Supply and Demand: The Effects of Development on the Hydrology of Lake Victoria

Philip A. Songa and Sowed M. Sewagudde
Admiral House
Rose Wharf
78 East Street
Leeds, LS9 8BB
E-mail: philip.songa@arup.com

ABSTRACT

The water level of Lake Victoria has been falling since 2001seriously affecting Uganda's economy. Since 2004 power generation has fallen due to reduced reservoir capacity. The 2004 Net Basin Supply (NBS) was only 37 Million Cubic Meters (MCM)/day or 49% of the long term NBS. Total outflow was 113 MCM/day in 2004, corresponding to a NBS exceeded 3 in 10 years. This unhinged the equilibrium of the system, highlighting the unsustainable use. At such outflows, the hydropower reservoir could be depleted in 5 to 6 years. If the next years are predominantly dry or wet this estimate would decrease or increase respectively. Returning to natural flow could lower energy production by up to 50% - 60% over the next two years. Planning and implementation of developments on Lake Victoria to date have not taken account of the multiple users of the lake, a factor that has contributed greatly to the crisis. Future developments should therefore consider all the competing uses by incorporating Integrated Water Resources Management (IWRM).

Keywords: Lake Victoria, IWRM, hydroelectric power, hydrology, Uganda, Agreed Curve, Net Basin Supply

Introduction

Lake Victoria is the largest fresh water lake in Africa and the second largest in the world, with a mean surface area of 68,870 km^2 and a maximum depth of 84 m. The 3,450 km of shoreline is shared by Kenya, Tanzania and Uganda. The lake basin covers about 181,000 km^2 (SIDA, 2003) and has an estimated population of 33 million (EAC Secretariat, 2004).

Lake Victoria and the River Nile have been the main source of hydropower for Uganda and the region since April 1954 when the Owen Falls Dam—now Nalubaale Dam—was commissioned. In recent years there has been a drastic drop in the water level of Lake Victoria. The drop has affected the socio-economic activities of Uganda and neighbouring states, notably through frequent and sever power shortages, a fall in fish supplies and unsafe docking of transport vessels. Various stakeholders have attributed the drop in lake level to the commissioning of the additional Kiira dam in 2000 (The New Vision newspaper 14/10/2004; 11/10/2004; 19/10/2004).

This paper aims to examine this assertion using available hydrological data. Emphasis has been placed on reviewing data from the recent period 1997 – 2004 with the full record (1900 - 2004) used as reference.

The Hydrology of Lake Victoria

Lake Victoria receives about 2100 mm of rainfall annually over two main rainy seasons—the primary season is from March to May and the secondary season from September to December. The dry seasons are June to August (main) and January to February. During the mid-year dry season, evaporation from the lake exceeds rainfall by a factor of approximately 2.5. During the primary rainy season, rainfall is just greater than or equal to evaporation (WRMD, 2003). This highlights the critical role of evaporation on Lake Victoria. Rainfall on the lake surface accounts for 82% of the inflow of water to the lake. Evaporation from the lake surface accounts for 76% of the outflow and the River Nile outlet at Jinja in Uganda accounts for the rest.

Lake Victoria Release/ Regulation Policy

The current release rule in use, commonly referred to as the 'Agreed Curve', extrapolates the natural flow of the river, without the Owen Falls Dam. It is represented by a mathematical equation and is derived from the water level-discharge relationship established at what was then Ripon Falls:

$$Q = 132.923(h - 8.486)^{1.686}$$

where Q = discharge
h = stage (water level)

The rule restricts the amount of water flowing through the dams to that which would have flowed under natural conditions. It was established between the Protectorate Government of Uganda and the Governments of Egypt and Sudan after the Owen Falls Dam (now Nalubaale Dam) was completed in 1953.

Impacts of the Fall in Lake Level

Concern was raised in the latter half of 2004 as hydropower production in Uganda started to fall as a result of the lake level reducing. Since then, hydropower production has fallen by half. From an expected combined capacity (full) of 380 MW (Kiira Dam 200 MW; Nalubaale 180 MW), the total on the grid is 264 MW (The Monitor Newspaper, April 8 2007). Of this, Nalubaale & Kiira dams are producing 153 MW, thermal –generated power accounts for 101 MW while 10 MW is imported. The total current deficit (April 2007) therefore is 120 MW (The Monitor Newspaper, April 8 2007).

Other notable effects within the region include:

- Fish production has decreased as breeding grounds in shallow water are no longer accessible.
- It was difficult for larger vessels to dock as jetties were exposed.
- The Water Hyacinth is re-establishing on some parts of the lake shores with the roots taking hold in mud.
- Water and sewerage pipes were exposed leading to poorer quality raw water being pumped to treatment, associated cost of extending water supply pipes and risk of contamination from wastewater.

Currently the Directorate of Water Development (DWD) has restricted outflow to 750 m^3/s (cf. Agreed Curve outflow of 530 m^3/s) (C. Tindimugaya in 'Squeezing Victoria's Curves).

Study Methodology

The balance of rainfall, evaporation and outflow defines the lake's mass balance. The hydrological processes on the lake from 1900 - 2004 were reviewed and a comparison made with the year 2004 by examining the long-term lake levels, the Net Basin Supply (NBS), water releases through the dams and the net storage.

Examination of the Rate of Lake Level Drop

We investigated the severity of the current drop in water levels in relation to major historical lake level drop periods. The period 2000-2004 was compared with major drop periods from 1900 to date and ranked. Given Lake Victoria's size, a change exceeding ± 0.3m in successive years is characteristic of a dry or wet period. Selection of drop periods was based on successive years in which the drop exceeded 0.3 m. For a series x_t $(t = 1,2,\ldots\ldots\ldots\ldots, n)$ a drop occurs at any time t $(t = 1,2,\ldots\ldots\ldots\ldots, n)$. In the interval selected the time series should satisfy the following condition:

$$\text{If } x_{t-1} > x_t > x_{t+1} \qquad (1)$$

Where i $(i = t+1,2,\ldots\ldots\ldots\ldots, n)$ and is the t-value for which Equation 1 is satisfied again. Where $x_i - x_t \leq 0.10m$, the rise was ignored and the period was treated as a drop period.

Comparison of NBS and Nile Outflow/ Dam Releases

The following expression was adopted to represent the water balance of Lake Victoria.

$$\Delta S = \underbrace{\text{Rainfall} + \text{Land discharge} - \text{Evaporation}}_{\psi} - \text{Re}\mathit{lease} \qquad (2)$$

Where ΔS = the net storage

The quantity ψ in Equation 2 is referred to as the Net Basin Supply (NBS) and is defined as the 'inflow available for out flow'.

We computed the difference between the NBS and the dam releases /Nile outflow. A positive result (NBS > outflow/dam releases) implied that water drawn from the lake can be sustained by the supply whereas a negative one implied no replenishment of the resource. In the absence of complete data for the 3 components of the NBS for the period of interest, the NBS was calculated as a function of the depth and surface area.

Comparison of 'Rate of Storage Deficit' (RSD) in Major Drop Periods

The analysis used for the rate of drop was repeated using the same selection criteria for the drop periods but analysing the NBS instead of water levels. The RSD for the major water level drop periods was computed using Equation 3.

$$RSD = \frac{1}{n}\sum_{t=1}^{n} NBS \qquad (3)$$

Where n = the number of years in drop period.

Analysis of the Releases at Nalubaale and Kiira Dams

The releases at Kiira and Nalubaale were expressed in terms of depth to determine their effect on the lake levels. The analysis was based on data beginning 1997/98 when first there were deviations from the Agreed Curve (releases were less than the Agreed Curve). At that time, the Directorate of Water Development (DWD) required further restriction of water releases to decrease the flow into Lake Kyoga downstream which had flooded following high El Nino rains.

Results and Discussions

Before 1960 the average Lake Victoria level was 1133.95 m above mean sea level (AMSL). The lake level rose by 2.4 m in a period of two and half years, a rise widely attributed to heavy rains between 1961 and 1964, and reflected in other lakes in the region (Plinston and Sene, 1994). The level remained at an average of 1134.9 m AMSL between 1960 - October 2004.

Figure 1 shows the long-term average lake level from 1900 to 2004 (1134.4 m AMSL). The lake level has shown a significant downward trend from 1960 with the level in 2004 being around the long-term average lake level from 1900 - 2003. By March 2005, the lake elevation was still in the natural fluctuating band of the lake but the increased rate at which the levels receded between 2003 and 2004 was of concern.

Table 1 shows the results from the examination of the rate of lake level drop and explains the most drastic drops in the level of Lake Victoria. It shows that 2002 - 2004 is not the worst elevation drop period for the lake. Three of the top five worst drop periods occurred before regulation of the lake i.e. 1917-1922, 1927-1929 and 1932-1935.

From the data, during the periods 1979-1982, 1964-1967, 1952-1955 and 1969-1977, lake rainfall and catchment discharges decreased considerably yet the losses due to evaporation and outflow at Jinja were on the increase, resulting in sharp declines in water level. The drop in levels for the period 1998-2000 however was caused by a decision to relieve Lake Victoria of excessive flooding caused by the El Niño rains. In drawing conclusions for 2000-2004, we should bear in mind that 2004 was not the end of the drop period but rather the end of the time series and it is clear that the drop period was still extending.

Figure 1. Long-Term Water level of Lake Victoria, 1900 – 2004.

Table 1. Periods of extreme water level drop.							
Period of drop			Water level (m AMSL)			Rate of drop (m/Yr)	Rank (Rate of Drop)
Start Year	End Year	Duration	Start	End	Drop (m)		
1932	1935	3	1134.27	1133.39	0.88	0.293	1
1979	1982	3	1135.58	1134.75	0.83	0.277	2
1964	1967	3	1135.92	1135.10	0.82	0.273	3
1917	1922	5	1134.61	1133.36	1.25	0.250	4
1927	1929	2	1134.15	1133.67	0.48	0.240	5
1948	1950	2	1134.12	1133.69	0.43	0.215	6
1942	1946	4	1134.40	1133.55	0.85	0.213	7
1952	1955	3	1134.33	1133.74	0.59	0.197	8
2002*	2004	2	1134.70	1134.32	0.38	0.190	9
1998	2004	6	1135.45	1134.32	1.13	0.188	10
1991	1994	3	1135.05	1134.51	0.54	0.180	11
1906	1912	6	1134.55	1133.54	1.01	0.168	12
1969	1977	8	1135.50	1134.33	1.17	0.146	13
1983	1986	3	1134.90	1134.54	0.36	0.120	14

*Does not satisfy set criterion not included because it is the period of concern.

Comparison of NBS, Nile Outflow/Dam Releases and RSD

The 2004 NBS was estimated as 37 x 10^6 m^3/day, which is 49% of the long term NBS average of 76 x 10^6 m^3/day. This corresponds to 27th percentile on the NBS frequency distribution. The Lake Victoria Water Management Study (2004) put the 2004 NBS at 22.9 x 10^6 m^3/day or approximately 31% of the historical average NBS, corresponding to the lower 24th percentile on the NBS frequency distribution (Figure 2). Clearly from both results the lake basin experienced a hydrological drought. The discrepancy in the two results could be explained by the fact that the Water Management Study NBS was computed in September 2004 when the levels were lowest in the year, yet the lake experienced significant inflows from the late rains in November and December 2004.

Considering the low NBS, 2004's total release of 41,200 x 10^6 m^3 (113 x 10^6 m3/day) severely destabilised the system equilibrium. Figure 2 establishes that 2004's water release corresponds to a NBS of 3 in 10 years (put another way, the NBS is less than this value 70% of the time); contrast with the average NBS of 5 in 10 years. Furthermore in the last two years the water releases have been above the average NBS, which is clearly unsustainable.

From the RSD analysis, 2002-2004 is not the period with the highest water level drop rate, but it is the period with the highest RSD (Table 2). Of the top 10 ranked storage deficits, 7 occur after 1953 when the Nalubaale dam was completed. It is most likely that the existence and operation of the power station bears some responsibility for this value.

Analysis of the releases at Kiira and Nalubaale Dams

In 1997/98, operation of the power stations deviated from the Agreed Curve on the advice of DWD, releasing less water with intent to restrict flooding in Lake Kyoga downstream. Between May 1998 and May 2000, the releases

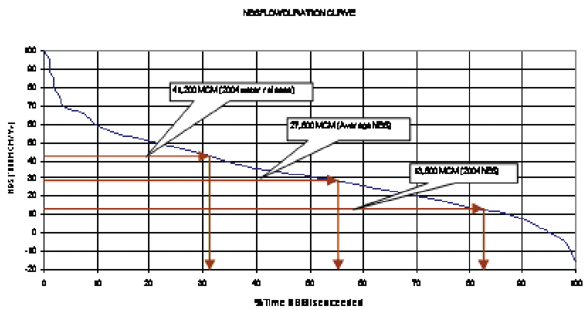

Figure 2. NBS duration curve.

were below what the natural flow would have been. As a result there was excess storage in Lake Victoria. Once the Kiira dam was commissioned (May 2000) the total releases exceeded what would have occurred under the Agreed Curve.

Between May 2000 and July 2001, the excess releases drew on accumulated storage which was used up by 15th July 2001 when the lake was back in balance (expected level equal to actual level).

From 2000 to May 2004, the lake experienced a recess in levels, attributed to low inflows due to less than average rainfall. The trend was worsened by sustained high releases in excess of the expectation at the prevailing lake level. Excess releases continued to deplete the lake leading to a final levels of 1133.87 m on 3 November 2004 (expected Agreed Curve level would have been 1134.21 m).

It is clear that deviation from the Agreed Curve led to an additional lake drop of

0.34 m in about 3 years. This is supported by Kull (2006) who states that "...since the historical data used to develop the Agreed Curve included previous droughts, dam operations according to the Agreed Curve would not lead to unnatural extreme drops in lake levels". The excess releases increased the rate of drop in lake levels three-fold, with 2003 and 2004 accounting for 77% of the extra drop, and over 50% occurring during 2004 alone. At the end of 2004, the lake level was 1134.09 m rather than the expected 1134.47 m at the Jinja water level gauge.

Table 2. Comparison of releases vs. NBS in the major water level drop periods.

Period of drop			NBS	Release	Net Storage ΔS	ΔS/Yr	Rank ΔS/Yr	Rank Drop rate
Start Year	End Year	Duration						
2002*	2004	2	9,992	109,696	-99,704	-49,852	1	9
1964	1967	3	13,497	159,850	-146,354	-48,785	2	3
1983	1986	3	13,146	144,035	-130,888	-43,629	3	14
1991	1994	3	13,212	141,114	-127,902	-42,634	4	11
1979	1982	3	13,200	136,738	-123,538	-41,179	5	2
1969	1977	8	30,254	340,025	-309,771	-38,721	6	13
1998	2004	6	23,384	242,262	-218,878	-36,480	7	10
1927	1929	2	9,992	71,227	-61,235	-30,617	8	5
1932	1935	3	13,323	93,429	-80,106	-26,702	9	1
1942	1946	4	16,654	119,624	-102,970	-25,742	10	7
1948	1950	2	9,992	61,409	-51,417	-25,709	11	6
1952	1955	3	13,292	81,748	-68,456	-22,819	12	8
1906	1912	6	23,316	136,125	-112,809	-18,802	13	12
1917	1922	5	19,985	113,040	-93,055	-18,611	14	4

Elsewhere, Georgakakos and Yao (2004) state that had the 2004 drought continued but the lake releases followed the Agreed Curve, draw down would have been reduced by more than half to an estimated 0.18 m. Corresponding energy generation would though decrease by 42% and would need to be supplemented. It is estimated that at the 2004 rate of release, the lake level would drop a further 2.5 m in 5 to 6 years before the minimum level for power generation (1131.40 m) were reached.

Potential Solutions

Thus current operation of the dams is clearly being done contrary to the regulation rule in order to meet electricity demand. It has been pointed out that the Agreed Curve does not reflect the most constructive way to manage the water resource because it does not encourage optimisation. A pragmatic solution could be to regulate the releases so that during periods of high inflow excess water is stored and utilised during periods of scarcity. This was proposed by Wardlaw et al (2005) who developed a procedure that would permit short-to-medium-term forecasts of potential reliable power generation to improve utilisation of high lake levels. This strategy could help maximise use of this water resource.

Historically the Agreed Curve has been followed to the extent that daily sluice discharges are adjusted to ensure that the total flow downstream of the Owen Falls power station met the requirements on a dekadal basis. If the level fluctuated rapidly, primarily due to the uneven timing of rainfall inputs, strict adherence to the Agreed Curve led to unpredictable requirements for flow adjustment in the very short term. With all the available water needed for energy generation and no surplus there was an undesirable fluctuation in energy supply.

To address this, Plinston (2002) proposed a rule to minimise the variation in flow caused by strict adherence to the Agreed Curve. He proposed an outflow that can be maintained for a whole year, based on the recognition of the equilibrium condition and the lake level at the start of the year.

Outflow = Equilibrium outflow + A*(mean Agreed Curve outflow – Equilibrium outflow) (5)

where *Outflow* = the constant flow proposed for the year ahead

A = a parameter ranging from 0 - 1. If A=0, the outflow is constant at the equilibrium flow; if A=1, the outflow is set to the mean Agreed Curve flow conditions. Intermediate values give a balance of the two scenarios

Mean Agreed Curve outflow = the average flow over the year that would occur under Agreed Curve operation, conditional on the start of the year lake level, and given the expected (mean) NBS for the year ahead.

Equilibrium outflow depends only on the assumed mean of the future NBS

This rule is useful for mid-term management of the lake because it has an in-built tendency to maintain the lake level at its equilibrium level without losing the link with the Agreed Curve.

Conclusions

- 2002 - 2004 is not the worst drop rate period for the lake; the worst period occurred before regulation of the lake.
- However, 2002 - 2004 is the period with the highest Storage Deficit.
- Lake Victoria is being used unsustainably, with focus on power generation. Currently hydropower production has fallen below average capacity.
- If a similar level of releases to 2004 continues at average rainfall, the hydropower reservoir could be depleted in 5 - 6 years. If future years are extremely dry or extremely wet this limit will change accordingly.
- Planning and implementation of developments dependent on Lake Victoria must take account of the lake's multiple users and future hydrological implications.

References

WRMD (2003) A Hydro-climatic Study for Uganda. Directorate of Water Development, Ministry of Water, Lands and Environment, Uganda.

LVEMP (2002) Lake Victoria Water Quality and Limnology Study. Lake Victoria Environment Management Project.

Plinston, D. (2000) An Appropriate Short-Term Management Strategy For Lake Victoria To Provide Enhanced Stability In Hydropower Generation. SWRMD Technical report Nr: TR 01, 2000.

EAC Secretariat (2004) Proposal for Feed Back of the Vision and Strategy Framework for the Management and Development of Lake Victoria Basin to Stakeholders. East African Council.

Wardlaw, R.B., Sharif, M., & Kimaite, F. (2005) Real-time Hydropower Forecasting on the Victoria Nile. Proceedings of the Institution of Civil Engineers, Water Management 158 (WM2), 45–54.

Kull, D. (2006) Connections Between Recent Water Level Drops in Lake Victoria, Dam Operations and Drought. Nairobi, Kenya.

The New Vision newspaper, Monday, 11th October, 2004, Pg 25, The New Vision Printing and Publishing Co. Ltd. 2004.

The New Vision newspaper, 11th May, 2005, www.newvision.co.ug; accessed 23rd May 2006.

Plinston, D. & Sene. K.J (1994) A Review and Update of the Hydrology of Lake Victoria in East Africa. Hydrological Sciences Journal, 39, 1, February 1994.

The Monitor Newspaper, April 8 2007, “Thermal Energy Now Half of Total Electricity” by Angelo Izama.

BBC Radio 4: Factual, Monday 2 April 2007, “Squeezing Victoria’s Curves”, Presented by Aisha Yahya.