrial uses, water as a cleansing agent, and water, the main constituent of what is called Lake Victoria.

Studies show that human control of the lake outflow at Jinja is the most important issue, and it accounts for most of the total level decrease (Kull, 2006). In 1959, when the construction of Nalubaale Dam was completed, the lake outflow was no longer controlled

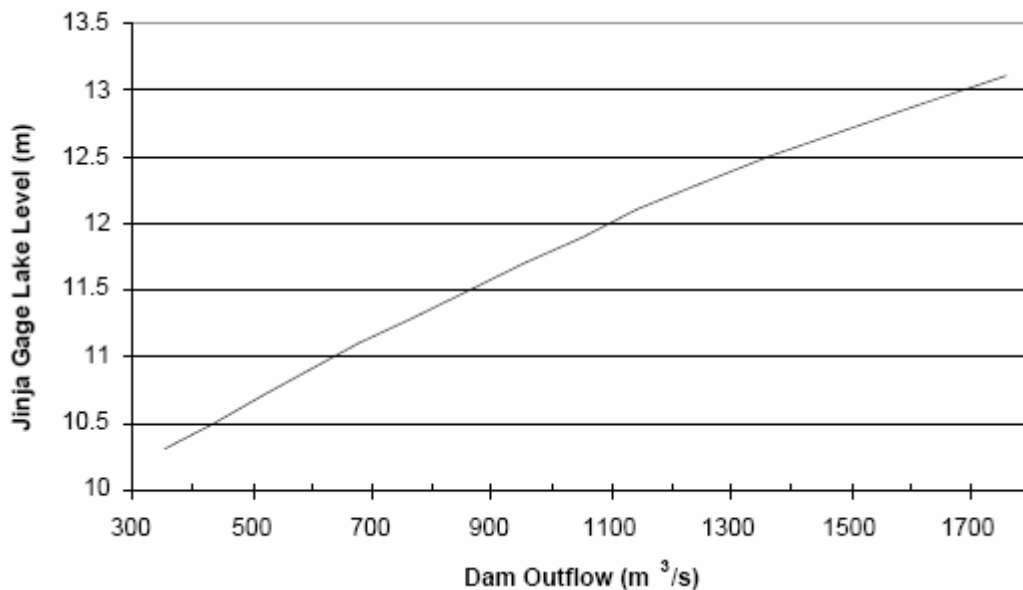


Figure 14. The agreed curve dictating how the Owen Falls dams are operated (Source; Kull, 2006).

by the natural outflow at Jinja through Ripon Falls, but instead the lake turned into a huge reservoir. The operation of the Nalubaale dam was based on an “agreed curve” (based on agreements in 1949, 1953 and again in 1991 between Uganda and Egypt). This was

developed for the operation of Nalubaale Dam to dictate how much water should be released from the Lake Victoria, based on the water level, whereby the dam was to mimic the natural outflow (Kull, 2006). This means that the lake level, which is determined by the balance of rainfall and evaporation, was to determine how much water was allowed to go past the dam outflow (Figure 14). However, due to demand for more electricity in Uganda, another dam was constructed at Kiira, 1.3 km downstream from the Nalubaale Dam in 1999. Three turbines were in operation at this dam by 2003. The two dams in combination were now in control of the quantity of water that flowed out of the lake to the White Nile. It was now impossible for Uganda to adhere to the agreed curve of natural flows. Kull (2006) estimated reduction of the water volume by the operation of the two dams to be responsible for 55% of the total water level decrease between 2004 and 2005. The recent power generation plants in Jinja, Uganda, are therefore drawing more water from the lake than the agreed curve. In fact, when the power generation plants in Jinja were temporarily stopped operating in December 2006 (Hall, 2007), the lake water level started to rise again.

Awange & Ong'ang'a (2006) reports an average of a 2.5 m water level decline in the Tanzanian part of Lake Victoria from 2004 to 2006.

2.3.4.1 General consequences of water level decrease

There are several consequences of water level decrease in the lake. Exposed shores are encroached for settlement, grazing and cultivation. Aquatic macrophytes, which are

important for nutrient circulation in the lake ecosystem, habitat for aquatic organisms and buffering functions, are lost as water level decreases.

The wetlands are refuges for endangered fish and used as breeding and nursery grounds (Kite, 1981; Mnaya & Wolanski, 2002), so there are losses to the fisheries when wetlands are destroyed. Due to the changes of water level in 2004 to 2006, vast areas of papyrus wetlands remained out of water and dried out.

Water level decrease is an obstacle to the free exchange of waters between the wetlands and the open lake (Kyambadde *et al.*, 2005), which is often brought about by wave movement and also during the rain season when the wetlands are flooded (Okot-Okumu, 2004). The decreasing water level (2004 – 2006) has resulted in a smaller area of wetlands in contact with water, which is brought to the wetland by seiches. The seiches bring water in and out of the wetlands from the open lake like an outflow. The water is then in contact with the papyrus root mat where nutrients especially nitrogen and phosphorus are utilized for plants growth (Kansiime & Nalubega, 1999). Therefore, reduced efficiency in purification of the water by wetlands is a result of water level drop, resulting into further eutrophication of the lake.

2.3.4.2 Quantification of the impact of the hydroelectricity plants in Jinja

Researchers need to have good data on the lake in order to estimate and predict future scenarios. Historical rainfall, water level, evaporation, inflow and outflow data on Lake Victoria is sometimes sparse and unavailable to the public and researches (Nicholson *et*

al., 1998; Kull, 2006). Data collection requires major financial input and in developing countries such as Tanzania, Kenya and Uganda, where Lake Victoria is, it is frequently not possible to collect adequate and appropriate data. Through modelling, researchers are able to overcome this problem and, by using the available historical data on the lake, to develop models that can be used to accurately estimate the missing parameters and predict the future of the lake in the face of changing climatic conditions. These studies resulted into the development of Model I and Model II (Yin & Nicholson, 1998, Nicholson *et al.*, 2000, Nicholson & Yin, 2001). By using these models, if rainfall in the catchment and water level are known, one can estimate inflows and outflows from the lake. Evaporation is taken to be a constant value of 1537 m per year and is calculated from surface energy balance considerations (Nicholson & Yin, 2001). The model is highly accurate as Figure 15 shows.

This study uses Model I (Nicholson & Yin, 2001) to calculate water inflow and outflow from Lake Victoria, and find out what the lake level should have been in absence of the parallel turbine, Kiira, at Jinja, and if the release of the lake water followed the agreed curve.

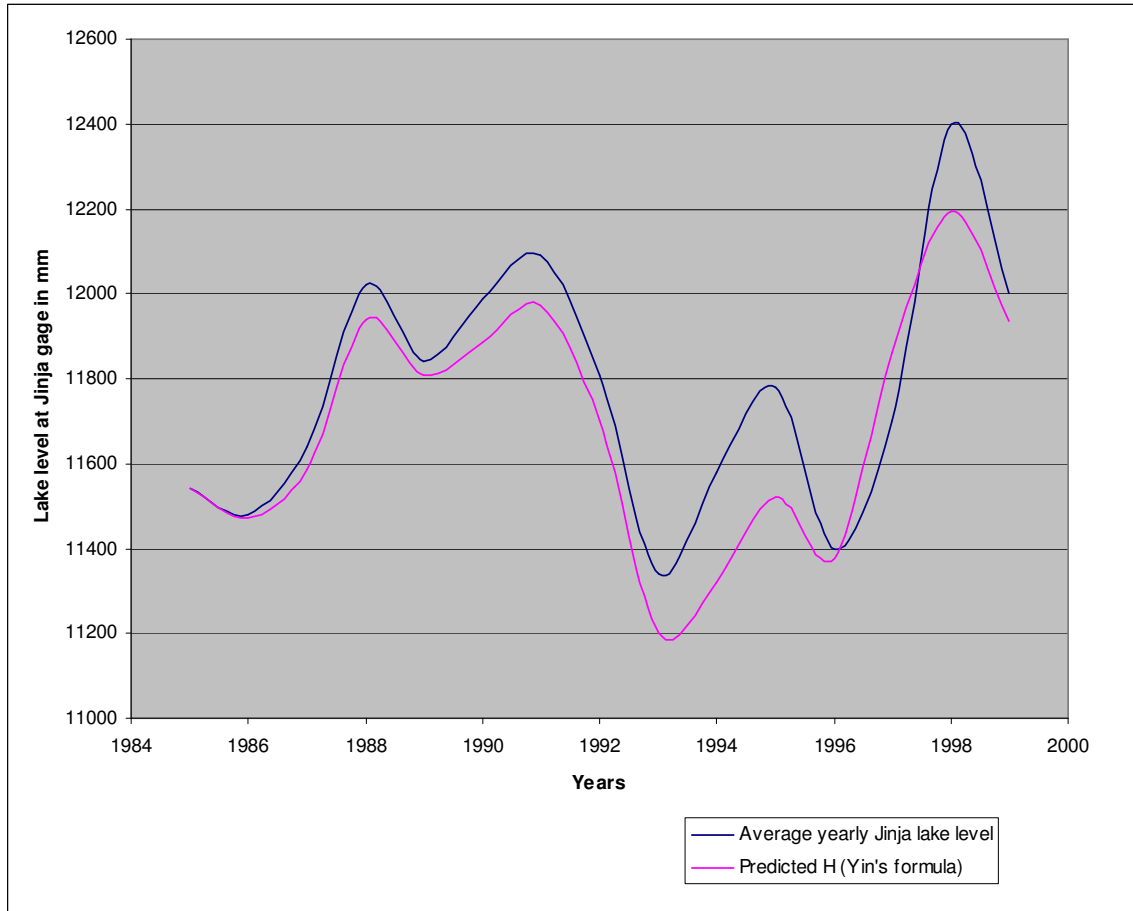


Figure 15. Observed and predicted water level from 1985 to 1999 by using Nicholson & Yin (2001) model I. The validity of the model is indicated by the good agreement of the comparison.

2.4 The eutrophication of Lake Victoria

Eutrophication can be defined as a natural process in which the addition of nutrients to wetlands and coastal waters from the watershed, atmosphere, and lakes stimulates excessive algal growth (NEEA, 2004). Despite sometimes it being a natural process, like upwelling in Chile (Meruane *et al.*, 2006), during the recent decades human activities have increased nutrient loads to many times natural levels. The impacts from these changes include occurrences of anoxia and hypoxia, nuisance and toxic algal blooms.

Contrary to some past reports on the lake, and as Rutagemwa *et al.* (2006^b) and COWI (2002) report, eutrophication in Lake Victoria is not uniform throughout the lake. It is severe especially at river mouths, bays and in certain hotspots. The hotspots include Winam Gulf, Murchison Bay, Napoleon Gulf and Mwanza Gulf. Since Talling studied the lake (1965, 1966), chlorophyll-a has risen from 70 ug/l in near shore areas of the lake to 170 ug/l. Strong oxygen deficit occur in the hotspot areas independently of the general oxygen regime of the lake (Rutagemwa *et al.*, 2006^b). In general, the offshore areas of the lake are not seriously eutrophicated. COWI, (2002) gives us an overview of current secchi depth variation in the lake (Figure 16).

A secchi depth, which is the maximum depth at which a disc lowered into the water can be seen from the surface, is a useful tool to measure the concentration of algae in the water. Algal particles and suspended particles not of biological origin affect the penetration of light into the water and therefore decrease secchi depths (Carlson & Simpson, 1996). Since excessive algal growth occurs in increased nutrients conditions, a secchi depth is an indicator of eutrophication of a water body. Compared to the situation in 1928, secchi transparency of Lake Victoria has decreased two fold. Typical secchi depth values in the middle of the lake now range from 3 m to 6 m with 7.2 m maximum. Secchi depth values of 1 m or less are now common in the bays and near shores. Silicon in the deep waters has decreased and nutrient inputs have increased three fold since 1960s. Together with nutrient increases of nitrogen and phosphorus, algal growth has been rampant and the shift of composition towards domination by blue-green algae from

dominance by diatoms (Ochumba & Kibaara, 1989; Mugidde, 1993), which causes de-oxygenation of the waters.

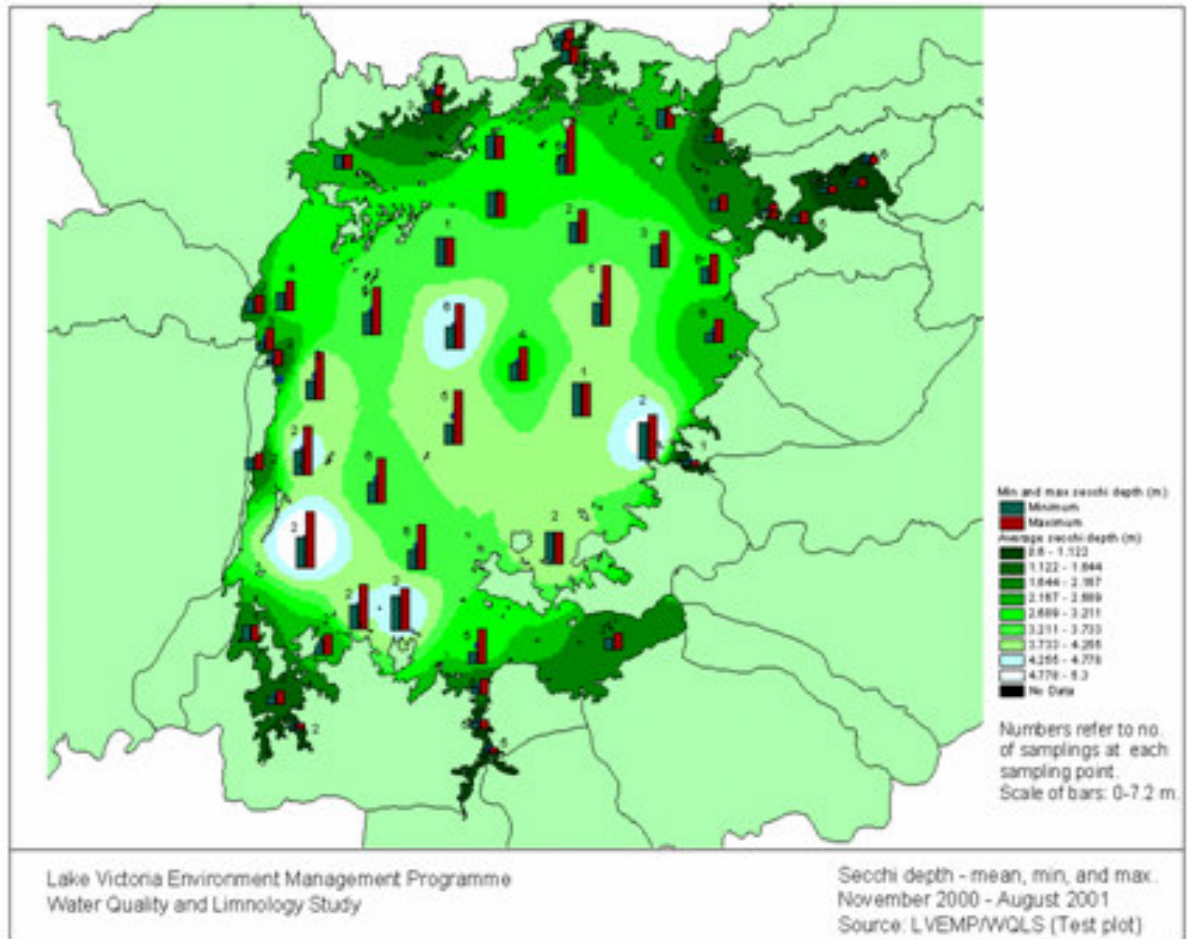


Figure 16. An overview of the ranges of measured secchi depth (transparency) in Lake Victoria (Source; COWI, 2002)

Other impacts are the clogging of water intake filters and increased chemical treatment costs for urban water supply authorities, and potentially, increased sickness to humans and animals drawing water from the lake due to toxic blooms from poisonous algae.

According to Talling 1965, 1966; Lehman *et al.*, 1998, the master variable controlling the eutrophication effects in Lake Victoria is the mixing depth. The mixing depth currently at 20 m separates the oxygen rich, warmer, upper lake waters from the deeper colder, hypoxic to anoxic waters. The maximum pelagic surface water temperature from past research is 27.4°C (Rutagemwa *et al.*, 2006^a), and the minimum deep water temperature recorded in the same study is 23.57°C.

2.4.1 DPSIR framework organisation of the eutrophication problem of Lake Victoria

DPSIR (Driving force, Pressures, State, Impact and Response) is a useful tool that can be used to organize environmental information by using a set of indicators and environmental state (Kristensen, 2004; OECD, 2004). The approach was used by the European Environmental Agency, as a structure within which to present indicators useful for decision makers on the environmental quality and to clarify the results of political decisions taken or to be taken about the environment in the future (NEEA, 2004). Like many other environmental problems, the eutrophication of Lake Victoria is interlinked through a number of cause-effect interactions as Figure 17 shows. The cycle can be effectively stopped with the right responses such as policies and management options.

There is significant human influence including impaired wetland uses, excessive water extraction from the lake leading to reduced efficiency and capacity of nutrient extraction by wetlands from the water due to level decrease. Potential management concerns should

include the restoration of wetland plants and restriction of water withdrawal from the lake. To this end, good data and research is required so as to enable informed decisions.

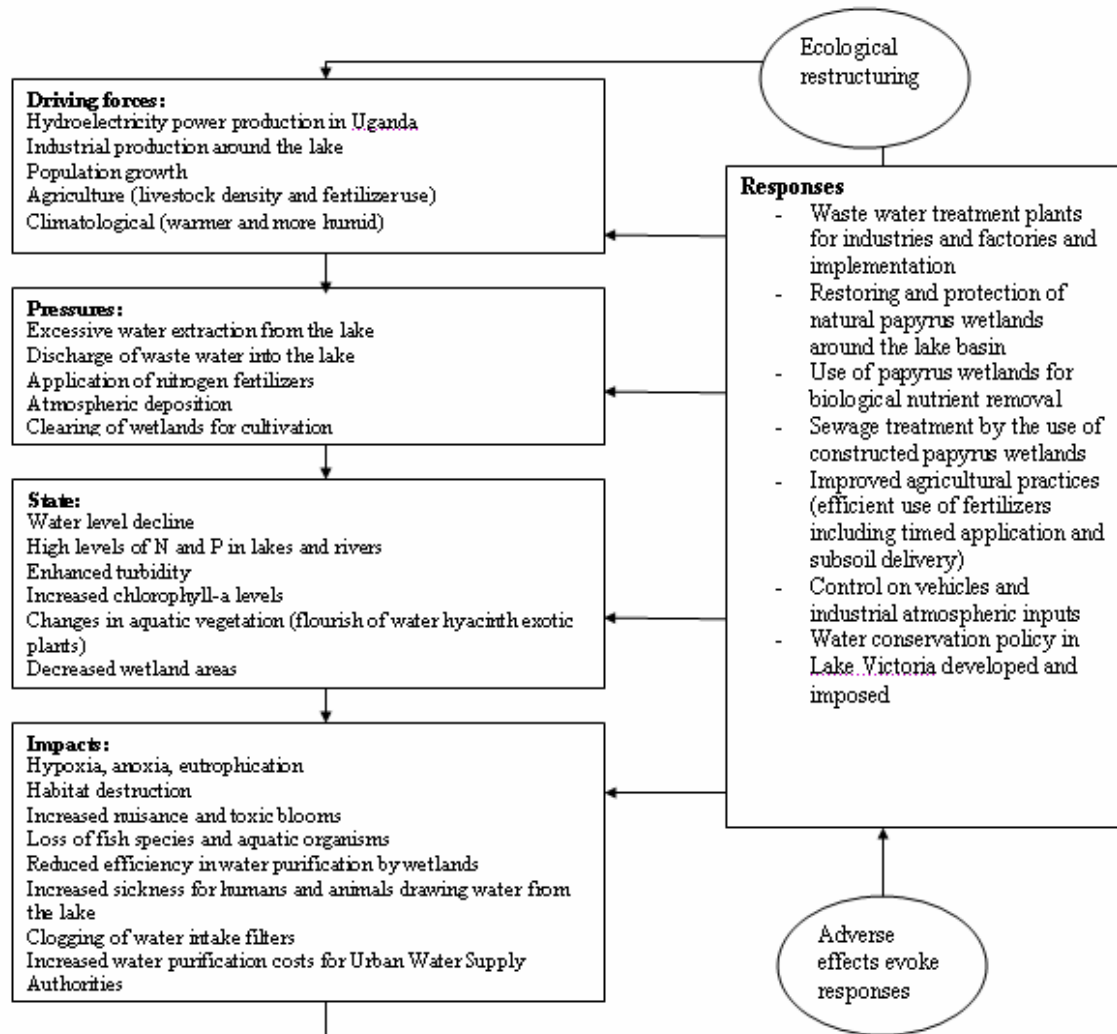


Figure 17. DPSIR framework approach to eutrophication problem of Lake Victoria

3.0 OBJECTIVES OF THIS STUDY

Previous research has not assessed and documented whether internal waves can upwell nutrients from below the thermocline and make them available for productivity above the thermocline thereby accelerating eutrophication for Lake Victoria. No previous studies have quantified the significance of papyrus wetlands in minimizing eutrophication of Lake Victoria. Also, there is no researched documentation of how water level decrease can impair wetlands function of water purification due to the recent water level falls.

Therefore, the main aim of this study is to predict the future health of Lake Victoria as a result of man made changes in the extent of papyrus wetlands.

Specific aims of this study are:

- To quantify the role of papyrus wetlands in the removal of nutrients from waters of Lake Victoria.
- To estimate the amounts of nitrogen and phosphorous extracted out of the water every year by papyrus wetlands.
- To assess the role of internal waves as an important mechanism through which nutrients are circulated in the water-wetland system and eventually removed from the system by papyrus wetlands hence reducing eutrophication of the lake.
- To investigate the effects of the rapid drop of the level of the lake water to the extent of the papyrus wetlands and its consequences to wetland function and the fisheries.

4.0 METHODOLOGY AND MATERIALS

Two types of field data were collected directly by the author. These are temperature data around Rubondo Island and fish larvae recruitment.

Temperature logging

Continuous surface temperature data were collected on an hourly basis since 2002 at five sites at Rubondo Island (shown in Figure 18), by using optic data loggers (StowAway Tidbit loggers). These temperature Tidbit Data Logger are small portable instruments the size of wrist watches but thicker, completely sealed underwater logger with optic communication system (Figure 19). The data loggers were deployed on depths varying from 2 m from the surface to 10.3 m at six sites. The optic data loggers were randomly located around Rubondo Island. The instruments were commanded to record data at hourly intervals. The instruments have a precision sensor for +/- 0.2 °C accuracy over 0 to 50 °C, and a time accuracy of +/- 1 minute per week at +20 °C, with the ability to take up to 32,520 measurements without download. An optic base station (HOBOWare) and Boxcar computer programme were used to start the logger, check the logger in-between measurements and readout the data. The data so downloaded was transferred to Excel spreadsheet for initial analysis whereby I checked for temperature values that were below 23.5 °C, which is the bottom water temperature observed by Lehman *et al.* (1989) at 60 m depth. Spatial and temporal assessment was done to see patterns in the data. Finally, Golden Grapher software was used for graphic presentations.

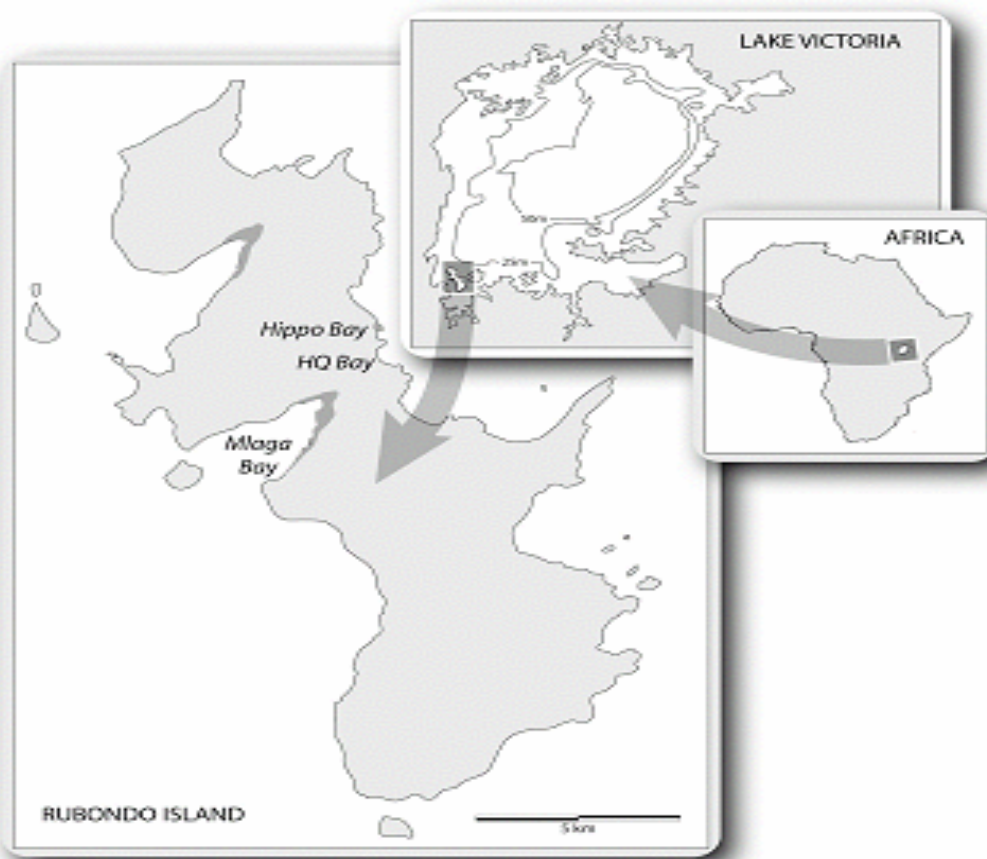


Figure 18. General location map of Rubondo Island National Park and Mlaga bay (Source; Mnaya & Wolanski 2002).



Figure 19. StowAway Tidbit Temperature Loggers (Source; <http://www.envco.info/stowaway-tidbit-temperature-loggers-557.html>).

Fish larvae recruitment

In 2006, fish larvae were sampled at night using a light trap (Figure 20) at Mlaga Bay (western of Rubondo Island). An underwater flashlight with a light scattering prism attached to its end was attached to the light box handle, and inserted just into the light box via the opening on its top center. The light trap so prepared was then attached to the end of a boat and stayed underwater for 2 hours for 24 moonless nights from 2000 hours to 2200 hours in 2000 and again in 2006 at Mlaga Bay in Rubondo Island National Park. Because many planktonic organisms navigate by, and are attracted by light (Mnaya & Wolanski, 2002), fish larvae were expected to be attracted into the light trap. The trap has slit openings made at its sides which allow small organisms to get in but not to get out. Having identified, counted and recorded their numbers, the fish larvae were released back into the water. This light trap used is similar to that described by Doherty (1987) except that this one was smaller, with a volume of 5 litres. This is the same methodology used in 2000 by Mnaya & Wolanski (2002) to assess fish recruitment at Mlaga Bay.



Figure 20. The light trap used for fish larvae recruitment in this study.

Other data

Monthly wind data over the lake were available for six stations located in the lake catchments from 1969 to 2006. Yearly water level and rainfall data over the lake for 1899 to 2006 were available from different sources. Monthly rainfall data at Mwanza station was available for 2001 to 2006. Literature was used to find scientific facts and historical data on the lake such as quantification of areas of the basin wetlands, amounts of nitrogen and phosphorus and other parameters as will be discussed in this thesis.

5.0 RESULTS

5.1 Quantification of nitrogen and phosphorus nutrients extracted from Lake Victoria wetlands by papyrus wetlands

The area of the papyrus wetlands in Lake Victoria basin is estimated in this study to be 10, 235.17 km² as shown in Table 3.

Table 3. Calculated area of Lake Victoria basin wetlands

Country	Wetlands in LV basin (km²)	Contribution to total wetland area (10,235.17 km²) in %	Contribution to total basin area (184,000 km²) in %
Kenya	2,168.60	21	1.17
Uganda	3,846.57	38	2.09
Tanzania	4,220.00	41	2.29
Total	10,235.17	100	5.5

5.1.1 Removal of nitrogen by denitrification.

Research has shown that papyrus plants are responsible for removal by denitrification of an average of 0.35 g of nitrogen per meter squared per day (Sloey *et al.*, 1978).

It follows that, papyrus removes 127.75 gN/m²/year, equivalent to $1.27 * 10^2$ tonne N/km²/year. Therefore, the total nitrogen removed by denitrification in papyrus wetlands in the entire basin is $1.27 * 10^2$ tonne N/km²/year * $1.02 * 10^4$ km² = $1.3 * 10^6$ tonneN/yr.

Total input of nitrogen into the lake is $2.43 * 10^6$ tonnesN/yr. This amount is derived from the nitrogen balance by COWI (2002) as summarized in Table 4. Thus, the papyrus

annually remove $1.3/2.43 = 0.53 = 53\%$ of the total annual input of nitrogen in the lake.
 They thus measurably help to slow down the lake eutrophication.

Table 4. Annual nitrogen input into Lake Victoria (Adopted from COWI, 2002)

Annual nitrogen input into Lake Victoria	
Source	Amount in t/y
Atmosphere	102000
Non-point sources	49500
Point sources	1900
Sediment release	2276600
Total input	2430000

It is then found that the time scale in years required for papyrus to filter the lake (by denitrification only) if there was no more input of nitrogen is 1.3 years.

[Average concentration of nitrogen in lake waters

$$= 0.640 \text{ mg/l (Scheren } et al., 2000)$$

$$= 0.64 \text{ g/m}^3$$

$$= 0.64 * 10^{-3} \text{ tonne/m}^3$$

$$= 0.64 * 10^{-3} * 10^9 \text{ tonne/km}^3$$

$$= 0.64 * 10^3 \text{ tonneN/km}^3$$

$$\text{Volume of the lake} = 2,760 \text{ km}^3 \text{ (Scheren } et al., 2000) = 2.76 * 10^3 \text{ km}^3$$

Annual removal of nitrogen through denitrification in papyrus =

$$= 1.3 * 10^6 \text{ tonnesN/yr}$$

Total amount of nitrogen in the lake = concentration of nitrogen * volume of the lake

$$= 0.64 * 10^3 \text{ tonne/km}^3 * 2.76 * 10^3 \text{ km}^3$$

$$= 1.7664 * 10^6 \text{ tonnesN.}$$

Hence, total amount of nitrogen in the lake is $1.7664 * 10^6$ tonnes (in year 2000).

Time scale (in years) required for papyrus to filter the lake through denitrification if there was no more input:

$$= 1.7664 * 10^6 \text{ tonnes} / 1.3 * 10^6 \text{ tonnes/yr} = 1.3 \text{ years}].$$

5.1.2 Removal of nitrogen by harvesting of above-ground biomass

In their study of Nakivubo swamp, Kansiime and Nalubega (1999) studied removal of nitrogen and phosphorus by harvesting above-ground biomass in a papyrus dominated area of 0.92 km². In this study, we use Nakivubo swamp values, in Ugandan Lake Victoria papyrus wetlands to represent the entire lakes papyrus wetlands situation. The limitation of this approach is that the specific local situation for Nakivubo may not apply exactly the same way to everywhere else in the lake basin; especially the nutrient content of papyrus plants may be different. It is assumed that the variation would however be less than the values of Naivasha, for example, which is reported to have papyrus plants of nearest similarity in comparison with those of Lake Victoria (Boar *et al.*, 1999). Due to limited research with papyrus of Lake Victoria, their capacity to assimilate nutrients from substrate of different concentrations of nutrients is not well known. This would imply

that applying the Nakivubo parameters to the rest of the lake is biased. It is however unavoidable in light of the data limitation.

The average above-ground biomass of Nakivubo is $4766 \text{ g/m}^2 (= 4.77 * 10^3 \text{ tonne/km}^2)$

Average papyrus nutrients content of Nakivubo is (N, 1.30% = 0.013 and P, 0.21% = 0.0021). Total papyrus area for Lake Victoria = $10,235 \text{ km}^2 = 1.02 * 10^4 \text{ km}^2$. Applying Nakivubo parameters to all the lake, removed nitrogen nutrients if all the papyrus is harvested in one year, is $6.3 * 10^5 \text{ tonneN/yr}$.

$$\begin{aligned} & [= \text{above ground biomass} * \% \text{ nutrient content} * \text{area of wetlands} \\ & = 0.013 * 4.77 * 10^3 \text{ tonne/km}^2 * 1.02 * 10^4 \text{ km}^2 \\ & = 6.3 * 10^5 \text{ tonneN/yr}] \end{aligned}$$

This is equivalent to 26% of annual input of nitrogen to the lake. Hence, to remove the annual load of nitrogen to the lake ($2.43 * 10^6 \text{ Ntonne/yr}$), the time required is: $2.43 * 10^6 \text{ Ntonne/yr} / 6.3 * 10^5 \text{ Tonne/yr} = 3.8$ or equivalent to 4 years, when all wetland area is harvested every year.

5.1.3 Removal of phosphorus by harvesting of above-ground biomass

Average phosphorus nutrient content in above-ground papyrus plant biomass is $6.3 * 10^5 \text{ tonne N}$ (nitrogen in above-ground biomass) * ratio P/N = $6.3 * 10^5 \text{ tonne N/yr} * 0.21/1.3, = 1.02 * 10^5 \text{ tonne P/yr}$.

Annually, $5.34 * 10^5$ tonnes of phosphorus enter the lake as Table 5 shows.

Table 5. Annual phosphorus input into Lake Victoria (Adopted from COWI, 2002).

Annual phosphorus input into Lake Victoria	
Source	Amount in t/y
Atmosphere	24400
Non-point sources	5700
Point sources	1000
Sediment release	502900
Total input	534000

The amount of phosphorus removed by harvesting of above-ground biomass of papyrus wetlands is equivalent to 19% of annual input of phosphorus to the lake. Hence, to remove one year input of phosphorus to the lake, the time required is: $5.34 * 10^5$ Ptonne/yr/ $1.02 * 10^5$ Ptonne/yr = 5.2 years, when all wetland area is harvested every year.

On the other hand, if there were no more inputs, and by using the concentration of phosphorus in the lake in 2000, the time scale required for removing the phosphorus in the lake if all papyrus wetlands are harvested is 2 years.

Total amount of phosphorus in the lake = average concentration of P * volume of the lake.

$$\text{Hence, in 1 l} = 0.074 \text{ mg}$$

$$\text{In } 10^{12} \text{ l (1 km}^3\text{)} = x$$

$$= 0.074 * 10^{12} = 7.4 * 10^{10} \text{ mgP}$$

$$1 \text{ km}^3 = 7.4 * 10^{10} \text{ mgP}$$

$$= 7.4 * 10^{10} \text{ mgP} * 2.76 * 10^3 \text{ km}^3$$

$$= 2.04 * 10^{14} \text{ mg}$$

$$= 2.04 * 10^{14}/10^9$$

$$= 204,240 \text{ tonnesP}$$

Hence, total amount of phosphorus in the lake = $2.04 * 10^5$ tonnesP

$$= 2.04 * 10^5/1.02 * 10^5 = 2 \text{ years.}$$

5.2 Lake level estimates (Effects of dams to water level of the lake)

The mean catchment rainfall from 2001 to 2006, calculated by correlating the mean catchment rainfall from 1986 to 2000 with measured rainfall over Mwanza from 1986 to 2006 (Annex 1), showed that the rainfall amount for 2001 to 2006 was within non-drought amounts. The calculated mean catchment rainfall agrees well with the observed mean catchment rainfall as Figure 21 shows.

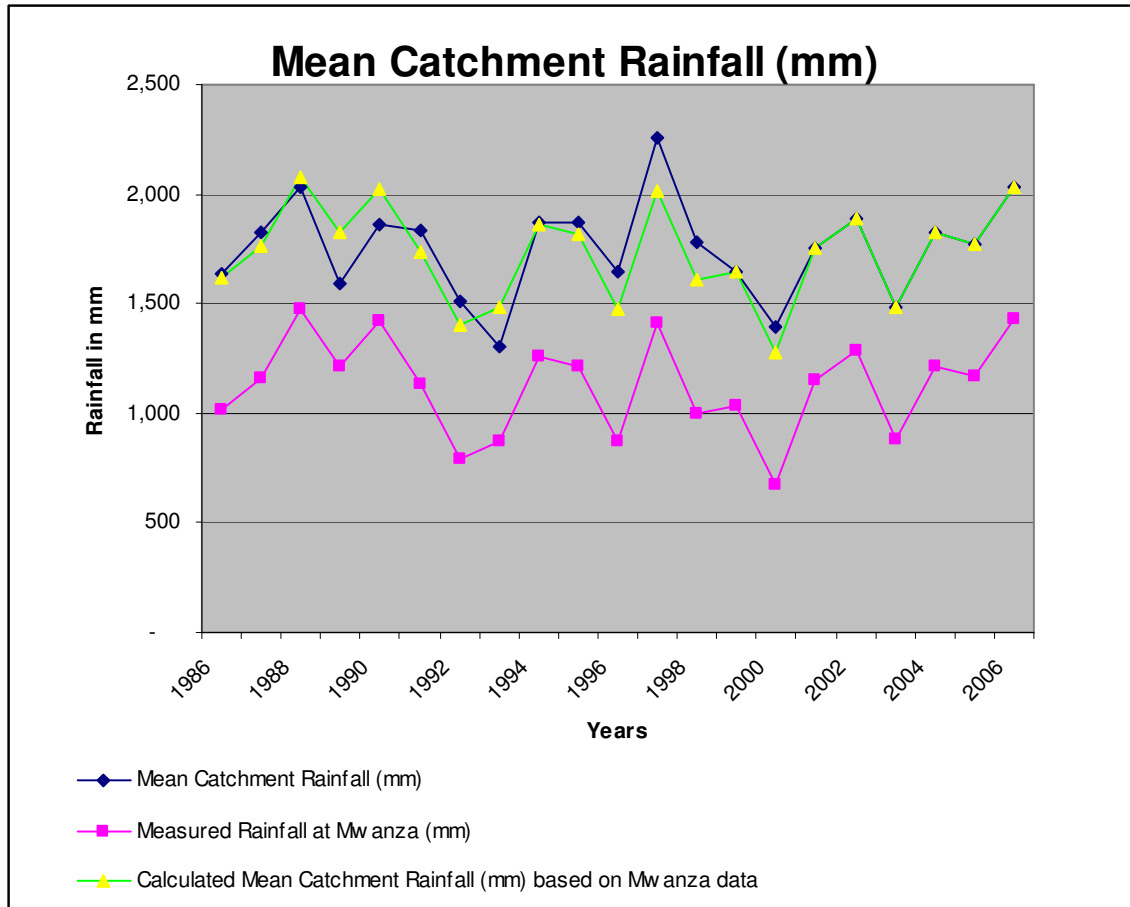


Figure 21. Estimated mean catchment rainfall for Lake Victoria from 2001 to 2006.

The calculated water levels for Lake Victoria for the years 2000 to 2006 without the parallel turbines at Jinja are shown in Figure 22. The calculations show that the water level dropped by 2.5 m from 2004 to end of 2006. From the water balance model, formula number 1 to number 4 as shown below were used from Nicholson & Yin (2001).

Formula 1:

$$H_i = P_w + I - (E + D)$$

where H_i is a change in end-of-year lake level from the preceding year, input is precipitation over the lake (P_w) plus tributary inflow (I) and output is evaporation over the lake (E) plus discharge (D).

Formula 2:

$$I_i = 0.33395H_i - 0.24311H_{(i-1)} - 0.266Pl(i) + 0.2356Pl(i-1) - 726.$$

Formula 3:

$$D_i = 0.15913H_{(i-1)} + 0.07054H_i - 223$$

Formula 4:

$$P_w(i) = 1.3533Pl(i) - 87.$$

where I_i is inflow in year i , $Pl(i)$ and $Pl(i-1)$ are catchment rainfall during years i and $i-1$, D_i is discharge in year i , $P_w(i)$ is the annual rainfall over the lake in year i , and H_i and $H_{(i-1)}$ are the lake levels at the end of the current and previous year respectively. Annex 2 shows a summary of these calculations.

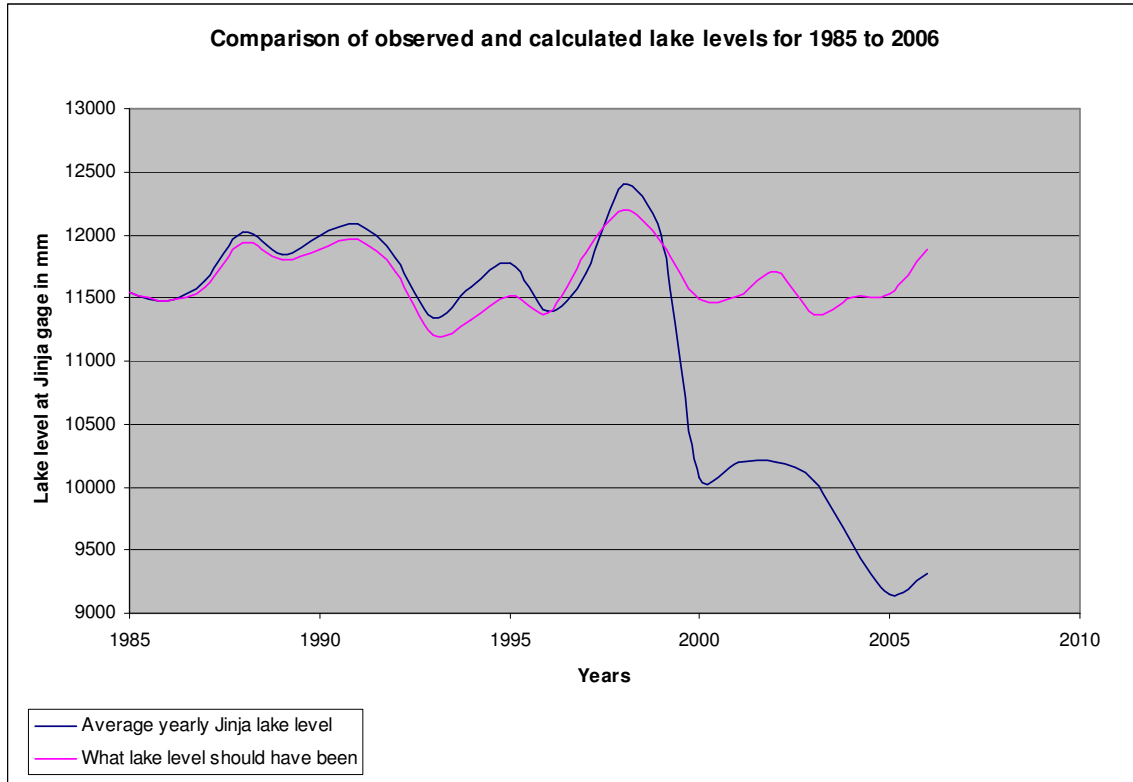


Figure 22. Prediction of Lake Victoria water level without the parallel turbine at Jinja for 2000 to 2006

In order to compare habitat change with change of water level, fish larvae recruitment was measured by the author for 24 moonless nights in 2000 and again in 2006 at Mlaga Bay in Rubondo Island National Park. The mean for the fish larvae recruitment in 2000 versus 2006 are 10.58 and 2.37, while the standard deviations are 13.46 and 1.52 respectively. A significant level of $t(23) = 2.967, p < 0.05$ was obtained. There was an 80% decrease of the number of fish larvae recruited at Mlaga Bay in the year 2000 and in the year 2006. The comparison is illustrated in Figure 23.

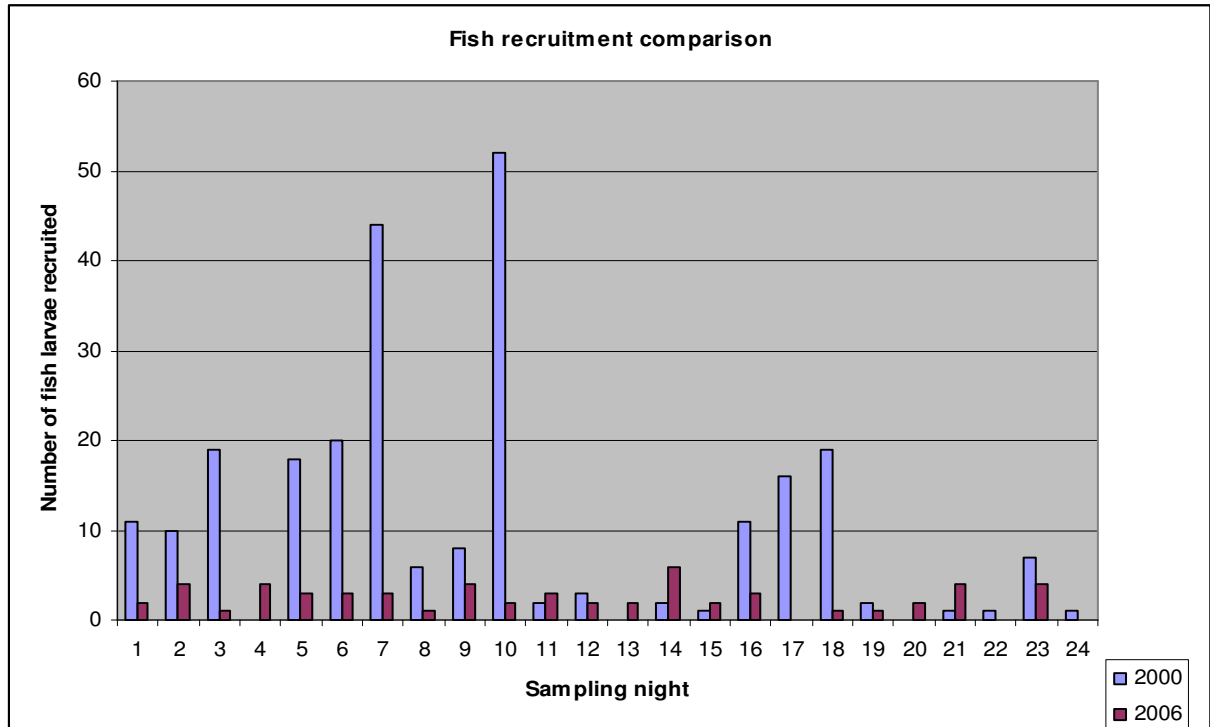


Figure 23. Comparison of fish larvae recruitment at Mlaga Bay, Rubondo Island National Park in 2000 and 2006.

5.3 Internal waves and nutrients dynamics

5.3.1 Upwelling in the open waters of Lake Victoria: Testing Wedderburn number applicability to Lake Victoria

The minimum temperature of this study, 21.79 °C (recorded by the author on 18.10.2003 at 0640 hours and as shown in section 5.3.2) was used to determine the difference between minimum and maximum temperature in the lake (27.4 °C open lake) to be 5.61 °C. A difference of water density between the two layers above and below the mixing depth is $\Delta\rho = 0.895 \text{ kg m}^{-3}$. Density of water = $\rho = 10^3 \text{ kg m}^{-3}$. Depth of the top layer (mixing layer of the lake) = $h_1 = 20 \text{ m}$. Length of the lake = $L = 200 \text{ km} = 2 * 10^2 \text{ km} = 2 * 10^5 \text{ m}$. Upwelling occurs and reaches the surface when the Wedderburn number $W = 1$,

$$W = 1 = g h_1^2 \Delta\rho / L u_*^2 \rho$$

where u_* is the kinematic shear stress measured in the water. Hence upwelling reaches the surface when $u_*^2 = g h_1^2 \Delta\rho / L \rho$.

$$u_*^2 = 9.81 * 20^2 0.895 / (2 * 10^5 * 10^3) \text{ m}^2 \text{ s}^{-2}$$

$$= 3511 / 2 * 10^8$$

$$= 1750 * 10^{-8} \text{ m}^2 \text{ s}^{-2}$$

$$u_* = (1750 * 10^{-8} \text{ m}^2 \text{ s}^{-2})^{0.5}$$

$$= 56 * 10^{-4} \text{ m s}^{-1}$$

To relate u_* to u_{10} (the wind speed at 10 m height over the lake):

The stress applied by the wind over the water is $= \rho_a C_d u_{10}^2$ (Hsu, 1998);

where C_d (drag coefficient) $\sim 0.001 \sim 10^{-3}$ and where ρ_a is the density of the air ($=1.3 \text{ kg m}^{-3}$). This wind stress is equal to the stress in the water calculated from the kinematic stress in the water $= \rho u_*^2$

Hence $\rho_a C_d u_{10}^2 = \rho u_*^2$. Thus

$$u_* = u_{10} (C_d \rho_a / \rho)^{0.5} = u_{10} (10^{-3} * 1.3 / 1000)^{0.5} = u_{10} (1.3 * 10^{-6})^{0.5}$$

$$u_* = 1.14 * 10^{-3} u_{10}$$

Thus u_{10} (wind at 10 m height over the lake) $= 10^3 u_* / 1.14$

Upwelling as a function of wind speed

Since for upwelling to reach the surface, the critical $u_* = 56 * 10^{-4} \text{ m s}^{-1}$; thus the critical wind speed at 10 m height for upwelling to occur

$$u_{10} = 10^3 u_* / 1.14$$

$$\begin{aligned}
&= 56 * 10^{-4} \text{ m s}^{-1} * 10^3 / 1.14 \\
&= 5.6/1.14 \\
&= 4.9 \text{ m s}^{-1}.
\end{aligned}$$

This is a very small wind speed, suggesting that upwelling would occur commonly. However, that is probably not true because upwelling is not set until the internal wave has traveled the length L of the lake. The internal wave travels at a horizontal speed V of about

$$V = (g \cdot 0.5 (h_1 + h_2) \Delta\rho / \rho)^{0.5}$$

where h_1 is the depth of the top layer and h_2 is the depth of the bottom layer. Assuming that the two layers have the same depth,

$$\begin{aligned}
V &= (9.81 * 20 \text{ m} * 0.895/1000)^{0.5} \\
&= (0.176)^{0.5} \\
&\sim 0.4 \text{ m s}^{-1}
\end{aligned}$$

The length of the lake $L = 200 \text{ km}$, so it takes a time T for that wave to travel across the lake:

$$T = L/V = 2*10^5 \text{ m}/0.4 \text{ m/sec} = 5 * 10^5 \text{ sec}$$

Since $1 \text{ day} = 8.64 * 10^4 \text{ sec}$,

$$T = 5 * 10^5 / 8.64 * 10^4 \sim 6 \text{ days}$$

Upwelling on the downwind side of the wind thus occurs if the wind at 10 m height over the lake is $> 4.9 \text{ m/sec}$ and lasts for at least 6 days with assumption that no opposing force is present.

5.3.2 Upwelling in the southwest region of the lake (small island areas)

Past studies reports average minimum deep water temperature for Lake Victoria as 23.94 ± -0.721 °C, and the maximum as 26.3 ± 0.832 * C (Rutagemwa *et al.*, 2006^b). The same study recorded the minimum deep water temperature at 23.57 °C. This value is only

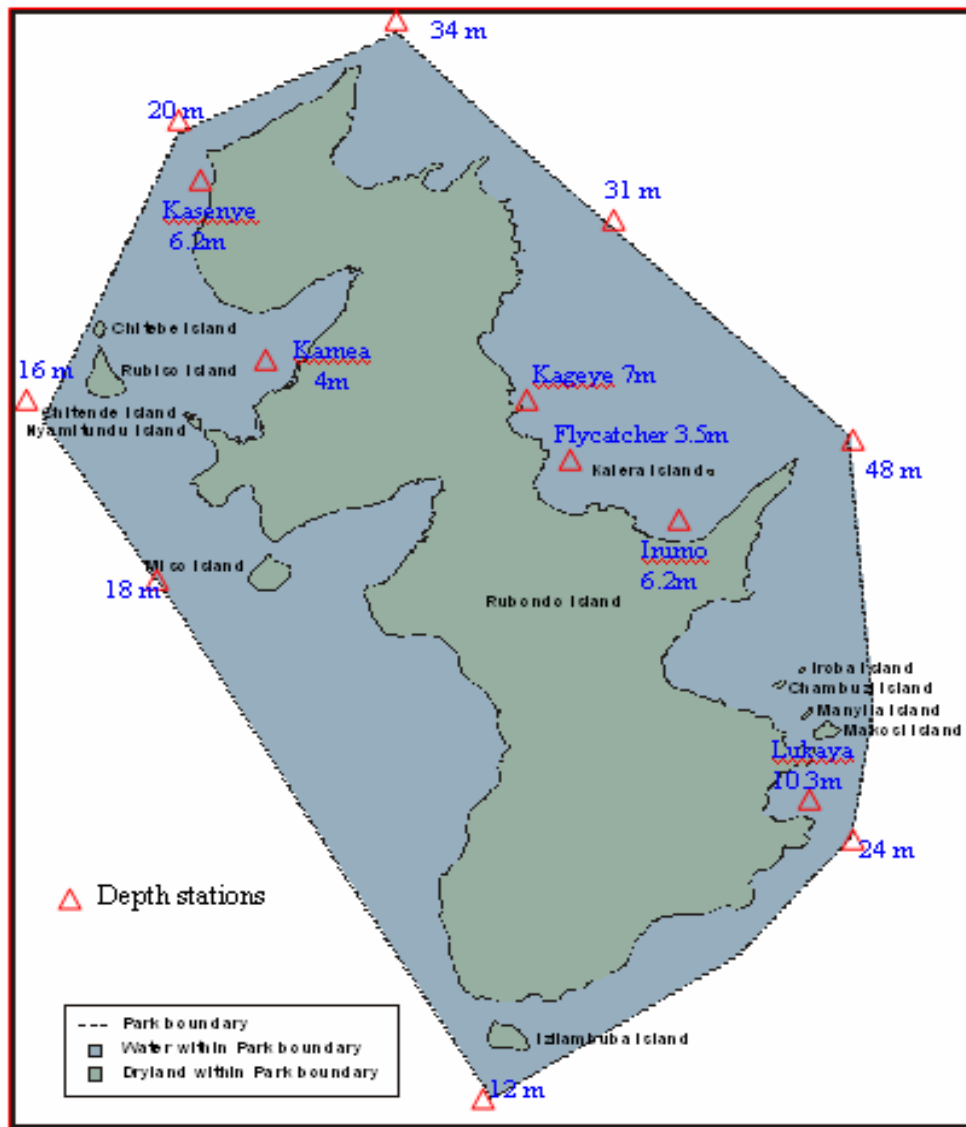


Figure 24. Location of the temperature data loggers around Rubondo Island. The western side is generally shallower than the eastern and northern sides, which overlook deeper and open waters. (Adapted from TANAPA, 2004).

slightly higher than historical values, such as recorded by Lehman *et al.* (1998), who recorded water temperature at 60 m depth at 23.5 °C in 1990 and 1992. Accordingly, in this study cold waters are taken to be the water temperatures recorded at and below 23.5 °C. Such low temperature, characteristic of deep Lake Victoria waters, were occasionally observed at five of the six measurements sites at Rubondo Island (Figure 24) for the total of 679 hours (i.e 1.3 % of the time) for the study period spanning October 2002 to December 2006. It should be noted that, selection of a slightly higher minimum temperature value would yield a definitely higher percent level, but this was chosen because of presence of a comparable past recorded value by Lehman *et al.* (1998) and Rutagemwa *et al.* (2006^b) as stated above.

Observations from Rubondo temperature data

The data shows frequent upwelling in some data loggers and infrequent in others and none in the two data loggers located at Flycatcher, located to the east of Rubondo Island. Frequency of upwelling per year is summarized as a total of 179, 0, 278 and 222 hours in 2003, 2004, 2005 and 2006 respectively as Table 6 shows.

- Irumo Area

Cold water at the surface (temperature ≤ 23.5 °C) indicating upwelling was observed at different extents and time intervals. Before the critical temperatures, often the water temperatures became low for few days, indicating a setting up of the upwelling, as can be

Table 6. Frequency of upwelling in six locations near Rubondo Island from 2003 to 2006.

Year	Area	Depth where the logger was suspended in total lake depth (m)	Number of upwell hours (temperature ≤ 23.5)	Total
2003	Flycatcher1	3 in 4.3	0	
Day number 366 to 730	Flycatcher2	3 in 4.1	0	
	Kageye1	2.5 in 3.5	14	
	Kageye2	4 in 6	8	
	Kageye3	2.3 in 3.2	2	
	Kamea1	2 in 3	33	
	Kasenyee1	3 in 4	122	
	Kasenyee2	2 in 3	0	179
	2004	Kageye4	4 in 5.5	0
Day number 731 to 1095	Kageye5	4 in 5.5	0	
	Kamea1	2 in 3	0	
	Kamea2	2.5 in 4	0	0
2005	Irumo1	5.5 in 6	54	
Day number 1096 to 1461	Irumo2	4.5 in 6	54	
	Irumo3	6 in 6.2	28	
	Kageye4	4 in 5.5	10	
	Kageye5	4 in 5.5	10	
	Kasenyee3	3 in 4	119	
	Kasenyee4	6 in 6.2	3	278
	2006	Irumo3	6 in 6.2	111
Day number 1462 to 1826	Kageye6	6 in 7	0	
	Kasenyee4	4 in 5.5	2	
	Lukaya1	10 in 10.3	109	222
Total			679	679

seen in the data from Irumo1 and Irumo2 (Figure 25). At Irumo, the water temperatures became low for several days indicating that the thermocline was near the surface, before day 1289 when the lower waters were recorded by the logger near surface.

Irumo2 was located near Irumo1 and at almost the same time (the two were stationed about 250 m apart, Irumo1 was suspended in 5.5 m while Iruom2 was suspended at 4.5

m), the cold water that crossed Irumo1 and recorded for two consecutive hours (day number 1289.275694 to 1289.317361) also was recorded at Irumo2 for the same duration of time but a delay of one hour occurred (day number 1289.318055 to 1289.359722). In Figure 25, it can be observed that Irumo1 and Irumo2 show almost the same pattern.

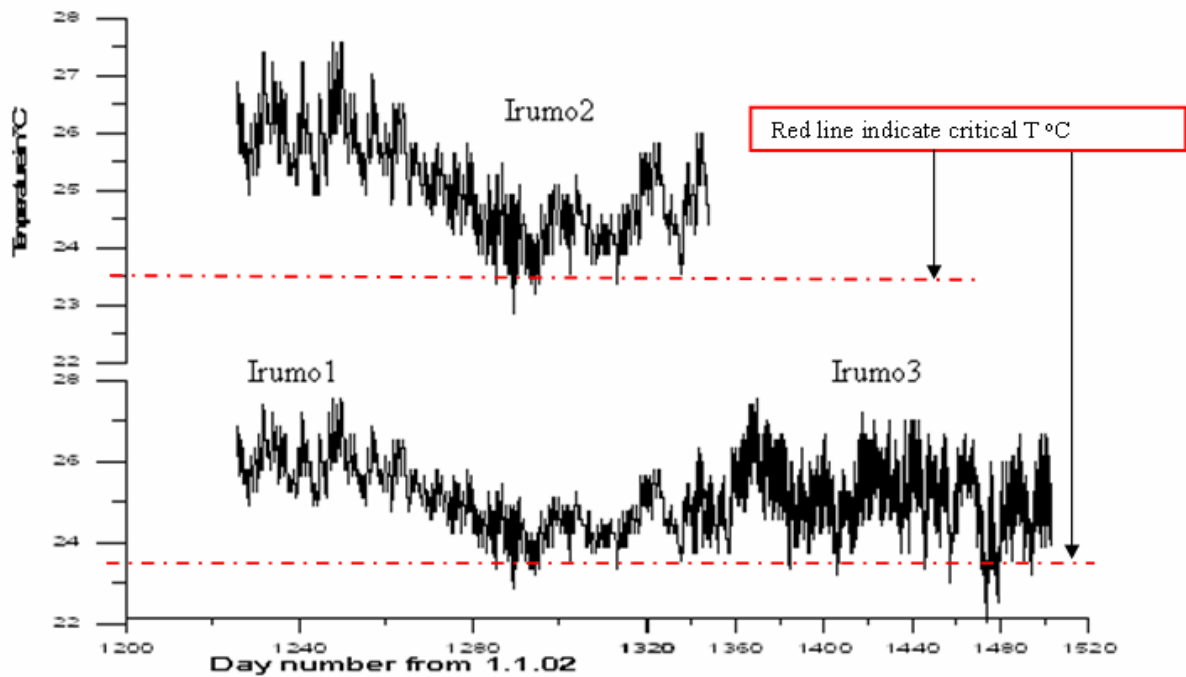


Figure 25. Temperature time series at Irumo from three data loggers. Time is measured in day number from January 1, 2002.

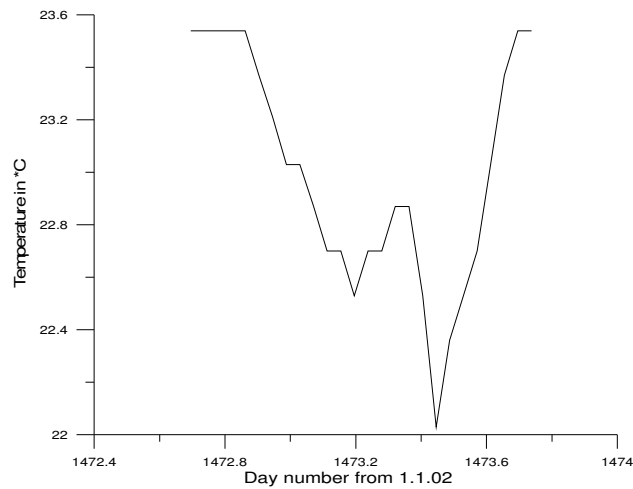


Figure 26. Coldest temperature for Irumo, 22.03°C.

The coldest temperature recorded at Irumo is 22.03 °C in Irumo3, and it occurred for one hour (Figure 26).

- Kageye area

The minimum temperature at Kageye was recorded at 23.2 °C (Figure 27). Thus the low temperature events at Kageye were not as severe as those at Irumo. Temperature between 23.2 and 23.5 °C were observed 44 times in five of the six loggers that were located here at this location at different times.

Kageye 1 and 2 were located 1 km apart and recorded data at the same time.

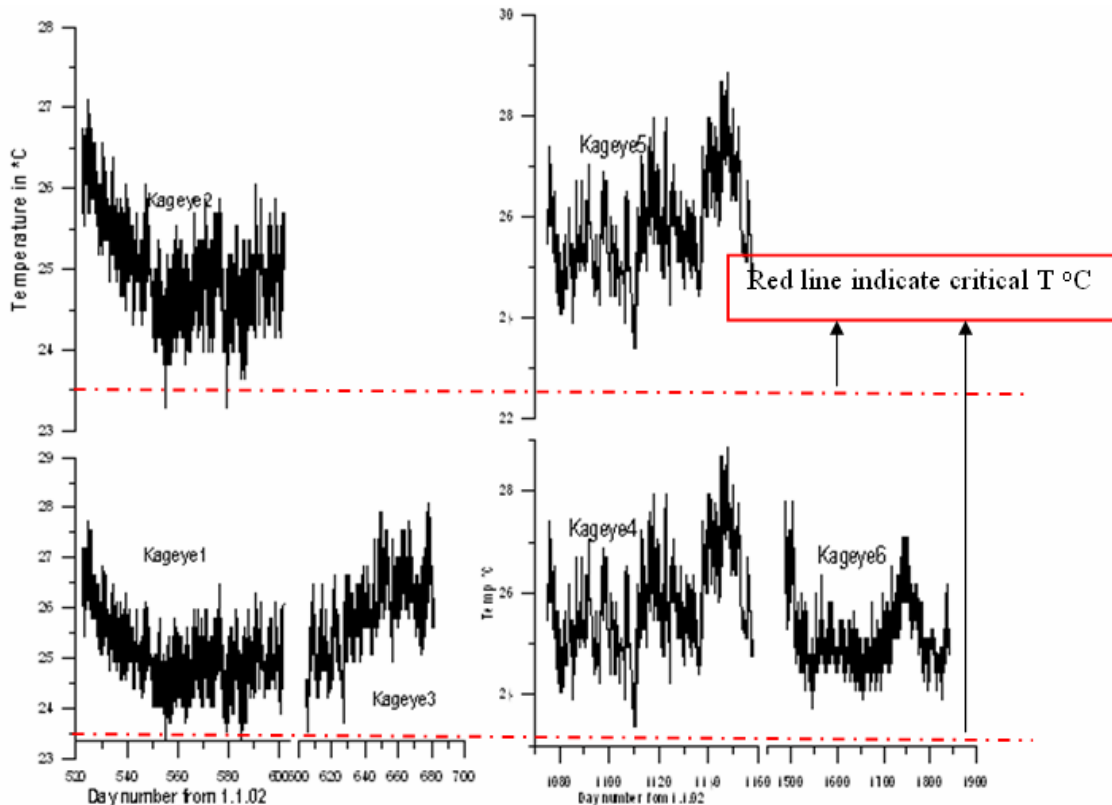


Figure 27. Temperature time series for Kageye from six data loggers.

The cold water events were not simultaneous at all sites. A cold water mass with 23.29 °C reached the Kageye1 site two hours and five minutes after it had crossed the Kageye2 site (Figure 28), which was located 1 km away. The water mass was slightly warmer by the time it reached Kageye1 (23.36°C from 23.29 at Kageye2).

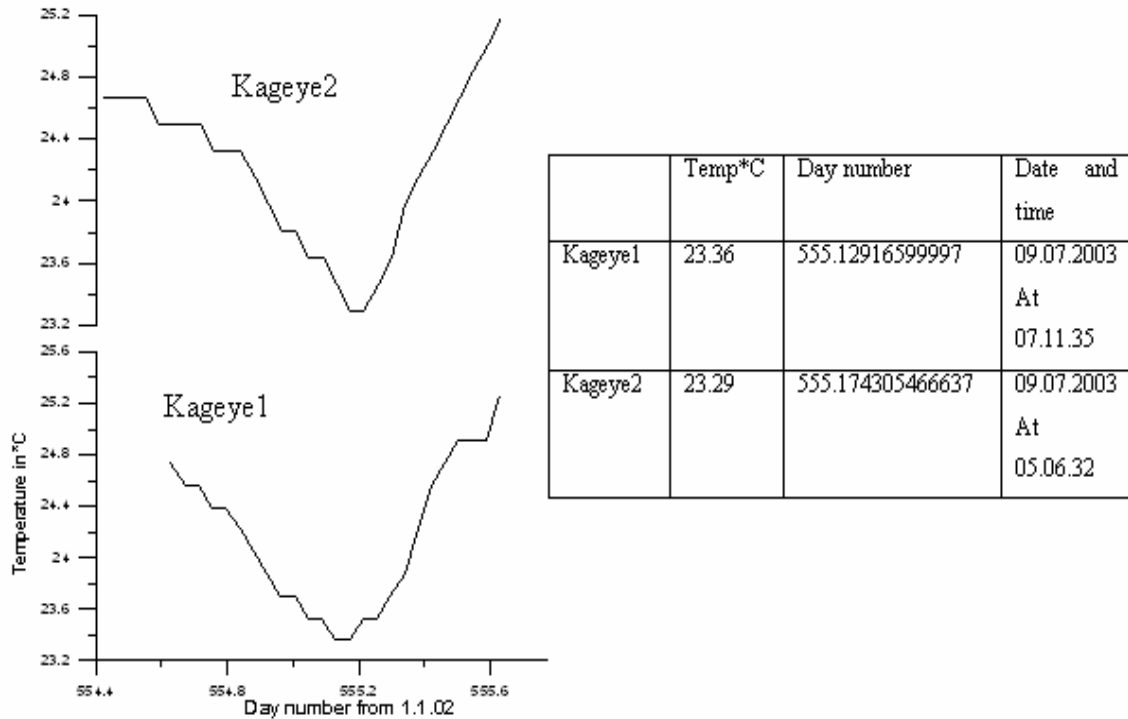


Figure 28. Overlay of Kageye1 and Kageye2 to show time delay in upwelling between the two data loggers. The cold water mass, 23.29 °C, crossed point Kageye1 two hours and five minutes after it crossed point Kageye2, which was located 1 km away

- Kamea

At Kamea 33 hours of cold water events were observed, all during Kamea1 data logging, while during Kamea2 no cold waters were observed at the surface (Figure 29).

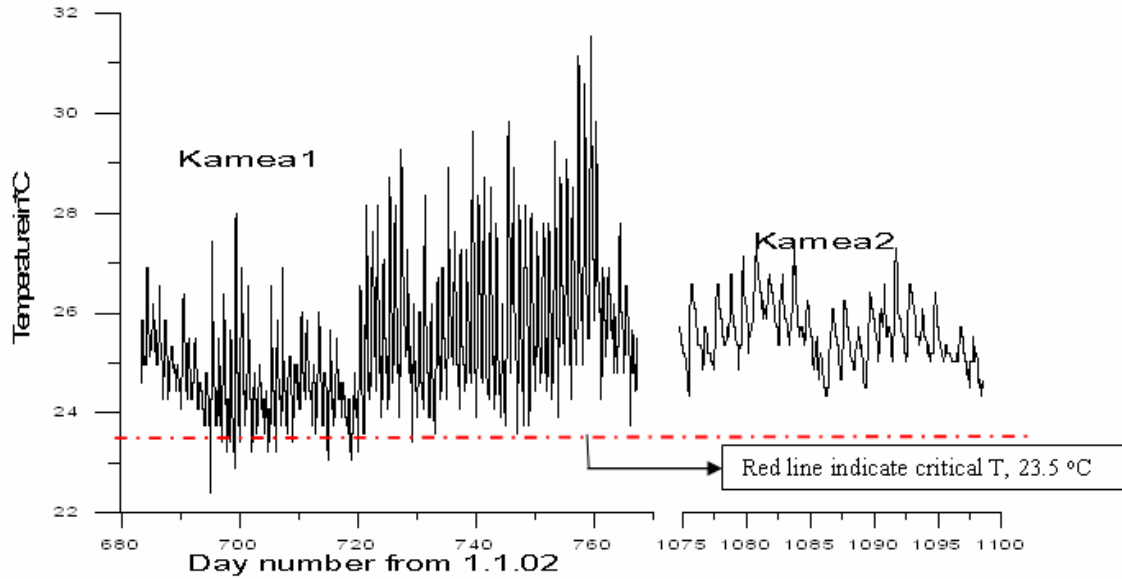


Figure 29. Temperature time series for Kamea.

The minimum temperature at Kamea was 22.39 °C (Figure 30). The setting of the upwelling of the cold water mass was observed during several hours before the water mass of 22.39 °C reached surface, the water temperature stayed low for 1 hour when the upwelled water has reached the surface. When the upwelled water downwelled again, the surface water temperature rose to higher values that are more normal for Lake Victoria surface waters.

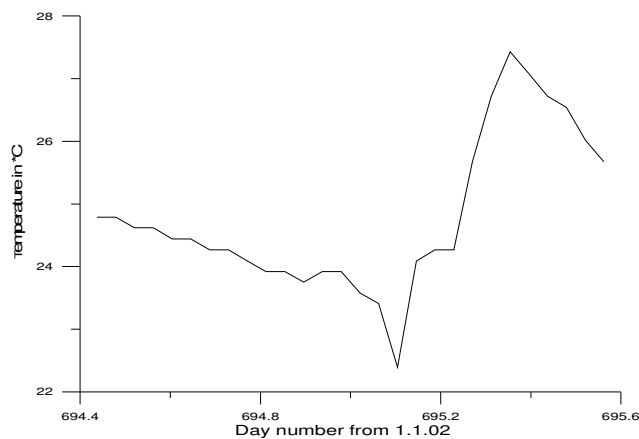


Figure 30. Cold water mass at Kamea, 22.39 °C lasting one hour

- Kasenye area

At Kasenye, the data showed frequent upwelling events to a total of 246 hours (Figure 31). During Kasenye1 (day number 611.7 to 682.6), cold water events were observed for a total of 122 hours. At one occasion, temperature as low as 21.79 °C was observed for two consecutive hours, which is the coldest water recorded in this study. This upwelling lasted for twelve hours as Figure 32 shows. During Kasenye4 however, only five occasions of isolated cold water events were observed.

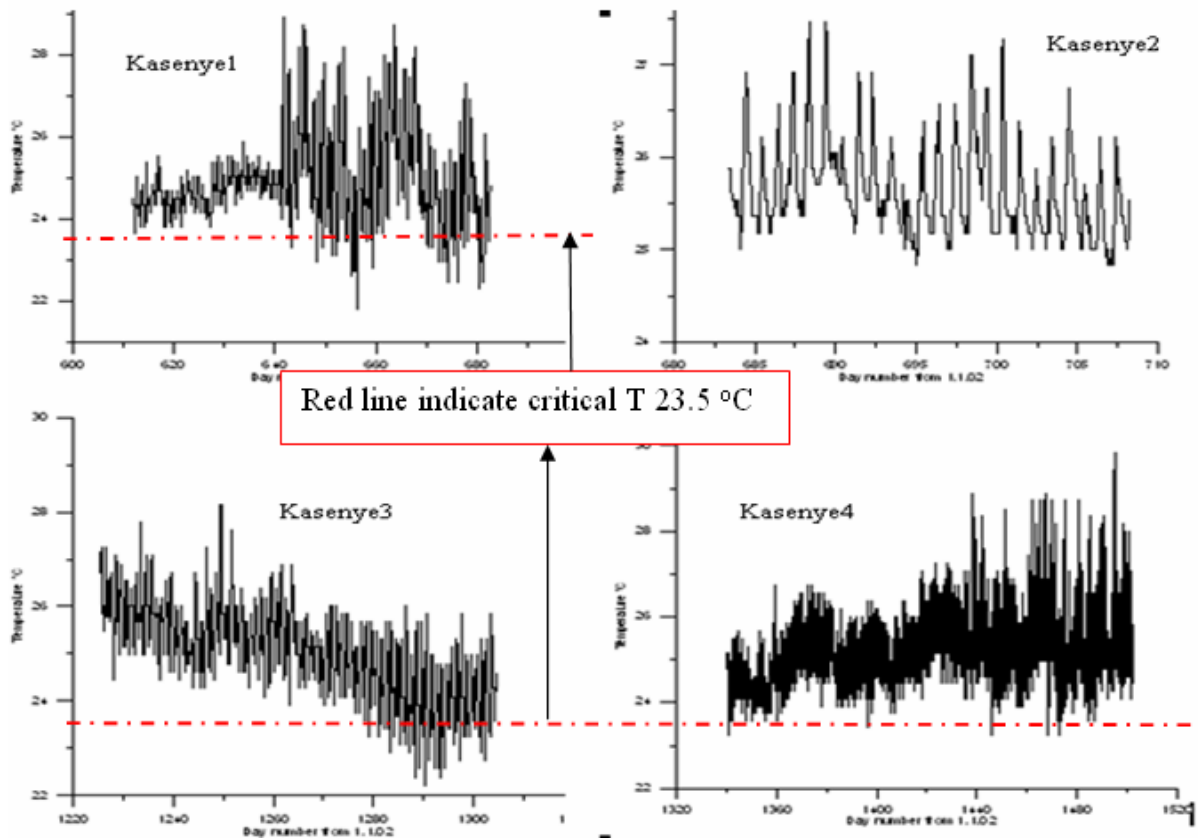


Figure 31. Temperature time series for Kasenye.

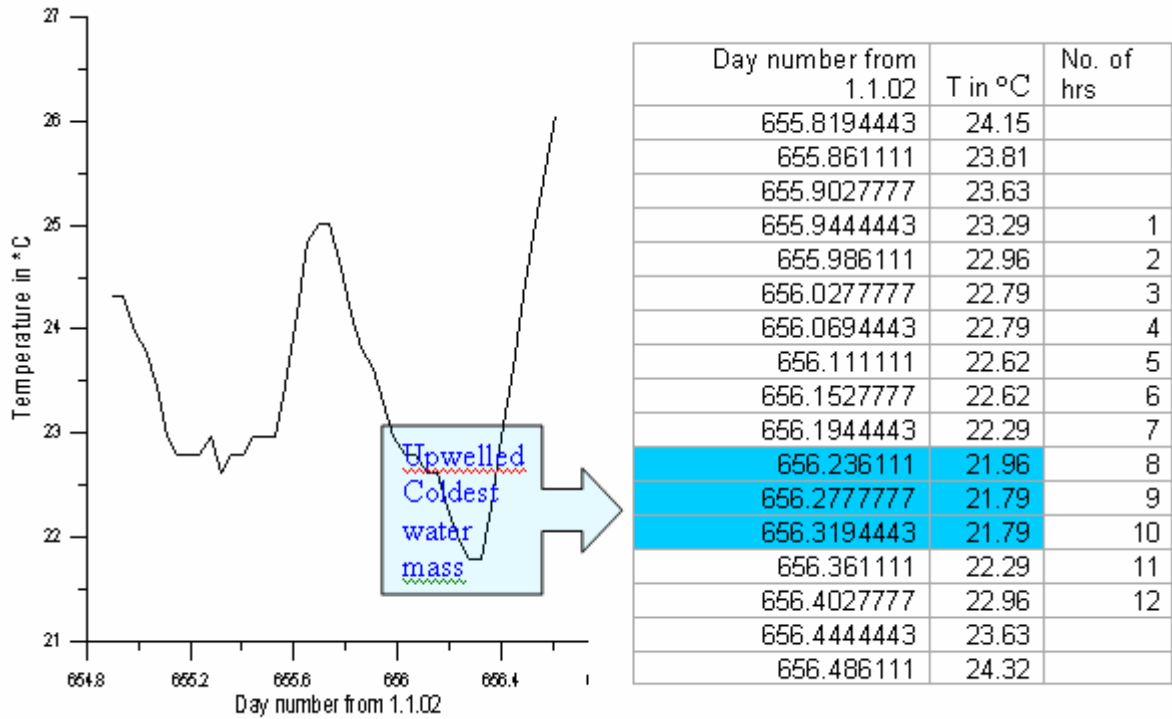


Figure 32. Coldest water mass for this study as observed at Kasenye1, 21.79 °C and lasting for 2 hours. The upwelling lasted for 12 hours.

- Lukaya

In Lukaya, cold water temperature was observed for a total of 108 hours, with the lowest value at 23.34 °C . Coldest waters occurred towards the end of the study period (Figure 33).

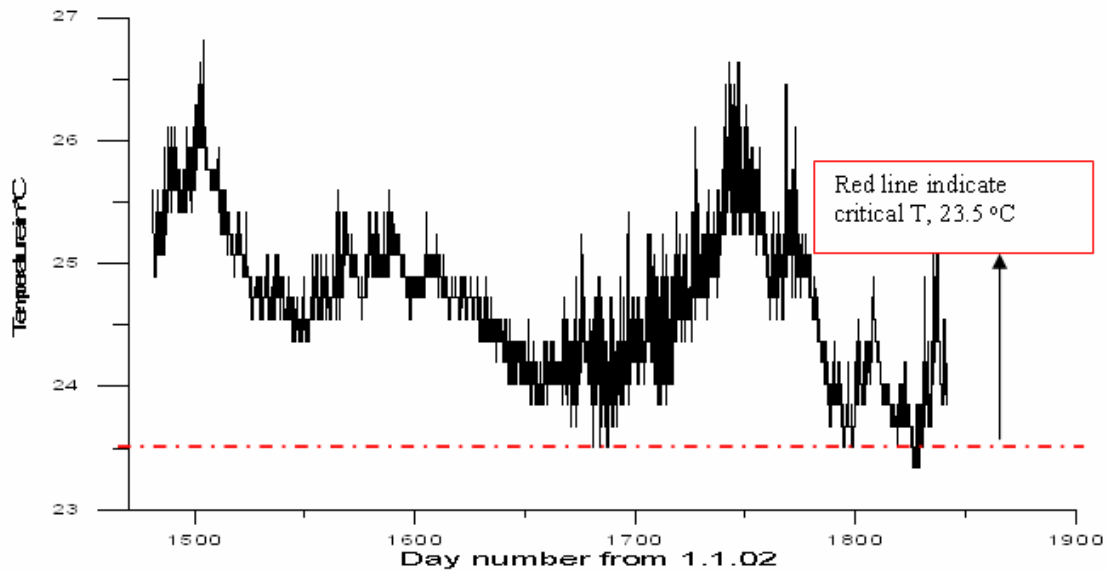


Figure 33. Temperature time series for Lukaya.

Fish kills during 2002 to 2006

During this study, at least four fish kill incidences were observed, which were on the 5th April 2002 (day number 95), 22nd December 2002 (day number 356) 14th February 2003 (day number 410) and for seven days from 22nd December to 28th December, 2005 (day numbers 1452 to 1458). The fish kills (only Nile Perch were seen), were localized, but wind drift transported the dead and dying fish to other areas of the lake and many were deposited on the shores of the surrounding islands including at Rubondo Island. In April 2002, more than 540 carcasses of dead fish were counted along Rubondo shoreline within a 7 km long strip (TANAPA, 2002). The fish kills were observed to the eastern and northern side of Rubondo, and none on the western side.

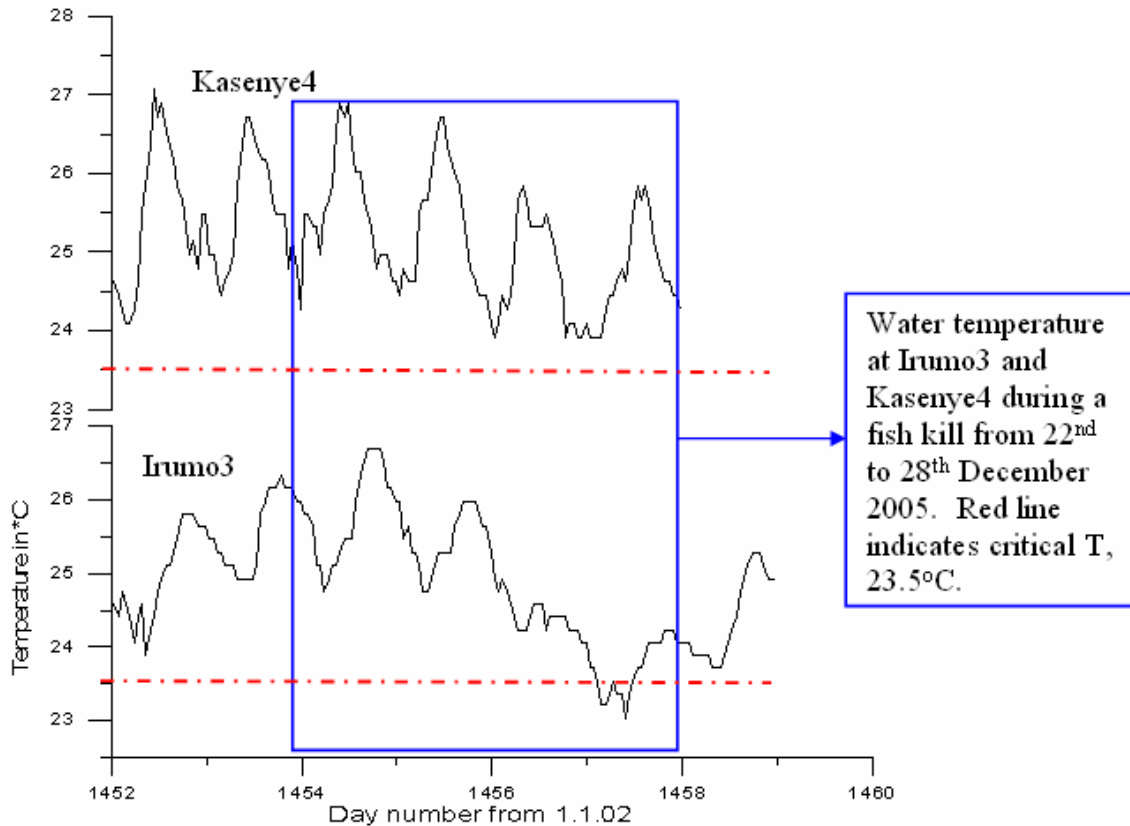


Figure 34. Water temperature during Nile Perch die offs from day number 1452 to 1458 observed near Rubondo Island.

The last witnessed episode (December 2005), took place nearer to Maisome Island, eastern of Rubondo and outside the national park borders, where we did not have a data logger. However, during these dates, the water temperatures recorded by Irumo3 and Kasenye4 data loggers which were in water during those dates, shows that the water temperature was minimum around day number 1457 (i.e. colder than on the previous and the following days (Figure 34). This observation suggests that the fish were asphyxiated by the surface intrusion of anoxic, cold, deep water upwelled to the surface. The deep water with equal or less than 23.5 C that was observed in this study has 1 ppm dissolved oxygen concentration. This water is thus hypoxic, approaching anoxia, and when internal

waves bring it to the surface this water is well able to shock, and possibly kill large fish that do not quickly react and swim to the surface to breathe. Because there was no a data logger at the exact point of the fish kills, the real temperature of the water mass upwelled and its duration can not be quantified here.

6.0 DISCUSSION

6.1 Significant role of papyrus wetlands

The nutrient input of nitrogen is probably greater than this study reports because of biological processes at the lake bottom. There is often zero dissolved oxygen at the lake bottom (Rutagemwa *et al.*, 2006^b) and this may accelerate nitrogen leaching due to anoxic bacteria denitrification from the mud on the bottom which has thousands of years of input locked in. Presently, there are no data on that rate. Phosphorus is also released in anoxic conditions.

The high amounts of nitrogen which can be removed from papyrus wetlands through denitrification confirms earlier speculations that denitrification plays a significant role in nutrient removal in Lake Victoria (Awange & Ong'ang'a, 2006). The fact that papyrus wetlands may be removing an estimated 53% (equivalent to $1.3 * 10^6$ tonnes/yr) of nitrogen annual input annually as calculated in this study, while nutrient levels in the lake remain high, signifies that the amounts of pollutants from the catchment entering the lake annually is much higher than the capacity of removal by denitrification within the same time. If there were no more inputs, the existing nitrogen concentration in the lake, can be removed through denitrification in as short a time as 1.3 years period only. As it is obvious that the amounts of pollutants from catchments may not be reduced to nil in practice, papyrus harvesting can be a complementary approach to the reduction of Lake Victoria eutrophication. Harvesting of papyrus plants for the purpose of nutrient removal requires careful timing. This is because depending on the age of the plants, only 5% to 20% of the total nutrients may be stored in harvestable parts of the plants (Wetzel, 1975).

This study estimates 19% and 26% of input removal of phosphorus and nitrogen from the lake basin respectively.

As Kanssiime & Nalubega (1999) reports, lake level drop decrease the total area available for wetland-water interaction, hence minimize the functionality of papyrus wetlands. Indeed, Awange and Ong'ang'a (2006) reports exposed shorelines in Lake Victoria in 2006 during the peak time of the lake level drop. The exposed shorelines are quickly encroached for settlements, grazing and cultivation due to the rising population around the lake basin. Studies noted that papyrus wetlands were been replaced by agricultural crops such as cocoyams (Kanssiime & Nalubega, 1999; ARCADIS, 2001; Kanssiime *et al.*, 2005), which is undesirable for optimum nutrient removal because the agricultural crops are far less efficient for nutrient removal from polluted waters.

Studies show that papyrus plants which dominate the lake's wetlands, have unique characteristics that make it the most efficient nutrient removal in the basin. These characteristics include its loose and thin mat allowing water to travel to the plant from the water column and high nutrient uptake capacity (Kanssiime & Nalubega, 1999; Mwanuzi *et al.*, 2003; Kyambadde *et al.*, 2004; Kanssiime *et al.*, 2005). Therefore, papyrus wetlands should not be replaced by other agricultural crops. Papyrus plants are high standing and most of its parts are above ground hence harvestable. Mnaya *et al.* (2007) reports a ration of 7:10 of below ground to above ground biomass of papyrus plants. In addition, papyrus plants are marketable plants; therefore they can be sustainably harvested. The plant is used to make domestic articles such as baskets, mats and roofing.

At the same time, it is necessary to reduce nutrient flows into the lake from the catchment because wetlands have a maximum nutrient assimilation capacity, which when exceeded leads to breakdown of nutrient retention (Sloey *et al.*, 1978). This means that papyrus wetlands have a limited capacity in nutrient removal.

Therefore, harvesting of above-ground biomass of papyrus plants is a practical alternative which can be considered for reducing Lake Victoria's nutrient levels.

6.2 Impacts of lake level decline

Contrary to other reported studies (Kull, 2006; Mubiru, 2006) that attribute part of the lake level drop to drought, this study finds that the water level decline from 2001 to 2006 was not caused by a drought. The findings of this study agree with the observations of Waweru (2006) who suggests that power crisis in Uganda and dam construction is depleting the lake waters. This study sees no indication from the Mwanza station rainfall that the catchments received less rain contrary to normal trend and pattern. This implies that Uganda is responsible for the lake level decline and the consequences that are related to that level decline. The consequences are, and to a varying degree, habitat modification, enhanced eutrophication and global warming due to greenhouse effect, and as clarified hereafter.

6.2.1 Habitat modification

The papyrus plants of Lake Victoria survived one year of no surface water because the peat conserved water for the rhizome. The papyrus behaved as the peat forest of Indonesia – it survives dryness by using water stored in the peat (Roach, 2004). Prolonged droughts will eventually dry the peat in the papyrus wetlands of the Lake Victoria. In Indonesia, water diversion schemes have dried the peat (Barbier, 1993) and now the Indonesians are burning the peat itself because the forest fire for land clearing has ignited the peat and the ground has been burning for several years (Roach, 2004).

Although the drying out of papyrus had no significant impact on the papyrus health, aquatic organisms, especially, fish were adversely affected. The data collected in 2000 and 2006 at the papyrus wetland in Mlaga bay in Rubondo Island, shows that the number of fish larvae recruited in the two years differs alarmingly. There is 80% decrease in the number of fish larvae recruited in 2006 from that recruited in 2000. Lake Victoria water level decrease by 2.5 m from 2000 to 2006 has resulted in an adverse loss of wetland areas where fish can breed and fish larvae hide from predators. Lung'aiya *et al.*, (2001) also reports that a decrease in water level modifies near-shore habitats and change breeding area available to many fish species. Urgent measures need to be taken to save Lake Victoria. Water withdrawal from the lake should be closely assessed and agreed measure adhered to.

The time that the wetlands of the lake lost 80% of their functionality corresponds with the time that the parallel turbine at Kiira was operating. This suggests that Uganda is

responsible for the habitat destruction that occurred during this period for the lake level decline they caused, by not adhering to the agreed curve of water withdrawal. If timely management of Lake Victoria wetlands and the lake levels is not taken seriously, it is possible for the same catastrophe that occurred in Indonesia (Barbier, 1993; Roach, 2004) to manifest itself here as well.

Mainly tilapia is caught in the light trap in papyrus wetlands as Mnaya & Wolanski (2002) found and as reported in this study, not Nile Perch. This suggests that the Nile Perch do not depend on papyrus, while the tilapia depends on the papyrus. The Nile Perch supports the commercial fisheries, while the tilapia supports the artisanal fisheries. The tilapia has lost their larval refuge, while the Nile Perch were not affected. This suggests that the future of the artisanal fisheries is at stake, while the commercial fisheries continue to flourish. The majorities of the people who live in the basin are poor, and depend on the basin resources especially fish for their livelihood. These people do not have access to the big commercial fish, the Nile Perch (Odada *et al.*, 2004; Ogotu-Ohwayo, 2005).

Research shows that the maximum *Tilapia osculenta* Graham in Lake Victoria reach a maximum age of 10 years, but at present time the level of exploitation of the stock is such that very few fish survive more than the first four years (Garrod, 2004). This implies that, with continued reduced water levels, in 5 years the population of local fish which supports the artisanal fisheries may be wiped out from the lake.

6.2.2 Enhanced eutrophication of the lake

Since papyrus left out of water for long enough time (more than one year) dries out and dies, the nutrients in the dry and dead papyrus material are flushed to the lake (Gaudet, 1977), this study estimated the eutrophication impact which Lake Victoria wetlands are capable of causing to the lake if they all dry out. Using the average biomass of papyrus in Mnaya *et al.*, (2007), (below ground biomass average is $6.67 * 10^3$ tonnes/km²/yr and above ground biomass average is $9.58 * 10^3$ tonnes/km²/yr, hence, total biomass of papyrus in one km² = $1.626 * 10^4$ tonnes per year). Below ground biomass/above ground biomass = $6.67 * 10^3 / 9.58 * 10^3 = 0.7$. In the entire lake wetland basin the amount of nitrogen in above-ground biomass is equivalent to $0.7 * 6.3 * 10^5$ tonneN * $1.02 * 10^5$ tonneP = $4.4982 * 10^{10}$ tonnesN.

If this entire nutrient ended up in the lake, this is equivalent to $4.4982 * 10^{10}$ tonnesN/N input to the lake = $4.4982 * 10^{10}$ tonneN / $2.43 * 10^6$ tonne N/year = $1.85 * 10^4 = 18,500$ years of nutrient inputs to the lake.

In accordance with the common practice in East Africa, papyrus wetlands if dried out can be burnt for land clearance for cultivation, access to the lake, settlements, and removal of pest animals (Awange & Ong'ang'a, 2006). Nitrogen released from biomass burning (Levine, 1999) contributes further to eutrophication because it leaches out in the next rain and by run-off into the lake.

By using the ratio for carbon to nitrogen, which is reported for Lake Naivasha to be 20:1 (Boar *et al.*, 1999), and the amount of particulate carbon from burning the 10,235.17 km² of papyrus wetlands = $8.658 * 10^6$ tonnes particulate carbon, the resultant nitrogen from burned biomass was estimated to be $4.1 * 10^5$ tonnes. (Particulate carbon is 13% of the burned carbon, after Lobert *et al.*, 2001 and as calculated in the next section).

This nitrogen is equivalent to 17% of the annual input (i.e. 17 years) of nitrogen into the lake (+ global warming); against 18,500 years of nitrogen input added in one year if there is no burning involved. In any case, even in the best case scenario, these amounts are most significant and can measurably exacerbate eutrophication of Lake Victoria. Thus if Uganda resumes overdrawing water from the lake (for hydroelectricity demand as have happened from 2004 to 2006) and dry out the papyrus of Lake Victoria long enough that it dries out and this is burned (the usual land-use practice in East Africa as Awange and Ong'ang'a, 2006 reports), the resultant eutrophication is massive.

6.2.3 Greenhouse effect due to wetlands burning

Increase of the carbon dioxide gas in the atmosphere is primarily from anthropogenic activities such as biomass burning, fossil fuels burning, clearing trees and ploughing the soil. If Lake Victoria wetlands dry out, die, and are burned, there are short and long term impacts on the environment. Burnt wetlands means hundreds of years of worth of stored carbon dioxide lost into the atmosphere in a matter of hours. Burning will also permanently destroy an important sink for CO₂ if the vegetation is not replaced (NASA).

The amounts of carbon dioxide and hence greenhouse effect and global warming possible from the lake's wetlands is quantified in this study.

Biomass material is mainly carbon (Levine, 1999) and it contains 40% carbon by weight (Bowen, 1979). Biomass burning results into CO₂ and water vapour under ideal conditions whereby complete combustion occurs. That is; CH₂O + O₂ to get CO₂ + H₂O whereby CH₂O represents average biomass material.

Hot, dry, fires with a good supply of oxygen produce mostly CO₂ with little CO, CH₄, and NMHCs (non-methane hydrocarbons). This is because the flaming phase of the fire approximated complete combustion resulting into mostly CO₂ around 90% of combustion product (Levine, 1999), while the smoldering phase approximates incomplete combustion, resulting into production of CO, CH₄, NMHCs and carbon ash/particulate carbon.

The total mass of the carbon species (CO₂ + CO + CH₄ + NMHCs + particulate carbon) M(C) is related to the mass of the burned biomass (M) by $M(C) = F * M$, where F= mass fraction of carbon in the biomass material (40% by weight).

Using the values in Mnaya *et al.*, (2007), Average biomass of roots = 2.2548 kg/m², average biomass of rhizomes = 4.4144 kg/m², average biomass of culm = 5.9109 kg/m², average biomass of umbel = 2.9233 kg/m² and average biomass of dead above ground biomass = 0.7471 kg/m². Thus, average below ground biomass of papyrus = 6.67 kg/m²

and average above ground biomass of papyrus = 9.58 kg/m². The sum of below ground and above ground papyrus biomass = 16.26 kg/m².

= 1.626 * 10⁷ kg/km² and 1.66 * 10⁸ tonnes in all Lake Victoria basin wetlands.

To convert into mass of carbon (Bowen, 1979's value of carbon by weight in biomass material, 40%), total weight of carbon is then obtained by multiplying the carbon weight fraction to the total mass of biomass material in the basin, $M(C) = F * M$, whereby, $M = 1.66 * 10^8$ tonnes, and $F = 0.4$ (Bowen, 1979). Hence, the amount of carbon in the entire basin's papyrus wetland area is $6.66 * 10^7$ tonnes of carbon.

Assuming that the average particulate carbon/carbon ash is 13% of the carbon species produced in the combustion (Lobert *et al.*, 2001), total contribution of carbon due to burning all the lake's papyrus wetlands is

$$\begin{aligned} &= 0.13 M (C) \\ &= 0.13 * 6.66 * 10^7 \text{ tonnes of carbon} = 8.658 * 10^6 \text{ tonnes particulate} \\ &\text{carbon/carbon ash.} \end{aligned}$$

The rest, (87%), is carbon material (CO₂, CO, CH₄ and NMHCs), of which 90% is CO₂ (Levine, 1999) which is released in the atmosphere. Therefore, the gaseous material released to the atmosphere as carbon dioxide is $0.87 * 6.66 * 10^7$ tonnes of carbon * 0.9, which is $5.2 * 10^7$ tonnes of carbon dioxide gas.

The Southeast Asia fires burnt both above-ground vegetation and below-ground peat, a form of coal (NASA). Researchers discovered that bacteria in the soil enhance

production of the greenhouse gas nitrous oxide after biomass burning because it converted ammonium found in the fire ashes to nitric acid and nitrous oxide. The amount of these gases produced by bacteria after a fire may surpass the amount released during biomass burning (NASA).

Except for Rubondo Island which is full protected as a national park in Tanzania, the open-access status of the rest of the wetlands in Lake Victoria makes them rather vulnerable to bushfires. It is important that more wetlands obtain full protection from human intervention and good policy put in place for governing use or controlled harvest of the remaining wetlands to save the environment from short and long term impacts from biomass burning.

Generally, monitoring of the lake ecosystem especially the lake levels is very important. However, more focus should focus on management plans so as to maintain the lake levels without which we can not have Lake Victoria and its ecosystem, which includes not only the water but also the wetlands, the fish and the people.

6.3 Role of upwelling

6.3.1 Applicability of Wedderburn number to Lake Victoria

There is a daily strong land-lake breeze in Lake Victoria. When this occurs, the mean wind over the lake is changed and the internal wave is dampened on the side of the lake where the daily land-lake breeze opposes the mean wind. These winds as measured in the Uganda part of the lake rarely show any consistency in speed and direction from point

to point as Figure 35 shows (COWI, 2002). This study conducted in the Ugandan side of the lake is a representative of the entire lake situation. The lake-land breeze makes it much harder for the upwelling to occur, and difficult to quantify in absence of detailed lake-land breeze data, and daily data on the global winds over the lake, which was not available for this study, rather than monthly average wind data due to the fact the Wedderburn number utilizes daily wind data and not monthly data. Generally, the findings of this study indicate that the frequency of upwelling will be much less than without the land-lake breeze. Table 7 shows the resulting upwelling frequency by using wind speed data at Musoma airport and the Wedderburn number. Upwelling would occur at the end of each of the sixth days as indicated enclosed in boxes in the Table 7. Therefore this finding can not be used to represent the real situation, but as a representation of the needed criteria for upwelling as determined by this study.

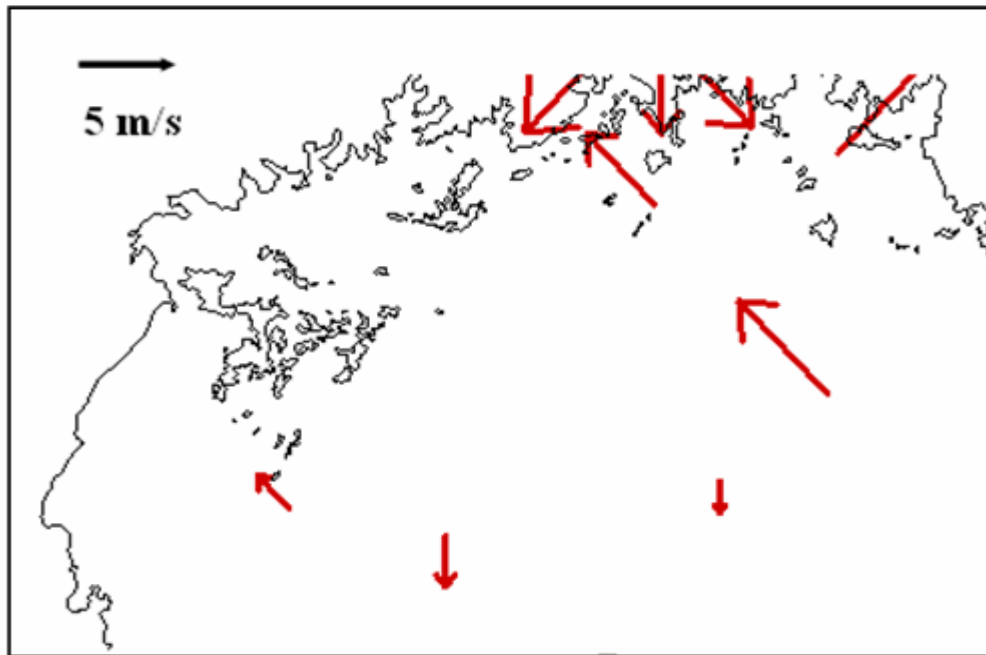


Figure 35. Wind speed and direction at Ugandan lake monitoring stations in February 2001. Winds rarely show any consistency in speed and direction from station to station (Source; COWI, 2002).

Table 7. Example of upwell frequency as quantified by using Wedderburn number and monthly average data at Musoma airport

MONTHLY MEAN WIND SPEED AT 0300, 0600, AND 1200 GMT AT MUSOMA AIRPORT, IN LAKE VICTORIA CATCHMENT AREA													
Wind speed in m/sec													
Year	Time	Jan	Feb	March	April	May	June	July	Aug	Sept	Oct	Nov	Dec
2001	0300	0	0	0	0	0	0	0.514	0	0	0.51	0	0
	0600	1.028	1.542	1.028	3.084	1.028	2.57	3.084	2.57	2.056	3.08	2.57	2.57
	1200	4.626	5.654	4.626	4.626	2.57	0.514	5.14	5.654	6.682	5.65	5.654	5.654
2002	0300	0	1.028	0.514	0.514	0	0.514	0.514	1.028	0.514	0.51	0	0
	0600	1.542	2.57	1.542	2.056	2.57	2.57	3.084	3.084	4.112	2.57	1.542	4.112
	1200	5.14	6.682	6.168	4.626	4.626	5.14	6.168	6.168	7.196	6.17	5.14	5.654
2003	0300	0.514	0.514	1.028	0.514	0.514	1.028	0	0	0.514	0	0	0
	0600	2.056	2.056	2.056	1.028	2.056	2.57	3.084	2.57	3.084	3.08	2.57	1.542
	1200	5.14	6.168	6.168	5.14	4.626	4.112	4.626	5.654	6.682	7.71	6.682	5.654
2004	0300	0.514	0	0	0	0	0	2.056	0	0	1.54	0	0
	0600	1.542	2.056	1.028	3.598	2.056	1.542	2.056	3.084	3.598	1.54	2.056	2.57
	1200	6.168	5.14	5.654	5.14	4.112	4.112	5.14	7.196	6.168	8.22	7.196	6.168

Upwelling in the open waters of Lake Victoria is not frequent because of the presence of a land-lake breeze that opposes the main global winds blowing over the lake. Without these local winds, 6 days of continuous wind of at least 5 m/s speed should cause an upwelling. Upwelling would then be frequent phenomena save for these land-lake breezes, because the maximum wind over the lake is up to 15 m/s (COWI, 2002). Upwelling would then occur whenever the land-lake breeze is absent and the wind speed

is between 5 m/s to 15 m/s for 6 or more consecutive days. Since the dominant wind is westward, upwelling occurs on the east side of the lake because there is downwelling at the west side of the lake. This could be a further explanation why the waters at the southern side of the lake are generally colder than the northern waters as reported by Rutagemwa *et al.*, (2006). Land-lake breeze (winds on the lake and around the shores) has not been studied yet and this study can not quantify the open lake upwelling further. Therefore, the applicability of the Wedderburn number for Lake Victoria depends on availability of main/global wind speed over the lake on daily resolution, detailed data on the direction, speed and pattern of the lake-land breeze and understanding of their interaction with the main winds over the lake.

6.3.2 Cold waters at the surface around Rubondo: small islands upwelling

Upwelling at local scales, especially around bays, headlands and islands are caused by topographic generated internal waves and not wind-driven internal waves. The difference is huge: the wind-driven internal wave is basin-scale (it would involve the whole upwind side of the lake i.e. 100 km). The topographic internal wave is at the scale of an island or a local bay, hence a few kilometers.

The temperature data from Rubondo Island shows that local upwelling is an uncommon (occurring only 1.3% of the time on the average) but not a rare phenomenon. It occurs for more than 200 hours in a year at one location. Table 6 show a summary of the upwelling which occurred during this study.

The data shows that upwelling in the island areas of Lake Victoria is a local phenomena. Upwelling did not occur at all areas at the same time. As an example, although the data was collected at the same time, Kasenye1 and Kageye3 data do not show similarity in the temperature fluctuations (Figure 36). Irumo3 and Kasenye4, during the fish kill that occurred on the eastern of Rubondo Island, show no relationship with each other (Figure 34).

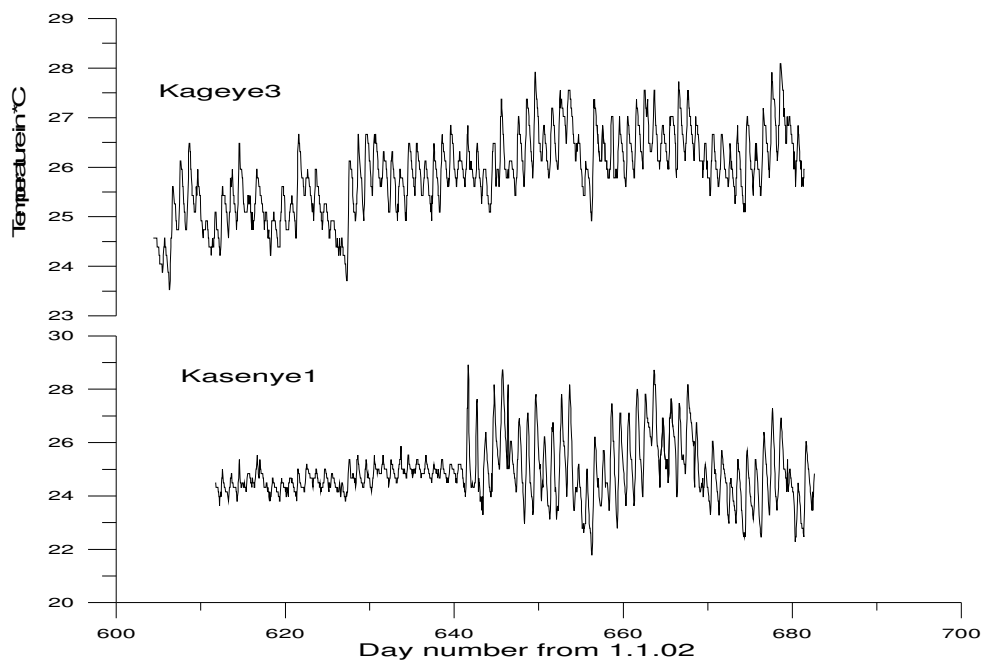


Figure 36. Differences in the upwelling pattern between Kasenye1 and Kageye3

The delay of observation of the same cold water mass between loggers about 1 km apart indicates a propagating internal wave. The wave is coherent over short distances less than 1 km. The wave is not coherent over scales greater than 5 km. This implies that the internal wave is local and not lake-wide. This suggests that the wave is generated by the interaction of wind-driven currents with the bathymetry principally near headlands, by analogy with similar observations at oceanic islands (Wolanski *et al.*, 2004).

This island-generated patchiness makes it difficult to characterize the upwelling dynamics in the southwest region of Lake Victoria where islands are scattered widely. Some sites have frequent local upwelling, such as at Irumo. This area is only 6 km away from the 48 m deep point, which is the deepest point in the southwestern side or one fourth of the lake, as indicated by the bathymetric map of the lake by Rutagemwa *et al.*, (2006^a) and is exposed to the open lake depending on wind direction. Irumo therefore showed many events of cold waters below 23.5°C, implying frequent upwelling events. The three data loggers were suspended at a depth between 4 m and 6 m. The Kasenye data loggers likewise, which captured the lowest water temperature of this study, show many hours of upwelling, although it was suspended at a depth of only 3 m, compared to Lukaya for example, which was suspended in 10 m. Kasenye, to the north of Rubondo Island, faces the open lake waters. Wind-driven currents and surface waves are largest there because of the long fetch of exposed water (Myanza *et al.*, 2006), which can facilitate upwelling when the currents are steered by a headland. Finally, it is important to note the implication of choosing the observation on the lake surface of cold waters of 23.5 °C temperature as the critical temperature to determine when there is an upwelling because it was measured at 60 m depth by past researchers. Use of a slightly higher critical value, such as 23.94 °C, which is the average minimum deep water temperature measured by Rutagemwa *et al.* (2006^b) would give different results. For example, if this criterion is applied to Kamea1 data logger, we get 152 more cold water hours over the 33 hours reported in this study. Annex 3 shows the actual data from Kamea1 data logger. A different study of the recorded water temperature of this study is recommended so as to

understand in more detail the patterns showed including the daily and hourly peaks as shown in most data loggers such as shown in Figure 36.

Upwelling enhances eutrophication of Lake Victoria

Upwellings are not uncommon in southwestern waters of Lake Victoria. Upwelling appears to be caused by internal waves generated by wind-driven currents interacting with the salient bathymetry around islands. Even when the internal wave does not reach the surface, the thermocline rises and comes close to the surface. This tilting of the thermocline brings deep, nutrient-rich, anoxic waters close to the surface within the reach of wind-mixing. Thus some nutrients become available for productivity in the biological active surface layer of the lake water. Such a process is beneficial in oligotrophic lakes where the surface layer is depleted of nutrients, such as Lake Villarria in central Chile (Meruane *et al.*, 2007) and Lake Tanganyika (Naithani *et al.*, 2007). But for Lake Victoria, which is already threatened by severe eutrophication problem, this upwelling exacerbates the problem because it recycles back to the surface layer the nutrients that were lost from that surface layer and stored in the bottom layer.

COWI (2002), reports that every year 2,276,600 N tonnes and 502,900 P tonnes are released from the bottom sediments in Lake Victoria into the bottom layer. This bottom layer is anoxic (Rutagemwa *et al.*, 2006). This nutrient is 'harmless' to the lake as long as it remains in the bottom layer. However, some of that nutrient is upwelled by internal waves into surface waters and this process exacerbates the eutrophication of the lake. Through improved agricultural practices, treatment of industrial effluents and above all,

conservation and maintenance of papyrus wetlands, this amount can be reduced to desirable amounts.

This study recommends that water temperature data should be collected at strategic points, including in deeper waters, for several years, while at the same time recording fish kills, to better refine the relationship between upwelling, wind and fish kills. As the lake eutrophication increases due to poor land-use in the catchment area, the anoxic layer will continue rising towards the surface, from > 50 m in 1961 to as low as 35 m in 1990, and 20-30 m in 2005 (Hecky *et al.*, 1994, 1996; Kaufman, 1992; Lehman *et al.*, 1998; Mugidde, 1993; Ochumba & Kibaara, 1989; Reinthal & Kling, 1994; World Bank, 1996; Rutagemwa *et al* 2006). As it rises to the surface, the internal waves will more frequently upwell nutrients to the surface waters, thus accelerating the eutrophication problem and the degradation of the lake.

7.0 CONCLUSIONS

Selective and rotating harvesting of above ground biomass of Lake Victoria papyrus wetlands can help to combat eutrophication of the lake. Quantitatively, removing of all above ground biomass of papyrus for 5.2 years consecutively will remove all excess nitrogen and phosphorus from the basin. This knowledge can be used to plan sustainable utilization of the papyrus plants to combat eutrophication. On the other hand, denitrification alone accounts for most removal of nitrogen from the basin (53% of input removed in one year). With this understanding, more effort should focus on the conservation of the wetlands so as to boost up this functionality. All wetland areas should be under state protection so as to minimize abuse.

This study confirms that island-driven upwelling by internal waves is very patchy for both lakes and ocean. This study found that internal waves occasionally upwell deepest lake water all the way to the surface, and frequently to the near vicinity of the surface. This study found the lowest minimum temperature value ever reported by past researchers. This might explain fish kills in southwestern Lake Victoria. More research is needed to refine this relationship. For upwelling to occur in the main lake, two conditions seem to be important, that is, a wind speed in the same direction of at least 5 m/s magnitude, and absence of the land-lake breeze which opposes the mean wind over the lake. This land-lake breeze may be the saviour of the lake by preventing frequent upwelling of cold anoxic nutrient rich bottom waters, which could otherwise occur in Lake Victoria.

In two years, from 2004 to 2006, aquatic habitat destruction accounted up to 80% loss of tilapia habitats. The artisanal fishermen who depend on tilapia will become poorer (in capital and in health due to decreased protein availability) if water level decline continue because their main target, the tilapia, will disappear from the lake. Furthermore, dried out papyrus wetlands can release nutrients equivalent to between 17 and 18,500 years in one year of annual input of nutrients depending on how the nutrients end up into the lake, which are alarmingly high amounts. Through burning of dried out papyrus wetlands, carbon dioxide released to the atmosphere is $5.2 * 10^7$ tonnes.

The findings in this study confirm that the future of Lake Victoria, the basin and the people, is highly related to the future of the status of its papyrus wetlands.

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ANNEXES

Annex 1. Calculation of Mean Catchment Rainfall for Lake Victoria for the year 2001 to 2006 by using mean catchment rainfall data from 1986 to 2000 and measured rainfall at Mwanza station from 1986 to 2006.

Year	Mean Catchment Rainfall (mm)	Measured Rainfall at Mwanza (mm)		RMSE	Mean Catchment Rainfall (mm) based on Mwanza data
1986	1,635	1,012.90	387,008.41	622.1	1,619.10
1987	1,822	1,156.50	442,890.25	644.1656	1,762.70
1988	2,036	1,475.00	314,721.00	617.6892	2,081.20
1989	1,590	1,217.70	138,607.29	566.398	1,823.90
1990	1,858	1,416.70	194,745.69	543.6861	2,022.90
1991	1,833	1,130.00	494,209.00	573.321	1,736.20
1992	1,511	792.60	516,098.56	596.2119	1,398.80
1993	1,308	876.20	186,451.24	578.2226	1,482.40
1994	1,875	1,259.60	378,717.16	582.4707	1,865.80
1995	1,870	1,212.10	432,832.41	590.4474	1,818.30
1996	1,648	870.10	605,128.41	609.874	1,476.30
1997	2,255	1,411.10	712,167.21	632.6911	2,017.30
1998	1,778	999.70	605,750.89	645.0598	1,605.90
1999	1,644	1,036.20	369,420.84	642.47	1,642.40
2000	1,395	671.00	524,176.00	648.2245	1,277.20
2001	1,756	1,150.10			1,756.30
2002	1,888	1,282.00			1,888.20
2003	1,484	878.20			1,484.40
2004	1,823	1,217.10			1,823.30
2005	1,776	1,169.50			1,775.70
2006	2,033	1,427.20			2,033.40
From 2001 to 2006, is the calculated mean catchment rainfall.					

Annex 2. Calculation of Lake Victoria's water level for 2000 to 2006 by using Yin & Nicholson formula

Calculation of estimated Inflow, Discharge and Lake Level for Lake Victoria											
Year	Mean Catchment Rainfall (mm)	Observed Lake Level	Average yearly Jinja lake level	Average Jinja level for end of year	Inflow I (Yin formula)	Natural discharge from Jinja	Delta H (Yin's formula)=annual change in water level (mm)	Predicted Lake level in mm (Yin's formula)	Assumed inflow - outflow past 2000	Predicted Delta H (Yin before 2000; assumed I-D after 2000)	What lake level should have been
1985	1,734	1,134.40	11,540.00					11540			11540
1986	1,635	1,134.34	11,480.00	11,510.00	258.54	423.16	-66.6224	11,473.38	-164.62	-66.6224	11473.3776
1987	1,822	1,134.50	11,640.00	11,560.00	254.48	424.9	114.5812	11,587.96	-170.42	114.5812	11587.9588
1988	2,036	1,134.88	12,020.00	11,830.00	327.75	477.16	349.5818	11,937.54	-149.42	349.5818	11937.5406
1989	1,590	1,134.70	11,840.00	11,930.00	342.17	524.94	-129.7688	11,807.77	-182.77	-129.7688	11807.7718
1990	1,858	1,134.85	11,990.00	11,915.00	264.11	506.87	78.2403	11,886.01	-242.76	78.2403	11886.0121
1991	1,833	1,134.95	12,090.00	12,040.00	328.15	537.8	86.3561	11,972.37	-209.64	86.3561	11972.3682
1992	1,511	1,134.67	11,810.00	11,950.00	290.35	533.96	-269.6107	11,702.76	-243.61	-269.6107	11702.7575
1993	1,308	1,134.20	11,340.00	11,575.00	182.82	456.25	-502.4314	11,200.33	-273.43	-502.4314	11200.3261
1994	1,875	1,134.44	11,580.00	11,460.00	180.61	398.39	120.221	11,320.55	-217.78	120.221	11320.5471
1995	1,870	1,134.64	11,780.00	11,680.00	318.3	450.69	200.6106	11,521.16	-132.39	200.6106	11521.1577
1996	1,648	1,134.26	11,400.00	11,590.00	200.7	455.71	-144.0092	11,377.15	-255.01	-144.0092	11377.1485
1997	2,255	1,134.56	11,700.00	11,550.00	181.72	416.4	483.3198	11,860.47	-234.68	483.3198	11860.4683
1998	1,778	1,135.26	12,400.00	12,050.00	606.37	513.52	333.856	12,194.32	92.86	333.856	12194.3243
1999	1,644	1,134.86	12,000.00	12,200.00	230.65	596.69	-259.0432	11,935.28	-366.04	-259.0432	11935.2811
2000	1,395	1,132.93	10,073.04	11,036.52	-279.61	397.11			-300	-442	11493.2811
2001	1,756	1,133.05	10,192.26	10,132.65	76.38	98.89			-200	19.3021	11512.58322
2002	1,888	1,133.06	10,196.77	10,194.52	95.33	118.17			-150	201.2021	11713.78534
2003	1,484	1,132.90	10,041.61	10,119.19	179.59	107.95			-300	-352.5979	11361.18746
2004	1,823	1,132.42	9,555.81	9,798.71	-126.17	48.99			-150	136.3021	11497.48958
2005	1,776	1,132.01	9,152.26	9,354.03	-53.72	-56.78			-200	38.7021	11536.1917
2006	2,033	1,132.17	9,314.52	9,233.39	19.29	-109.56			-150	346.4021	11882.59381

Annex 3. Temperature data for Kamea1 site.

	Day number			Day number			Day number			Day number	
S/N	from 1.1.02	T °C	S/N	from 1.1.02	T °C	S/N	from 1.1.02	T °C	S/N	from 1.1.02	T °C
1	683.395833	24.6	47	685.3124997	26	93	687.2291663	25	139	689.145833	24.8
2	683.4374997	25.7	48	685.3541663	26.2	94	687.270833	25.1	140	689.1874997	24.8
3	683.4791663	25.7	49	685.395833	26	95	687.3124997	25.1	141	689.2291663	24.6
4	683.520833	25.7	50	685.4374997	25.8	96	687.3541663	25.3	142	689.270833	24.4
5	683.5624997	25.8	51	685.4791663	25.8	97	687.395833	25.5	143	689.3124997	24.8
6	683.6041663	25.8	52	685.520833	25.8	98	687.4374997	25.7	144	689.3541663	24.8
7	683.645833	25.7	53	685.5624997	25.8	99	687.4791663	25.8	145	689.395833	24.8
8	683.6874997	25.5	54	685.6041663	25.8	100	687.520833	25.8	146	689.4374997	25
9	683.7291663	25	55	685.645833	25.8	101	687.5624997	25.8	147	689.4791663	25
10	683.770833	25.3	56	685.6874997	25.7	102	687.6041663	25.7	148	689.520833	25
11	683.8124997	25.5	57	685.7291663	25.5	103	687.645833	25.7	149	689.5624997	25
12	683.8541663	25.1	58	685.770833	25.5	104	687.6874997	25.5	150	689.6041663	25
13	683.895833	25.1	59	685.8124997	25	105	687.7291663	25.3	151	689.645833	24.8
14	683.9374997	25.1	60	685.8541663	25.1	106	687.770833	25	152	689.6874997	24.6
15	683.9791663	25.1	61	685.895833	25.1	107	687.8124997	24.8	153	689.7291663	24.6
16	684.020833	25	62	685.9374997	25.3	108	687.8541663	25.1	154	689.770833	24.6
17	684.0624997	25.1	63	685.9791663	25.7	109	687.895833	24.6	155	689.8124997	24.6
18	684.1041663	25.1	64	686.020833	25.5	110	687.9374997	24.8	156	689.8541663	24.6
19	684.145833	25	65	686.0624997	25.5	111	687.9791663	24.3	157	689.895833	24.4
20	684.1874997	25.3	66	686.1041663	25.1	112	688.020833	24.6	158	689.9374997	24.6
21	684.2291663	25.5	67	686.145833	25	113	688.0624997	24.4	159	689.9791663	24.3
22	684.270833	26	68	686.1874997	25	114	688.1041663	24.8	160	690.020833	24.1
23	684.3124997	26.5	69	686.2291663	25	115	688.145833	24.4	161	690.0624997	24.4
24	684.3541663	26.7	70	686.270833	25.1	116	688.1874997	25	162	690.1041663	24.4
25	684.395833	26.9	71	686.3124997	25.3	117	688.2291663	24.8	163	690.145833	24.6
26	684.4374997	26.9	72	686.3541663	25.5	118	688.270833	25	164	690.1874997	24.6
27	684.4791663	25.8	73	686.395833	26	119	688.3124997	25.1	165	690.2291663	24.6
28	684.520833	25.8	74	686.4374997	26.4	120	688.3541663	25.3	166	690.270833	24.8
29	684.5624997	25.7	75	686.4791663	26.5	121	688.395833	25.1	167	690.3124997	25.1
30	684.6041663	25.7	76	686.520833	25.7	122	688.4374997	25.3	168	690.3541663	25.3
31	684.645833	25.7	77	686.5624997	25.5	123	688.4791663	25.3	169	690.395833	25.5
32	684.6874997	25.5	78	686.6041663	25.5	124	688.520833	25.3	170	690.4374997	25.7
33	684.7291663	25.5	79	686.645833	25.5	125	688.5624997	25.3	171	690.4791663	25.3
34	684.770833	25.5	80	686.6874997	25.3	126	688.6041663	25.3	172	690.520833	26.2
35	684.8124997	25.3	81	686.7291663	25.3	127	688.645833	25.3	173	690.5624997	26.4
36	684.8541663	25.3	82	686.770833	25.1	128	688.6874997	25.1	174	690.6041663	25.7
37	684.895833	25.3	83	686.8124997	25.1	129	688.7291663	25.1	175	690.645833	25.5
38	684.9374997	25.1	84	686.8541663	25.1	130	688.770833	25.1	176	690.6874997	25.5
39	684.9791663	25.1	85	686.895833	25.1	131	688.8124997	25.1	177	690.7291663	25.7
40	685.020833	25.3	86	686.9374997	25	132	688.8541663	25	178	690.770833	25.5
41	685.0624997	25.5	87	686.9791663	24.6	133	688.895833	24.8	179	690.8124997	25.5
42	685.1041663	25.3	88	687.020833	24.8	134	688.9374997	25	180	690.8541663	25.3
43	685.145833	25.3	89	687.0624997	24.3	135	688.9791663	25	181	690.895833	25
44	685.1874997	25.3	90	687.1041663	24.6	136	689.020833	25	182	690.9374997	24.8
45	685.2291663	25.5	91	687.145833	24.4	137	689.0624997	24.8	183	690.9791663	24.6
46	685.270833	25.8	92	687.1874997	24.4	138	689.1041663	24.8	184	691.020833	24.6

185	691.0624997	24.6	235	693.145833	24.3	285	695.2291663	24.3	335	697.3124997	25.7
186	691.1041663	24.3	236	693.1874997	24.4	286	695.270833	25.7	336	697.3541663	26
187	691.145833	24.3	237	693.2291663	24.4	287	695.3124997	26.7	337	697.395833	26.4
188	691.1874997	24.4	238	693.270833	24.6	288	695.3541663	27.4	338	697.4374997	26.2
189	691.2291663	24.6	239	693.3124997	24.6	289	695.395833	27.1	339	697.4791663	25.7
190	691.270833	25	240	693.3541663	24.4	290	695.4374997	26.7	340	697.520833	25.8
191	691.3124997	25.3	241	693.395833	24.4	291	695.4791663	26.5	341	697.5624997	25.1
192	691.3541663	25.5	242	693.4374997	24.4	292	695.520833	26	342	697.6041663	25.1
193	691.395833	25.5	243	693.4791663	24.4	293	695.5624997	25.7	343	697.645833	25.1
194	691.4374997	25.3	244	693.520833	24.4	294	695.6041663	25.5	344	697.6874997	24.6
195	691.4791663	25	245	693.5624997	24.4	295	695.645833	25.7	345	697.7291663	24.3
196	691.520833	25	246	693.6041663	24.4	296	695.6874997	25	346	697.770833	24.1
197	691.5624997	25	247	693.645833	24.3	297	695.7291663	25	347	697.8124997	23.8
198	691.6041663	25	248	693.6874997	24.3	298	695.770833	24.6	348	697.8541663	24.3
199	691.645833	24.8	249	693.7291663	24.3	299	695.8124997	24.4	349	697.895833	24.3
200	691.6874997	24.8	250	693.770833	24.3	300	695.8541663	24.3	350	697.9374997	23.2
201	691.7291663	24.6	251	693.8124997	24.3	301	695.895833	24.1	351	697.9791663	23.8
202	691.770833	24.6	252	693.8541663	24.1	302	695.9374997	23.8	352	698.020833	23.8
203	691.8124997	24.4	253	693.895833	24.1	303	695.9791663	24.3	353	698.0624997	24.3
204	691.8541663	24.3	254	693.9374997	24.1	304	696.020833	24.1	354	698.1041663	23.8
205	691.895833	24.3	255	693.9791663	24.1	305	696.0624997	23.9	355	698.145833	23.6
206	691.9374997	24.3	256	694.020833	23.9	306	696.1041663	23.8	356	698.1874997	24.3
207	691.9791663	24.3	257	694.0624997	23.9	307	696.145833	23.8	357	698.2291663	23.6
208	692.020833	24.3	258	694.1041663	23.8	308	696.1874997	23.8	358	698.270833	23.6
209	692.0624997	24.3	259	694.145833	23.8	309	696.2291663	24.4	359	698.3124997	23.4
210	692.1041663	24.4	260	694.1874997	23.9	310	696.270833	24.1	360	698.3541663	23.6
211	692.145833	24.4	261	694.2291663	23.8	311	696.3124997	23.8	361	698.395833	23.6
212	692.1874997	24.4	262	694.270833	24.1	312	696.3541663	24.1	362	698.4374997	24.6
213	692.2291663	24.8	263	694.3124997	24.3	313	696.395833	24.4	363	698.4791663	25.3
214	692.270833	24.8	264	694.3541663	24.4	314	696.4374997	25.1	364	698.520833	25.7
215	692.3124997	24.6	265	694.395833	24.8	315	696.4791663	25.5	365	698.5624997	25.3
216	692.3541663	25	266	694.4374997	24.8	316	696.520833	25.5	366	698.6041663	25
217	692.395833	25.1	267	694.4791663	24.8	317	696.5624997	25.5	367	698.645833	25
218	692.4374997	25.3	268	694.520833	24.6	318	696.6041663	25.1	368	698.6874997	24.6
219	692.4791663	25.5	269	694.5624997	24.6	319	696.645833	24.8	369	698.7291663	24.4
220	692.520833	25.3	270	694.6041663	24.4	320	696.6874997	24.6	370	698.770833	24.1
221	692.5624997	25.3	271	694.645833	24.4	321	696.7291663	24.4	371	698.8124997	24.1
222	692.6041663	25.1	272	694.6874997	24.3	322	696.770833	24.3	372	698.8541663	23.8
223	692.645833	25	273	694.7291663	24.3	323	696.8124997	24.3	373	698.895833	23.6
224	692.6874997	25	274	694.770833	24.1	324	696.8541663	23.9	374	698.9374997	23.2
225	692.7291663	25	275	694.8124997	23.9	325	696.895833	23.8	375	698.9791663	23.4
226	692.770833	24.8	276	694.8541663	23.9	326	696.9374997	23.8	376	699.020833	23.2
227	692.8124997	24.8	277	694.895833	23.8	327	696.9791663	23.4	377	699.0624997	23.6
228	692.8541663	24.6	278	694.9374997	23.9	328	697.020833	24.4	378	699.1041663	23.6
229	692.895833	24.4	279	694.9791663	23.9	329	697.0624997	24.1	379	699.145833	22.9
230	692.9374997	24.4	280	695.020833	23.6	330	697.1041663	23.8	380	699.1874997	22.9
231	692.9791663	24.1	281	695.0624997	23.4	331	697.145833	23.6	381	699.2291663	24.6
232	693.020833	24.1	282	695.1041663	22.4	332	697.1874997	24.3	382	699.270833	25.7
233	693.0624997	24.1	283	695.145833	24.1	333	697.2291663	24.8	383	699.3124997	26
234	693.1041663	24.1	284	695.1874997	24.3	334	697.270833	25.1	384	699.3541663	26.5

385	699.395833	27.8	435	701.4791663	26.2	485	703.5624997	24.6	535	705.645833	24.8
386	699.4374997	28	436	701.520833	26.5	486	703.6041663	24.6	536	705.6874997	24.6
387	699.4791663	27.1	437	701.5624997	26	487	703.645833	24.6	537	705.7291663	24.4
388	699.520833	26	438	701.6041663	25.7	488	703.6874997	24.4	538	705.770833	24.4
389	699.5624997	25.5	439	701.645833	25.3	489	703.7291663	24.4	539	705.8124997	24.4
390	699.6041663	25	440	701.6874997	25.1	490	703.770833	24.3	540	705.8541663	24.1
391	699.645833	24.8	441	701.7291663	24.8	491	703.8124997	24.1	541	705.895833	24.3
392	699.6874997	24.8	442	701.770833	24.8	492	703.8541663	24.3	542	705.9374997	23.8
393	699.7291663	24.3	443	701.8124997	24.4	493	703.895833	24.3	543	705.9791663	24.1
394	699.770833	24.1	444	701.8541663	24.3	494	703.9374997	24.3	544	706.020833	24.1
395	699.8124997	23.9	445	701.895833	24.3	495	703.9791663	24.1	545	706.0624997	23.9
396	699.8541663	24.1	446	701.9374997	24.1	496	704.020833	24.1	546	706.1041663	23.8
397	699.895833	23.8	447	701.9791663	23.8	497	704.0624997	24.1	547	706.145833	23.2
398	699.9374997	23.8	448	702.020833	23.4	498	704.1041663	23.9	548	706.1874997	24.1
399	699.9791663	23.8	449	702.0624997	23.2	499	704.145833	23.9	549	706.2291663	24.4
400	700.020833	23.9	450	702.1041663	23.8	500	704.1874997	24.1	550	706.270833	24.8
401	700.0624997	23.9	451	702.145833	23.6	501	704.2291663	23.9	551	706.3124997	25.1
402	700.1041663	23.9	452	702.1874997	23.8	502	704.270833	23.6	552	706.3541663	25.5
403	700.145833	23.4	453	702.2291663	23.4	503	704.3124997	23.9	553	706.395833	25.8
404	700.1874997	24.1	454	702.270833	23.9	504	704.3541663	23.9	554	706.4374997	25.3
405	700.2291663	25.3	455	702.3124997	23.8	505	704.395833	24.3	555	706.4791663	25.1
406	700.270833	25.7	456	702.3541663	24.3	506	704.4374997	24.3	556	706.520833	25.1
407	700.3124997	26.5	457	702.395833	24.4	507	704.4791663	24.4	557	706.5624997	25.1
408	700.3541663	26.9	458	702.4374997	24.4	508	704.520833	24.4	558	706.6041663	24.8
409	700.395833	26.5	459	702.4791663	24.6	509	704.5624997	24.3	559	706.645833	24.6
410	700.4374997	26.4	460	702.520833	24.8	510	704.6041663	24.3	560	706.6874997	24.6
411	700.4791663	26.2	461	702.5624997	24.8	511	704.645833	24.1	561	706.7291663	24.4
412	700.520833	25.8	462	702.6041663	24.6	512	704.6874997	23.9	562	706.770833	24.3
413	700.5624997	25.3	463	702.645833	24.6	513	704.7291663	24.1	563	706.8124997	24.4
414	700.6041663	25	464	702.6874997	24.4	514	704.770833	23.8	564	706.8541663	24.6
415	700.645833	24.8	465	702.7291663	24.3	515	704.8124997	23.8	565	706.895833	24.4
416	700.6874997	24.8	466	702.770833	24.3	516	704.8541663	23.4	566	706.9374997	24.3
417	700.7291663	24.8	467	702.8124997	24.1	517	704.895833	23.6	567	706.9791663	24.3
418	700.770833	24.6	468	702.8541663	23.9	518	704.9374997	23.2	568	707.020833	24.3
419	700.8124997	24.4	469	702.895833	23.6	519	704.9791663	23.8	569	707.0624997	24.3
420	700.8541663	24.3	470	702.9374997	23.9	520	705.020833	23.6	570	707.1041663	24.1
421	700.895833	24.4	471	702.9791663	24.1	521	705.0624997	23.9	571	707.145833	23.8
422	700.9374997	23.8	472	703.020833	24.1	522	705.1041663	24.1	572	707.1874997	24.3
423	700.9791663	24.1	473	703.0624997	23.9	523	705.145833	23.8	573	707.2291663	24.8
424	701.020833	24.1	474	703.1041663	23.8	524	705.1874997	23.4	574	707.270833	25
425	701.0624997	24.4	475	703.145833	24.1	525	705.2291663	24.1	575	707.3124997	25.7
426	701.1041663	24.3	476	703.1874997	24.1	526	705.270833	24.6	576	707.3541663	26.9
427	701.145833	24.4	477	703.2291663	24.1	527	705.3124997	24.8	577	707.395833	25.5
428	701.1874997	24.3	478	703.270833	24.4	528	705.3541663	25.5	578	707.4374997	25.1
429	701.2291663	24.6	479	703.3124997	24.6	529	705.395833	26.5	579	707.4791663	25
430	701.270833	24.4	480	703.3541663	25	530	705.4374997	26.2	580	707.520833	25
431	701.3124997	24.1	481	703.395833	25	531	705.4791663	25.5	581	707.5624997	24.8
432	701.3541663	24.4	482	703.4374997	24.8	532	705.520833	25.1	582	707.6041663	24.8
433	701.395833	25.1	483	703.4791663	24.8	533	705.5624997	25	583	707.645833	24.8
434	701.4374997	25.5	484	703.520833	24.6	534	705.6041663	24.8	584	707.6874997	24.8

585	707.7291663	24.4	635	709.8124997	24.3	685	711.895833	24.3	735	713.9791663	24.4
586	707.770833	24.4	636	709.8541663	24.4	686	711.9374997	24.4	736	714.020833	23.8
587	707.8124997	24.1	637	709.895833	24.4	687	711.9791663	24.4	737	714.0624997	24.1
588	707.8541663	24.4	638	709.9374997	24.4	688	712.020833	24.3	738	714.1041663	24.3
589	707.895833	23.9	639	709.9791663	24.4	689	712.0624997	24.4	739	714.145833	23.8
590	707.9374997	23.9	640	710.020833	24.3	690	712.1041663	24.3	740	714.1874997	24.1
591	707.9791663	23.9	641	710.0624997	24.4	691	712.145833	24.4	741	714.2291663	24.4
592	708.020833	23.8	642	710.1041663	24.4	692	712.1874997	24.4	742	714.270833	24.6
593	708.0624997	23.9	643	710.145833	24.6	693	712.2291663	24.4	743	714.3124997	24.6
594	708.1041663	23.8	644	710.1874997	24.4	694	712.270833	23.8	744	714.3541663	24.8
595	708.145833	23.6	645	710.2291663	24.1	695	712.3124997	24.1	745	714.395833	24.8
596	708.1874997	23.8	646	710.270833	24.4	696	712.3541663	24.3	746	714.4374997	24.8
597	708.2291663	24.1	647	710.3124997	24.1	697	712.395833	24.4	747	714.4791663	24.8
598	708.270833	24.4	648	710.3541663	24.8	698	712.4374997	24.8	748	714.520833	24.8
599	708.3124997	25	649	710.395833	25.3	699	712.4791663	25	749	714.5624997	24.8
600	708.3541663	25	650	710.4374997	25.7	700	712.520833	25	750	714.6041663	24.6
601	708.395833	25	651	710.4791663	25.8	701	712.5624997	25	751	714.645833	24.6
602	708.4374997	25	652	710.520833	26	702	712.6041663	25	752	714.6874997	24.4
603	708.4791663	25.1	653	710.5624997	25.8	703	712.645833	24.6	753	714.7291663	24.4
604	708.520833	25.1	654	710.6041663	25.8	704	712.6874997	24.6	754	714.770833	24.4
605	708.5624997	25.1	655	710.645833	25.7	705	712.7291663	24.6	755	714.8124997	24.4
606	708.6041663	25.1	656	710.6874997	25.5	706	712.770833	24.4	756	714.8541663	24.1
607	708.645833	24.8	657	710.7291663	25.1	707	712.8124997	24.1	757	714.895833	24.1
608	708.6874997	24.8	658	710.770833	24.8	708	712.8541663	24.4	758	714.9374997	23.4
609	708.7291663	24.6	659	710.8124997	24.8	709	712.895833	24.4	759	714.9791663	23.1
610	708.770833	24.6	660	710.8541663	24.8	710	712.9374997	24.1	760	715.020833	23.6
611	708.8124997	24.4	661	710.895833	24.6	711	712.9791663	23.6	761	715.0624997	23.8
612	708.8541663	24.3	662	710.9374997	24.4	712	713.020833	24.3	762	715.1041663	23.8
613	708.895833	24.1	663	710.9791663	24.4	713	713.0624997	24.1	763	715.145833	24.1
614	708.9374997	23.9	664	711.020833	24.4	714	713.1041663	24.3	764	715.1874997	24.3
615	708.9791663	23.8	665	711.0624997	24.4	715	713.145833	23.9	765	715.2291663	24.4
616	709.020833	23.4	666	711.1041663	24.3	716	713.1874997	24.4	766	715.270833	24.4
617	709.0624997	24.1	667	711.145833	24.3	717	713.2291663	24.4	767	715.3124997	24.8
618	709.1041663	24.1	668	711.1874997	24.3	718	713.270833	24.6	768	715.3541663	25
619	709.145833	23.9	669	711.2291663	24.3	719	713.3124997	25	769	715.395833	25.5
620	709.1874997	24.1	670	711.270833	24.4	720	713.3541663	25	770	715.4374997	25.7
621	709.2291663	24.4	671	711.3124997	25.1	721	713.395833	25.1	771	715.4791663	25.1
622	709.270833	24.8	672	711.3541663	25.3	722	713.4374997	25.5	772	715.520833	25
623	709.3124997	25	673	711.395833	25.8	723	713.4791663	25.8	773	715.5624997	24.8
624	709.3541663	24.8	674	711.4374997	25.7	724	713.520833	26	774	715.6041663	24.8
625	709.395833	24.6	675	711.4791663	25.8	725	713.5624997	25.8	775	715.645833	24.6
626	709.4374997	24.6	676	711.520833	25.5	726	713.6041663	25.7	776	715.6874997	24.6
627	709.4791663	24.6	677	711.5624997	25.3	727	713.645833	25.5	777	715.7291663	24.4
628	709.520833	25	678	711.6041663	25.1	728	713.6874997	25.1	778	715.770833	24.1
629	709.5624997	24.6	679	711.645833	25	729	713.7291663	25.1	779	715.8124997	24.1
630	709.6041663	24.8	680	711.6874997	25	730	713.770833	25.1	780	715.8541663	23.9
631	709.645833	25	681	711.7291663	24.8	731	713.8124997	24.8	781	715.895833	24.3
632	709.6874997	25	682	711.770833	24.8	732	713.8541663	24.4	782	715.9374997	24.3
633	709.7291663	24.8	683	711.8124997	24.6	733	713.895833	24.6	783	715.9791663	23.8
634	709.770833	24.6	684	711.8541663	24.6	734	713.9374997	24.1	784	716.020833	23.9

785	716.0624997	24.1	835	718.145833	23.8	885	720.2291663	24.3	935	722.3124997	25.5
786	716.1041663	23.9	836	718.1874997	23.8	886	720.270833	24.6	936	722.3541663	25.7
787	716.145833	24.1	837	718.2291663	23.8	887	720.3124997	24.8	937	722.395833	26
788	716.1874997	24.1	838	718.270833	23.9	888	720.3541663	25	938	722.4374997	26.5
789	716.2291663	24.1	839	718.3124997	23.9	889	720.395833	25.5	939	722.4791663	27.3
790	716.270833	24.4	840	718.3541663	23.8	890	720.4374997	26.4	940	722.520833	27.4
791	716.3124997	24.6	841	718.395833	23.6	891	720.4791663	26.5	941	722.5624997	27.6
792	716.3541663	25	842	718.4374997	23.8	892	720.520833	26.4	942	722.6041663	27.4
793	716.395833	25.1	843	718.4791663	24.1	893	720.5624997	26	943	722.645833	27.1
794	716.4374997	25.3	844	718.520833	24.3	894	720.6041663	24.8	944	722.6874997	26.9
795	716.4791663	25.5	845	718.5624997	24.3	895	720.645833	24.6	945	722.7291663	26.2
796	716.520833	25.5	846	718.6041663	24.3	896	720.6874997	24.6	946	722.770833	26
797	716.5624997	25.3	847	718.645833	23.9	897	720.7291663	24.4	947	722.8124997	25.8
798	716.6041663	25	848	718.6874997	23.9	898	720.770833	24.4	948	722.8541663	25.5
799	716.645833	24.8	849	718.7291663	23.4	899	720.8124997	24.3	949	722.895833	25.5
800	716.6874997	24.8	850	718.770833	23.2	900	720.8541663	24.3	950	722.9374997	25.3
801	716.7291663	24.8	851	718.8124997	23.6	901	720.895833	24.3	951	722.9791663	25.1
802	716.770833	24.6	852	718.8541663	23.6	902	720.9374997	24.1	952	723.020833	25.1
803	716.8124997	24.4	853	718.895833	23.4	903	720.9791663	23.6	953	723.0624997	24.6
804	716.8541663	24.4	854	718.9374997	23.1	904	721.020833	23.8	954	723.1041663	24.4
805	716.895833	24.3	855	718.9791663	23.4	905	721.0624997	24.1	955	723.145833	24.8
806	716.9374997	24.6	856	719.020833	23.4	906	721.1041663	23.9	956	723.1874997	24.8
807	716.9791663	24.4	857	719.0624997	23.4	907	721.145833	23.6	957	723.2291663	25.5
808	717.020833	24.4	858	719.1041663	23.6	908	721.1874997	24.6	958	723.270833	26.2
809	717.0624997	24.4	859	719.145833	23.6	909	721.2291663	25.1	959	723.3124997	27.3
810	717.1041663	24.3	860	719.1874997	23.8	910	721.270833	25.3	960	723.3541663	27.6
811	717.145833	24.4	861	719.2291663	23.8	911	721.3124997	25.7	961	723.395833	28
812	717.1874997	24.1	862	719.270833	23.9	912	721.3541663	25.8	962	723.4374997	28.2
813	717.2291663	24.1	863	719.3124997	24.1	913	721.395833	25.7	963	723.4791663	27.6
814	717.270833	24.4	864	719.3541663	24.3	914	721.4374997	25.7	964	723.520833	27.3
815	717.3124997	24.1	865	719.395833	24.4	915	721.4791663	25.5	965	723.5624997	26.5
816	717.3541663	23.9	866	719.4374997	24.6	916	721.520833	26.9	966	723.6041663	26
817	717.395833	24.4	867	719.4791663	24.4	917	721.5624997	28.2	967	723.645833	25.7
818	717.4374997	24.6	868	719.520833	24.8	918	721.6041663	26.2	968	723.6874997	25.5
819	717.4791663	24.6	869	719.5624997	24.4	919	721.645833	26	969	723.7291663	25.1
820	717.520833	24.6	870	719.6041663	24.3	920	721.6874997	25.7	970	723.770833	25
821	717.5624997	24.6	871	719.645833	24.1	921	721.7291663	25.5	971	723.8124997	24.8
822	717.6041663	24.4	872	719.6874997	24.3	922	721.770833	25.3	972	723.8541663	25.1
823	717.645833	24.3	873	719.7291663	24.1	923	721.8124997	25.1	973	723.895833	24.3
824	717.6874997	24.4	874	719.770833	24.1	924	721.8541663	25.1	974	723.9374997	24.1
825	717.7291663	24.3	875	719.8124997	23.9	925	721.895833	24.4	975	723.9791663	24.4
826	717.770833	24.1	876	719.8541663	23.9	926	721.9374997	24.8	976	724.020833	24.4
827	717.8124997	23.9	877	719.895833	23.9	927	721.9791663	24.3	977	724.0624997	24.3
828	717.8541663	23.9	878	719.9374997	24.1	928	722.020833	24.8	978	724.1041663	23.9
829	717.895833	23.9	879	719.9791663	23.4	929	722.0624997	24.3	979	724.145833	24.6
830	717.9374997	23.9	880	720.020833	23.8	930	722.1041663	24.3	980	724.1874997	24.3
831	717.9791663	23.9	881	720.0624997	23.4	931	722.145833	24.4	981	724.2291663	25.7
832	718.020833	23.9	882	720.1041663	23.2	932	722.1874997	24.6	982	724.270833	26.5
833	718.0624997	23.8	883	720.145833	23.4	933	722.2291663	25	983	724.3124997	26.9
834	718.1041663	23.8	884	720.1874997	23.8	934	722.270833	25.3	984	724.3541663	26.9

985	724.395833	27.1	1035	726.4791663	27.1	1085	728.5624997	26.4	1135	730.645833	25.5
986	724.4374997	26.9	1036	726.520833	26.7	1086	728.6041663	26	1136	730.6874997	25.3
987	724.4791663	26.9	1037	726.5624997	26.4	1087	728.645833	26	1137	730.7291663	25
988	724.520833	26.7	1038	726.6041663	25.8	1088	728.6874997	25.8	1138	730.770833	24.6
989	724.5624997	26.2	1039	726.645833	25.7	1089	728.7291663	25.5	1139	730.8124997	24.6
990	724.6041663	25.7	1040	726.6874997	25.7	1090	728.770833	25.7	1140	730.8541663	24.3
991	724.645833	25.5	1041	726.7291663	25.7	1091	728.8124997	24.8	1141	730.895833	24.6
992	724.6874997	25.5	1042	726.770833	25.3	1092	728.8541663	25.1	1142	730.9374997	24.3
993	724.7291663	25.1	1043	726.8124997	25.1	1093	728.895833	25.3	1143	730.9791663	24.3
994	724.770833	25	1044	726.8541663	24.8	1094	728.9374997	25.1	1144	731.020833	24.3
995	724.8124997	24.8	1045	726.895833	25	1095	728.9791663	24.8	1145	731.0624997	24.4
996	724.8541663	24.8	1046	726.9374997	25	1096	729.020833	24.6	1146	731.1041663	24.4
997	724.895833	24.8	1047	726.9791663	24.3	1097	729.0624997	24.6	1147	731.145833	24.1
998	724.9374997	24.8	1048	727.020833	23.9	1098	729.1041663	25	1148	731.1874997	24.4
999	724.9791663	25	1049	727.0624997	24.1	1099	729.145833	25	1149	731.2291663	25
1000	725.020833	24.6	1050	727.1041663	24.6	1100	729.1874997	23.9	1150	731.270833	25.8
1001	725.0624997	25.1	1051	727.145833	24.6	1101	729.2291663	24.4	1151	731.3124997	26.9
1002	725.1041663	24.6	1052	727.1874997	24.8	1102	729.270833	23.4	1152	731.3541663	27.8
1003	725.145833	24.8	1053	727.2291663	25.3	1103	729.3124997	24.6	1153	731.395833	28.3
1004	725.1874997	24.1	1054	727.270833	26.5	1104	729.3541663	24.6	1154	731.4374997	27.6
1005	725.2291663	24.4	1055	727.3124997	27.3	1105	729.395833	25.1	1155	731.4791663	26.9
1006	725.270833	24.6	1056	727.3541663	29.1	1106	729.4374997	24.8	1156	731.520833	26
1007	725.3124997	25.7	1057	727.395833	29.3	1107	729.4791663	25.8	1157	731.5624997	26
1008	725.3541663	26.5	1058	727.4374997	28.9	1108	729.520833	26.2	1158	731.6041663	25.5
1009	725.395833	27.1	1059	727.4791663	28.9	1109	729.5624997	25.8	1159	731.645833	25.7
1010	725.4374997	27.1	1060	727.520833	28.5	1110	729.6041663	25.5	1160	731.6874997	25.5
1011	725.4791663	28.7	1061	727.5624997	28.7	1111	729.645833	25.1	1161	731.7291663	25.1
1012	725.520833	28	1062	727.6041663	28	1112	729.6874997	25	1162	731.770833	25
1013	725.5624997	28	1063	727.645833	27.6	1113	729.7291663	24.8	1163	731.8124997	24.8
1014	725.6041663	27.3	1064	727.6874997	27.3	1114	729.770833	24.8	1164	731.8541663	24.8
1015	725.645833	27.1	1065	727.7291663	26.9	1115	729.8124997	24.6	1165	731.895833	24.8
1016	725.6874997	26.5	1066	727.770833	26.5	1116	729.8541663	24.6	1166	731.9374997	24.6
1017	725.7291663	26.2	1067	727.8124997	26.4	1117	729.895833	24.4	1167	731.9791663	24.4
1018	725.770833	25.8	1068	727.8541663	26.2	1118	729.9374997	24.4	1168	732.020833	24.3
1019	725.8124997	25.7	1069	727.895833	26	1119	729.9791663	24.4	1169	732.0624997	23.9
1020	725.8541663	25.7	1070	727.9374997	26	1120	730.020833	24.4	1170	732.1041663	24.3
1021	725.895833	25.5	1071	727.9791663	25.8	1121	730.0624997	24.4	1171	732.145833	23.9
1022	725.9374997	24.8	1072	728.020833	25.7	1122	730.1041663	24.3	1172	732.1874997	24.1
1023	725.9791663	24.6	1073	728.0624997	25.7	1123	730.145833	23.9	1173	732.2291663	24.4
1024	726.020833	25.1	1074	728.1041663	25.5	1124	730.1874997	24.4	1174	732.270833	25
1025	726.0624997	25.1	1075	728.145833	25.7	1125	730.2291663	24.6	1175	732.3124997	25.1
1026	726.1041663	25	1076	728.1874997	25.3	1126	730.270833	25.1	1176	732.3541663	25.1
1027	726.145833	25.3	1077	728.2291663	25.1	1127	730.3124997	25.5	1177	732.395833	25.3
1028	726.1874997	25.7	1078	728.270833	25.3	1128	730.3541663	25.8	1178	732.4374997	25.7
1029	726.2291663	26	1079	728.3124997	25.5	1129	730.395833	26	1179	732.4791663	26
1030	726.270833	26.7	1080	728.3541663	26.2	1130	730.4374997	26	1180	732.520833	26.2
1031	726.3124997	27.4	1081	728.395833	26.9	1131	730.4791663	26	1181	732.5624997	25.8
1032	726.3541663	28.2	1082	728.4374997	27.3	1132	730.520833	26	1182	732.6041663	25.5
1033	726.395833	27.8	1083	728.4791663	26.9	1133	730.5624997	25.7	1183	732.645833	25
1034	726.4374997	27.4	1084	728.520833	26.4	1134	730.6041663	25.5	1184	732.6874997	24.8

1185	732.7291663	24.6	1235	734.8124997	25.1	1285	736.895833	25	1335	738.9791663	25.3
1186	732.770833	24.4	1236	734.8541663	25.1	1286	736.9374997	25	1336	739.020833	25.1
1187	732.8124997	24.3	1237	734.895833	25	1287	736.9791663	24.8	1337	739.0624997	25
1188	732.8541663	24.3	1238	734.9374997	24.8	1288	737.020833	24.8	1338	739.1041663	24.6
1189	732.895833	23.9	1239	734.9791663	24.3	1289	737.0624997	24.8	1339	739.145833	24.6
1190	732.9374997	23.9	1240	735.020833	24.8	1290	737.1041663	24.8	1340	739.1874997	25
1191	732.9791663	23.9	1241	735.0624997	24.4	1291	737.145833	24.6	1341	739.2291663	25.5
1192	733.020833	23.8	1242	735.1041663	24.4	1292	737.1874997	24.4	1342	739.270833	26.7
1193	733.0624997	23.9	1243	735.145833	24.6	1293	737.2291663	24.1	1343	739.3124997	27.6
1194	733.1041663	23.8	1244	735.1874997	24.8	1294	737.270833	24.6	1344	739.3541663	27.8
1195	733.145833	23.6	1245	735.2291663	25.3	1295	737.3124997	25.1	1345	739.395833	28.7
1196	733.1874997	24.4	1246	735.270833	26.4	1296	737.3541663	25.5	1346	739.4374997	29.1
1197	733.2291663	24.6	1247	735.3124997	27.3	1297	737.395833	27.1	1347	739.4791663	29.6
1198	733.270833	25.1	1248	735.3541663	28.2	1298	737.4374997	27.3	1348	739.520833	29.4
1199	733.3124997	25.5	1249	735.395833	28.9	1299	737.4791663	27.1	1349	739.5624997	28.9
1200	733.3541663	26	1250	735.4374997	27.4	1300	737.520833	26.5	1350	739.6041663	28.3
1201	733.395833	25.5	1251	735.4791663	27.1	1301	737.5624997	26.2	1351	739.645833	27.8
1202	733.4374997	26	1252	735.520833	27.3	1302	737.6041663	26	1352	739.6874997	27.1
1203	733.4791663	26.4	1253	735.5624997	26.9	1303	737.645833	25.7	1353	739.7291663	26
1204	733.520833	26.5	1254	735.6041663	26.7	1304	737.6874997	25.3	1354	739.770833	25.3
1205	733.5624997	26.7	1255	735.645833	26.4	1305	737.7291663	25.3	1355	739.8124997	25.3
1206	733.6041663	26.7	1256	735.6874997	26.2	1306	737.770833	25.3	1356	739.8541663	25.1
1207	733.645833	26.4	1257	735.7291663	26	1307	737.8124997	25.1	1357	739.895833	24.8
1208	733.6874997	26.2	1258	735.770833	25.8	1308	737.8541663	25.1	1358	739.9374997	25
1209	733.7291663	25.3	1259	735.8124997	25.7	1309	737.895833	25.1	1359	739.9791663	24.6
1210	733.770833	25.1	1260	735.8541663	25.5	1310	737.9374997	25	1360	740.020833	24.6
1211	733.8124997	25	1261	735.895833	25.7	1311	737.9791663	25	1361	740.0624997	24.8
1212	733.8541663	25.1	1262	735.9374997	25.1	1312	738.020833	25	1362	740.1041663	23.9
1213	733.895833	24.8	1263	735.9791663	25.1	1313	738.0624997	24.8	1363	740.145833	24.4
1214	733.9374997	25.1	1264	736.020833	25.1	1314	738.1041663	24.4	1364	740.1874997	24.8
1215	733.9791663	25	1265	736.0624997	25.1	1315	738.145833	24.6	1365	740.2291663	25
1216	734.020833	24.8	1266	736.1041663	25	1316	738.1874997	24.8	1366	740.270833	26.2
1217	734.0624997	24.3	1267	736.145833	25	1317	738.2291663	24.6	1367	740.3124997	27.1
1218	734.1041663	24.4	1268	736.1874997	25.3	1318	738.270833	24.6	1368	740.3541663	28
1219	734.145833	24.4	1269	736.2291663	25.3	1319	738.3124997	24.8	1369	740.395833	28.3
1220	734.1874997	24.6	1270	736.270833	25.7	1320	738.3541663	25.3	1370	740.4374997	27.8
1221	734.2291663	25	1271	736.3124997	26.2	1321	738.395833	26	1371	740.4791663	27.8
1222	734.270833	25.1	1272	736.3541663	27.1	1322	738.4374997	26.9	1372	740.520833	28.2
1223	734.3124997	25.5	1273	736.395833	27.6	1323	738.4791663	27.3	1373	740.5624997	28
1224	734.3541663	26.5	1274	736.4374997	27.1	1324	738.520833	26.7	1374	740.6041663	27.4
1225	734.395833	26.9	1275	736.4791663	27.3	1325	738.5624997	26.5	1375	740.645833	27.1
1226	734.4374997	26.9	1276	736.520833	27.1	1326	738.6041663	26.5	1376	740.6874997	26.7
1227	734.4791663	26.4	1277	736.5624997	26.7	1327	738.645833	26.4	1377	740.7291663	26.4
1228	734.520833	26	1278	736.6041663	26.2	1328	738.6874997	26.2	1378	740.770833	26.4
1229	734.5624997	25.8	1279	736.645833	25.7	1329	738.7291663	25.8	1379	740.8124997	26.2
1230	734.6041663	25.5	1280	736.6874997	25.5	1330	738.770833	26	1380	740.8541663	25.8
1231	734.645833	25.5	1281	736.7291663	25.3	1331	738.8124997	25.7	1381	740.895833	25.5
1232	734.6874997	25.5	1282	736.770833	25.3	1332	738.8541663	25.7	1382	740.9374997	25.7
1233	734.7291663	25.3	1283	736.8124997	25.1	1333	738.895833	25.5	1383	740.9791663	25.1
1234	734.770833	25.3	1284	736.8541663	25	1334	738.9374997	25.3	1384	741.020833	24.8

1385	741.0624997	24.6	1435	743.145833	24.8	1485	745.2291663	25.3	1535	747.3124997	28
1386	741.1041663	25	1436	743.1874997	25	1486	745.270833	26.7	1536	747.3541663	28.2
1387	741.145833	24.6	1437	743.2291663	24.6	1487	745.3124997	27.3	1537	747.395833	28
1388	741.1874997	25	1438	743.270833	24.1	1488	745.3541663	27.6	1538	747.4374997	27.8
1389	741.2291663	26	1439	743.3124997	24.6	1489	745.395833	28.2	1539	747.4791663	26.9
1390	741.270833	26.5	1440	743.3541663	25.5	1490	745.4374997	29.3	1540	747.520833	26.9
1391	741.3124997	27.3	1441	743.395833	26.2	1491	745.4791663	29.8	1541	747.5624997	26.4
1392	741.3541663	27.6	1442	743.4374997	26.9	1492	745.520833	29.8	1542	747.6041663	26
1393	741.395833	28.2	1443	743.4791663	27.4	1493	745.5624997	29.4	1543	747.645833	25.8
1394	741.4374997	28.7	1444	743.520833	27.8	1494	745.6041663	28.9	1544	747.6874997	25.7
1395	741.4791663	28.5	1445	743.5624997	27.3	1495	745.645833	28.7	1545	747.7291663	25.3
1396	741.520833	27.6	1446	743.6041663	26.9	1496	745.6874997	28.3	1546	747.770833	25.3
1397	741.5624997	26.5	1447	743.645833	26.7	1497	745.7291663	27.8	1547	747.8124997	25
1398	741.6041663	26.2	1448	743.6874997	25.7	1498	745.770833	27.3	1548	747.8541663	24.6
1399	741.645833	26	1449	743.7291663	25.5	1499	745.8124997	26.9	1549	747.895833	24.4
1400	741.6874997	25.5	1450	743.770833	25.3	1500	745.8541663	26.7	1550	747.9374997	25
1401	741.7291663	25.5	1451	743.8124997	25.1	1501	745.895833	26.5	1551	747.9791663	24.6
1402	741.770833	25.1	1452	743.8541663	25	1502	745.9374997	25.1	1552	748.020833	24.8
1403	741.8124997	25	1453	743.895833	24.8	1503	745.9791663	24.8	1553	748.0624997	23.8
1404	741.8541663	24.8	1454	743.9374997	24.6	1504	746.020833	26	1554	748.1041663	24.6
1405	741.895833	24.6	1455	743.9791663	24.6	1505	746.0624997	26.4	1555	748.145833	25.1
1406	741.9374997	24.6	1456	744.020833	24.6	1506	746.1041663	26.2	1556	748.1874997	25
1407	741.9791663	24.6	1457	744.0624997	24.4	1507	746.145833	26.2	1557	748.2291663	25.7
1408	742.020833	24.6	1458	744.1041663	24.3	1508	746.1874997	26.4	1558	748.270833	26.4
1409	742.0624997	24.4	1459	744.145833	24.1	1509	746.2291663	26.9	1559	748.3124997	27.4
1410	742.1041663	24.4	1460	744.1874997	24.3	1510	746.270833	27.4	1560	748.3541663	28
1411	742.145833	24.3	1461	744.2291663	24.4	1511	746.3124997	28.2	1561	748.395833	28
1412	742.1874997	24.4	1462	744.270833	23.9	1512	746.3541663	28.9	1562	748.4374997	28.2
1413	742.2291663	24.8	1463	744.3124997	24.6	1513	746.395833	28.9	1563	748.4791663	27.4
1414	742.270833	25.5	1464	744.3541663	24.6	1514	746.4374997	27.8	1564	748.520833	27.1
1415	742.3124997	26.2	1465	744.395833	25	1515	746.4791663	26.9	1565	748.5624997	26.7
1416	742.3541663	26.7	1466	744.4374997	25.1	1516	746.520833	26.5	1566	748.6041663	26.9
1417	742.395833	27.4	1467	744.4791663	26.2	1517	746.5624997	26.2	1567	748.645833	26.7
1418	742.4374997	27.8	1468	744.520833	25.7	1518	746.6041663	25.8	1568	748.6874997	26.2
1419	742.4791663	28.5	1469	744.5624997	25.5	1519	746.645833	25.7	1569	748.7291663	25.8
1420	742.520833	28	1470	744.6041663	25.3	1520	746.6874997	25.5	1570	748.770833	25.8
1421	742.5624997	27.6	1471	744.645833	25.1	1521	746.7291663	25.1	1571	748.8124997	25.7
1422	742.6041663	27.1	1472	744.6874997	25	1522	746.770833	25.1	1572	748.8541663	25
1423	742.645833	26.9	1473	744.7291663	24.8	1523	746.8124997	25.1	1573	748.895833	24.8
1424	742.6874997	26.5	1474	744.770833	24.4	1524	746.8541663	25.1	1574	748.9374997	25.3
1425	742.7291663	26.2	1475	744.8124997	24.1	1525	746.895833	25	1575	748.9791663	25.5
1426	742.770833	25.8	1476	744.8541663	24.4	1526	746.9374997	24.4	1576	749.020833	24.4
1427	742.8124997	25.5	1477	744.895833	24.4	1527	746.9791663	23.6	1577	749.0624997	23.8
1428	742.8541663	25.5	1478	744.9374997	24.3	1528	747.020833	24.6	1578	749.1041663	24.3
1429	742.895833	25.5	1479	744.9791663	23.8	1529	747.0624997	24.3	1579	749.145833	25.1
1430	742.9374997	25.1	1480	745.020833	24.4	1530	747.1041663	24.8	1580	749.1874997	25.3
1431	742.9791663	25	1481	745.0624997	23.8	1531	747.145833	24.6	1581	749.2291663	26
1432	743.020833	25.1	1482	745.1041663	24.3	1532	747.1874997	24.6	1582	749.270833	26.7
1433	743.0624997	25.1	1483	745.145833	24.4	1533	747.2291663	26.2	1583	749.3124997	27.8
1434	743.1041663	25	1484	745.1874997	24.8	1534	747.270833	26.9	1584	749.3541663	28

1585	749.395833	27.3	1635	751.4791663	27.8	1685	753.5624997	27.4	1735	755.645833	26.7
1586	749.4374997	27.3	1636	751.520833	27.8	1686	753.6041663	26.5	1736	755.6874997	26.5
1587	749.4791663	27.3	1637	751.5624997	27.3	1687	753.645833	26.5	1737	755.7291663	26
1588	749.520833	26.9	1638	751.6041663	26.7	1688	753.6874997	26.2	1738	755.770833	25.8
1589	749.5624997	26.5	1639	751.645833	26.2	1689	753.7291663	25.8	1739	755.8124997	25.8
1590	749.6041663	26.4	1640	751.6874997	25.8	1690	753.770833	25.5	1740	755.8541663	25.3
1591	749.645833	26	1641	751.7291663	25.8	1691	753.8124997	25.7	1741	755.895833	25
1592	749.6874997	25.8	1642	751.770833	25.3	1692	753.8541663	25.3	1742	755.9374997	25.5
1593	749.7291663	25.5	1643	751.8124997	25.3	1693	753.895833	25.5	1743	755.9791663	25.5
1594	749.770833	25.3	1644	751.8541663	24.8	1694	753.9374997	25	1744	756.020833	25.1
1595	749.8124997	25.1	1645	751.895833	24.8	1695	753.9791663	23.9	1745	756.0624997	25.8
1596	749.8541663	25.1	1646	751.9374997	25.3	1696	754.020833	25.3	1746	756.1041663	24.3
1597	749.895833	25	1647	751.9791663	25.3	1697	754.0624997	25.1	1747	756.145833	25.1
1598	749.9374997	25.1	1648	752.020833	25.5	1698	754.1041663	25.5	1748	756.1874997	25
1599	749.9791663	25.1	1649	752.0624997	24.4	1699	754.145833	25.3	1749	756.2291663	26.4
1600	750.020833	25.3	1650	752.1041663	24.4	1700	754.1874997	25.3	1750	756.270833	27.4
1601	750.0624997	25.3	1651	752.145833	25	1701	754.2291663	26.5	1751	756.3124997	28.3
1602	750.1041663	24.4	1652	752.1874997	25.5	1702	754.270833	27.1	1752	756.3541663	28.3
1603	750.145833	24.4	1653	752.2291663	25.8	1703	754.3124997	28.2	1753	756.395833	28.5
1604	750.1874997	25.1	1654	752.270833	27.4	1704	754.3541663	28.7	1754	756.4374997	28.3
1605	750.2291663	25.1	1655	752.3124997	27.8	1705	754.395833	28.5	1755	756.4791663	28.3
1606	750.270833	26.4	1656	752.3541663	27.8	1706	754.4374997	28.3	1756	756.520833	28
1607	750.3124997	27.3	1657	752.395833	27.6	1707	754.4791663	28.2	1757	756.5624997	27.4
1608	750.3541663	27.6	1658	752.4374997	27.6	1708	754.520833	27.6	1758	756.6041663	26.7
1609	750.395833	27.6	1659	752.4791663	27.4	1709	754.5624997	27.1	1759	756.645833	26.4
1610	750.4374997	27.6	1660	752.520833	27.4	1710	754.6041663	26.5	1760	756.6874997	25.8
1611	750.4791663	27.3	1661	752.5624997	26.9	1711	754.645833	26.5	1761	756.7291663	25.7
1612	750.520833	27.1	1662	752.6041663	26.5	1712	754.6874997	26.2	1762	756.770833	25.5
1613	750.5624997	27.1	1663	752.645833	26.2	1713	754.7291663	25.8	1763	756.8124997	25.8
1614	750.6041663	26.2	1664	752.6874997	25.8	1714	754.770833	25.8	1764	756.8541663	25.5
1615	750.645833	26.2	1665	752.7291663	25.5	1715	754.8124997	25.5	1765	756.895833	25.5
1616	750.6874997	25.8	1666	752.770833	25.1	1716	754.8541663	25.5	1766	756.9374997	25.3
1617	750.7291663	25.5	1667	752.8124997	25	1717	754.895833	25.7	1767	756.9791663	25.3
1618	750.770833	25.1	1668	752.8541663	25.1	1718	754.9374997	25.1	1768	757.020833	25.7
1619	750.8124997	25.1	1669	752.895833	24.3	1719	754.9791663	25.1	1769	757.0624997	25.5
1620	750.8541663	25	1670	752.9374997	25.1	1720	755.020833	25.5	1770	757.1041663	25.5
1621	750.895833	25	1671	752.9791663	25	1721	755.0624997	25.5	1771	757.145833	25
1622	750.9374997	24.8	1672	753.020833	25.1	1722	755.1041663	25	1772	757.1874997	26.4
1623	750.9791663	24.6	1673	753.0624997	25.3	1723	755.145833	25.5	1773	757.2291663	27.1
1624	751.020833	24.8	1674	753.1041663	25.1	1724	755.1874997	26	1774	757.270833	28.2
1625	751.0624997	25.1	1675	753.145833	24.6	1725	755.2291663	26.7	1775	757.3124997	29.4
1626	751.1041663	25	1676	753.1874997	25.5	1726	755.270833	27.6	1776	757.3541663	30.2
1627	751.145833	24.8	1677	753.2291663	26	1727	755.3124997	28.2	1777	757.395833	31.1
1628	751.1874997	25.1	1678	753.270833	26.9	1728	755.3541663	28.9	1778	757.4374997	30.8
1629	751.2291663	25.5	1679	753.3124997	28	1729	755.395833	29.1	1779	757.4791663	30.2
1630	751.270833	26.4	1680	753.3541663	28.5	1730	755.4374997	29.1	1780	757.520833	29.4
1631	751.3124997	27.1	1681	753.395833	29.4	1731	755.4791663	28.3	1781	757.5624997	29.1
1632	751.3541663	27.4	1682	753.4374997	29.1	1732	755.520833	27.8	1782	757.6041663	28.5
1633	751.395833	27.6	1683	753.4791663	28.2	1733	755.5624997	27.6	1783	757.645833	28
1634	751.4374997	27.4	1684	753.520833	28	1734	755.6041663	26.9	1784	757.6874997	27.1

1785	757.7291663	26.54
1786	757.770833	26.19
1787	757.8124997	26.19
1788	757.8541663	25.84
1789	757.895833	26.37
1790	757.9374997	26.54
1791	757.9791663	25.67
1792	758.020833	26.19
1793	758.0624997	25.67
1794	758.1041663	25.32
1795	758.145833	25.32
1796	758.1874997	24.97
1797	758.2291663	26.54
1798	758.270833	27.26
1799	758.3124997	28.52
1800	758.3541663	29.63
1801	758.395833	30.57
1802	758.4374997	29.26
1803	758.4791663	29.63
1804	758.520833	29.44
1805	758.5624997	28.89
1806	758.6041663	28.52
1807	758.645833	27.98
1808	758.6874997	27.43
1809	758.7291663	26.9
1810	758.770833	26.9
1811	758.8124997	26.54
1812	758.8541663	26.19
1813	758.895833	25.84
1814	758.9374997	25.67
1815	758.9791663	25.49
1816	759.020833	25.49
1817	759.0624997	25.67
1818	759.1041663	25.49
1819	759.145833	25.49
1820	759.1874997	25.67
1821	759.2291663	26.37
1822	759.270833	27.26
1823	759.3124997	28.52
1824	759.3541663	28.52
1825	759.395833	27.98
1826	759.4374997	27.62
1827	759.4791663	27.43

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