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Recent changes in level of Lake Victoria / Récents changements enregistrés dans le niveau du Lac Victoria

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Recent changes in level of Lake Victoria

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ABSTRACT The level of Lake Victoria rose by over 2.5 m between October 1959 and May 1964. Following a slight fall the lake began to rise again in 1978 and by mid 1979 had again reached almost to the level of 1964. Because these recent rises are in contrast to the previous long period (60 years) of relatively stable levels they aroused considerable interest. This paper examines possible manmade and natural causes for the rises and opts for an increase in over-lake precipitation as the most likely cause. Comparison is also made with similar rises in other East African lakes.

Récents changements enregistrés dans le niveau du Lac Victoria
RESUME On a enregistré une augmentation de plus de 2.5 m du niveau du Lac Victoria entre les mois d'octobre 1959 et mai 1964. Suite à une légère baisse, le niveau d'eau du lac a monté à nouveau en 1978 pour atteindre, au milieu de l'année 1979, presque ce qu'il était en 1964. Ces récentes élévations du niveau d'eau qui font contraste avec la longue période (de 60 années) relativement stable enregistrée précédemment ont suscité un vif intérêt. On examine donc, dans ce document, les causes naturelles et artificielles de ces élévations et l'on constate que les précipitations abondantes sur l'étendue du lac sont le motif le plus vraisemblable de ces changements. On compare également la situation avec des montées analogues survenues pour d'autres lacs de l'Afrique.

INTRODUCTION

Lake Victoria is the third largest lake in the world and together with Lakes Kyoga and Mobutu Sese Seko (formerly Lake Albert) forms a chain containing an estimated 3200 km^3 of fresh water. The tributaries of Lake Victoria come from five countries, Burundi, Kenya, Rwanda, Tanzania and Uganda. The sole outflow from the lake, the River Nile, flows through Lakes Kyoga and Mobutu Sese Seko, through the Sud and to its junction with the Blue Nile at Khartoum.

Although the White Nile contributes on average only 14% of the flow in the combined White and Blue Niles as measured at Aswan (Hurst, 1952) its importance lies in the constancy of its flow. This constancy is due to the natural regulatory effect of the equatorial

Lakes Victoria, Kyoga and Mobutu. It is clear then that any change in the characteristics of these lakes and, particularly of Lake Victoria because of its size, is of major importance to the riparian countries.

Many studies of the Nile and the equatorial lakes have been reported (e.g. WMO, 1974 and 1980). The most well known of the authors, because of his important contributions to statistics and hydrology, is undoubtedly H.E. Hurst. His many investigations of the river included several plans (Hurst, 1952) for the control of the equatorial lakes. Hurst (1952) also pointed out the apparent inconsistencies in the statistics of Nile flows over different periods, showing that over the period 1870-1898 the mean flow at Aswan was 110 x 10^9 m^3 $year^{-1}$ while for the period 1899-1957 the average had decreased to 83 x 10^9 m^3 $year^{-1}$, a drop of nearly 25%.

In a later paper, Hurst (1957) noted that the expected values of the range of annual Nile flows did not correspond to the theoretical expected values from commonly used statistical models. It has been suggested (Klemes, 1974) that the shifting mean and the Hurst phenomenon are a cause and effect.

Whether or not the 1898 change in discharge was related to a

Table 1 Beginning-of-year lake levels and annual over-lake precipitation data

Year	Lake Victoria levels* (m) Entebbe	Jinja	Kisumu	Mwanza	Lake Victoria precipitation† (mm)	Lake Mobutu levels* (m)	Lake Malawi levels§ (m)	Lake Tanganyika levels¶ (m)
1950	10.25	10.69	10.59	7.59	1640	10.32	473.05	773.32
1951	10.13	10.65	10.83	7.52	2199	9.94	472.90	773.14
1952	10.15	11.18	11.39	8.05	1457	10.57	473.29	773.71
1953	10.80	11.31	11.34	8.20	1523	10.83	472.74	774.11
1954	10.53	11.06	11.32	7.88	1514	10.25	472.38	773.95
1955	10.36	10.86	11.19	7.74	1793	10.43	472.44	773.63
1956	10.34	10.84	11.21	7.70	1550	10.46	473.29	773.67
1957	10.40	10.91	11.25	7.75	1483	10.69	473.35	773.85
1958	10.53	11.02	11.27	7.70	1469	10.76	473.90	774.12
1959	10.44	10.94	11.26	7.74	1646	10.67	473.42	774.02
1960	10.34	10.84	11.36	7.57	1781	10.56	472.93	773.87
1961	10.35	10.87	11.14	7.70	2201	10.98	472.74	773.89
1962	11.43	11.95	12.16	8.72	1596	12.57	472.93	774.51
1963	11.88	12.40	12.64	9.23	2019	13.85	473.72	775.55
1964	12.39	12.91	13.16	9.77	1871	13.88	474.27	776.35
1965	12.39	12.89	13.16	9.75	1615	13.61	474.06	776.49
1966	11.98	12.49	12.76	9.35	1720	12.59	473.81	776.10
1967	11.83	12.33	12.63	9.20	1726	12.30	473.60	775.70
1968	11.78	12.32	12.45	9.13	1989	11.94	473.42	775.83
1969	12.06	12.58	12.76	9.39	1745	12.28	473.60	776.21
1970	11.83	12.36	12.53	9.22	2023	12.02	473.48	775.78
1971	11.95	12.46	12.63	9.23	1329	12.14	473.51	775.63
1972	11.68	12.18	12.35	9.09	1715	11.60	473.29	775.35
1973	11.83	12.28	12.51	9.15	1433	11.59	473.35	775.12
1974	11.54	12.06	12.23	8.89	1763	11.42	474.02	774.67
1975	11.46	11.97	12.17	8.78	1963	11.30	473.96	774.63
1976	11.47	12.04	12.24	8.87	2068	11.70	474.27	774.37
1977	11.34	11.70	12.05	8.69	1712	11.32	474.02	774.35
1978	11.61	12.03	12.32	9.00	1412	11.87	474.63	774.60
1979	12.06	12.56	12.75	9.38	1355	12.27	475.73	774.65
1980	12.00	–	–	–	–	–	–	–

* Gauge datums are as follows (metres a.m. s.l.):

Entebbe	1123.46	Mwanza	1125.83
Jinja	1122.95	Butiaba (L. Mobutu)	609.82
Kisumu	1122.34		

† Precipitation data are total over-lake rainfall.

§ Extracted from figure in *Summary Report on High Levels of Lake Malawi* by Malawi Ministry of Agriculture and Natural Resources, Lilongwe, 1979.

¶ From Ministère d'Agriculture Burundi.

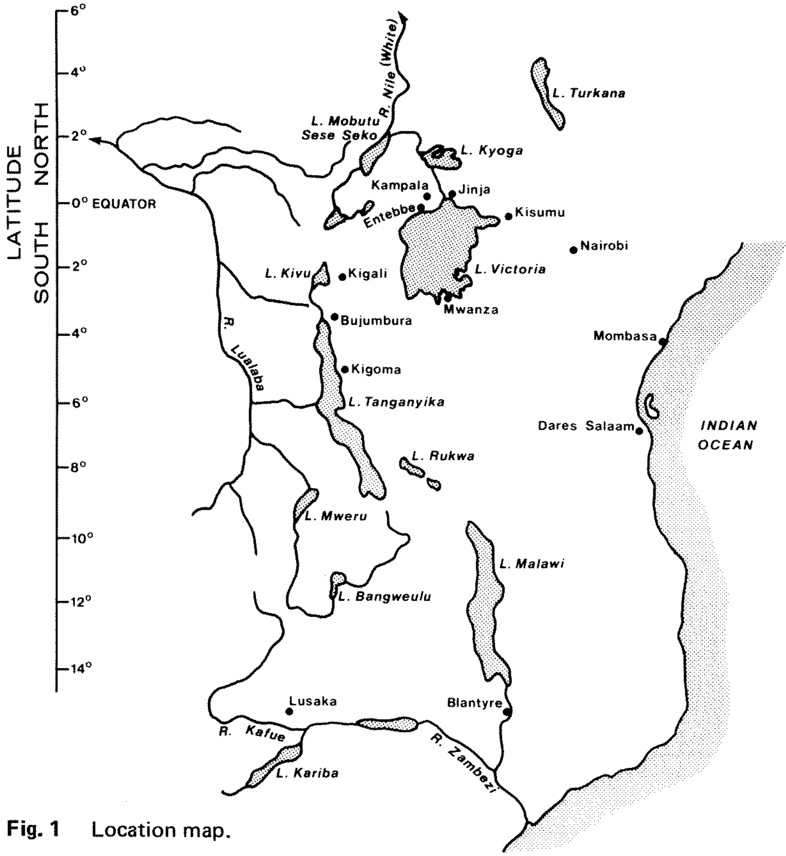

Fig. 1 Location map.

change in level of the equatorial lakes is not known although Lamb (1966) has pointed out that the level of Lake Victoria was "high" until about 1895 but by 1902 it had dropped by around 0.75 m. The latest scientific study of the Upper River Nile basin is that by the WMO/UNDP Hydrometeorological Survey, a cooperative project of the eight riparian countries and the UN (WMO, 1974). This latest study has shown that the more recent significant jumps in flow of the White Nile are related to changes in level of Lakes Victoria and Mobutu. The average annual outflow from Lake Victoria over the period 1900-1961 was 20.8 x 10^9 m^3 while for the period 1962-1979 the average was 38.6 x 10^9 m^3, nearly double. The standard deviation of the annual flows for 1962-1979, 10.40 x 10^9 m^3, is more than twice the standard deviation, 4.60 x 10^9 m^3, of the earlier period. This dramatic change in the flow of the Nile, which in 1964 flooded parts of Cairo, is clearly a result of the rise in level of Lake Victoria by around 2.5 m between 1960 and 1964; such a rise accounting for a volume of 70 x 10^9 m^3 of water. Similarly a somewhat smaller rise in level of Lake Victoria has taken place since January 1977 with, again, a corresponding increase in River Nile flows.

Table 1 lists the beginning-of-year lake levels as measured at Entebbe, Jinja, Kisumu and Mwanza around the shores of Lake Victoria. Figure 1 shows the locations of these towns. Figure 2 which plots the lake levels for the years 1950 - 1980 clearly shows the increase

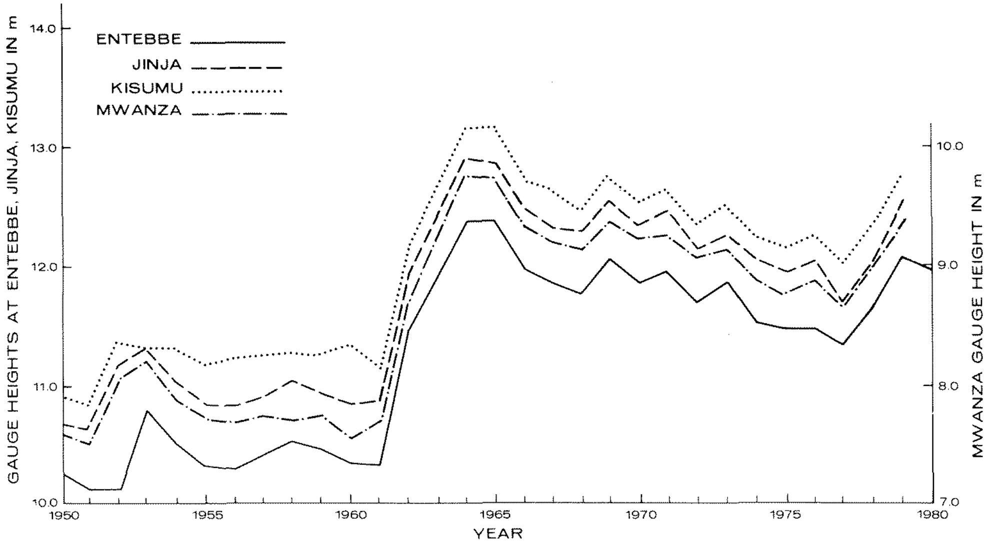

Fig. 2 Lake Victoria beginning-of-year lake levels (note that all gauges have different datums).

in lake level in the early 1960's and the second rise in the late 1970's. (Figure 5 shows in more detail the lake levels at Jinja for the period January 1977 - December 1979.) The two rises are confirmed on all four gauges which, with very minor exceptions, follow the same pattern. The gauge datums are not identical which explains the differences in elevation between the various gauges and, of course, reduces the accuracy of lake volume determinations.

It is also interesting to compare the changes in the level of Lake Victoria with those of other lakes in East Africa. Figure 3 shows the beginning-of-year levels for Lakes Victoria, Mobutu Sese Seko, Tanganyika and Malawi. All four lakes show the same rises in

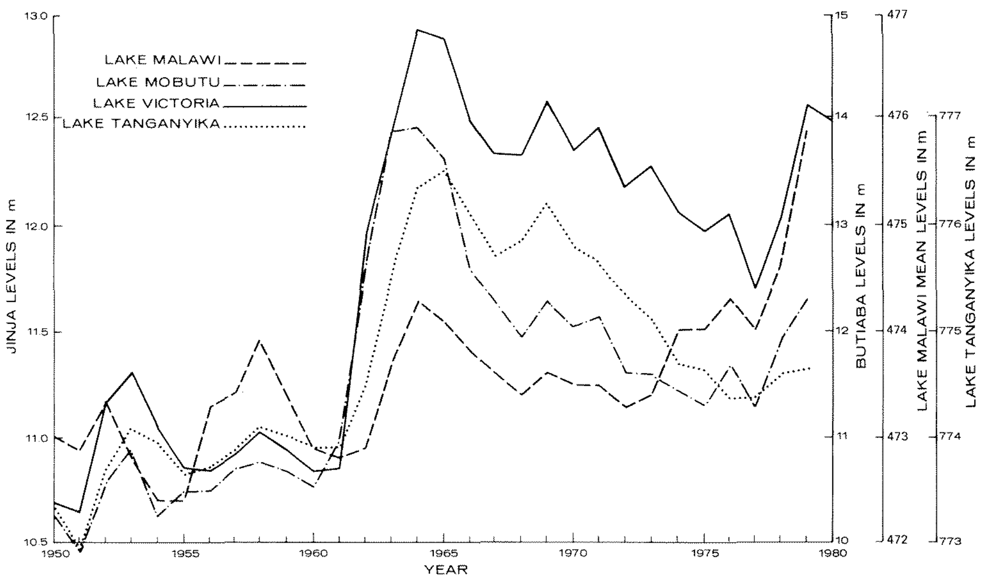

Fig. 3 Beginning-of-year levels for various East African Lakes.

the early 1960's and late 1970's. Even the smaller rises and falls over the period 1965-1975 are reproduced on all of these lakes. This is curious considering the wide geographical spacing of these lakes and implies some large scale climatic feature affecting the entire area. Lamb (1966) has concluded that a change in the general wind circulation occurred in the late 1950's to early 1960's which has affected rainfall patterns in many parts of the world.

Besides their scientific interest, these comparatively rapid steps in lake level, and consequently in lake outflow, have a considerable importance since shore settlements and installations as well as international agreements on River Nile flow have been founded on the assumption of the validity of long term mean statistics. It now appears that this assumption must be questioned and alternate procedures devised.

EFFECT OF OWEN FALLS DAM

Under natural conditions the outflow from Lake Victoria was controlled by the Ripon Falls in the Victoria Nile at Jinja. Following construction of the Owen Falls Dam these falls have become partially submerged (Westlake *et al.*, 1954). The centre portion of the falls was removed so that today there is subcritical flow in the

Table 2 Possible effect of Owen Falls Dam on Lake Victoria levels

Year	Excess (+) or shortage (−) in River Nile flows (10^6 m^3)	Possible increase (+) or decrease (−) in natural level of Lake Victoria (cm)
1954		
1955		
1956		
1957	+6.37	−.01
1958	+30.44	−.05
1959	+17.73	−.03
1960	+1.15	0
1961	+61.75	−.09
1962	+66.24	−.10
1963	+60.73	−.09
1964	+468.70	−.69
1965	+3183.20	−4.68
1966	+896.08	−1.32
1967	+40.92	−.06
1968	+20.27	+.03
1969	+571.05	−.84
1970	−503.99	+.74
1971	+30.71	−.05
1972	+16.30	−.02
1973	−150.40	+.22
1974	−1188.65	+1.76
1975	−1585.68	+2.34
1976	+209.10	−.31
1977	+289.07	−.43
1978	−1161.51	+1.71
1979	−3316.21	+4.84
	−2569.08	+2.89

centre of the river and supercritical flow on each side over the remains of the rapids.

Operation of the dam controls the flow such that the sum of turbine and sluice discharges, calculated from rating curves based on model tests, is equal to the natural river flow as calculated from an "agreed curve". This agreed curve relates Jinja lake levels to preconstruction discharge measurements at Namasagali over the range 10-12 m. Above the 12 m mark the curve has been extended on the basis of model tests. There are a number of problems with this agreed curve; first, the gauging site at Namasagali was found, by the Hydrometeorology Project, to be inaccurate because of backwater from Lake Kyoga and was abandoned in favour of the site at Mbulamuti, 20 km upstream. However the Mbulamuti rating curve must also be inaccurate, since it is asymptotic to level 12.9 m while recent Jinja levels have exceeded 13.0 m. On the basis of this rating curve the dam operating authorities prepare a monthly summary hydraulic statement listing excesses or shortages. Table 2 summarizes published excesses and shortages on an annual basis for the available period, 1957-1979.

The excesses and shortages are volumes of water and, when divided by the areas of Lake Victoria corresponding to the appropriate levels, can be converted to depths over the lake; thus apparently establishing the effects of the Owen Falls dam on the level of Lake Victoria. The last column of Table 2 has been computed in this way and shows a cumulative effect over the period 1957-1980 of a rise in lake level of just under 3 cm, a negligible figure compared to the recorded change in lake level over the same period.

NATURAL CAUSES OF CHANGES IN LAKE LEVELS

The components of the water balance of Lake Victoria are, in order of decreasing importance, rainfall over the lake, evaporation from the lake, outflow from the lake and runoff from the surrounding land areas. Table 3 shows the values of each of these variables

Table 3 Monthly water balance of Lake Victoria in millimetres of depth averaged over the 5 years ending 31 December 1974

Month	Precipitation	Tributary inflow	Outflow	Evaporation
January	137	26	47	119
February	114	21	43	112
March	185	26	48	139
April	299	51	48	154
May	202	51	52	151
June	37	38	51	166
July	72	39	50	175
August	60	38	50	137
September	78	38	46	109
October	108	30	47	114
November	172	33	45	107
December	151	28	47	110
Totals	1660	420	570	1590

averaged over the 5 year period 1970-1974. It can be seen that the average annual over-lake precipitation and evaporation are of the same order of magnitude while the average annual land runoff and lake outflow are only one quarter as large.

The annual imbalance of 80 mm calculated from the figures in Table 3 (precipitation + land runoff - evaporation - outflow) corresponds to the observed fall in lake level of 390 mm over the 5 year period.

It is also important to consider the magnitude of changes in the values of these variables. For the same period, 1970-1974, the range of each of the variables expressed as multiples of the average annual values is, for precipitation, 0.84 - 1.22; for evaporation, 0.99 - 1.02; land runoff, 0.71 - 1.06; and for lake outflow 0.90 - 1.14. It is clear that annual evaporation remains relatively constant while precipitation (and hence land runoff) is more variable. The rate of evaporation depends primarily on the availability of water and heat; since, on Lake Victoria, water is constantly available and the temperature is virtually constant, it is to be expected that the annual evaporation will show little change. It is likely, therefore, that natural changes in lake level will be caused more by changes in precipitation than by changes in evaporation.

To reproduce the effect of the rise in lake level of the early 1960's, a water balance was calculated for the three periods 1950-1960, 1961-1964 and 1965-1976 representing a period before the rise, during the rise, and after the rise.

First consider the recorded lake levels for these periods:

	1950-1960	*1961-1964*	*1965-1976*
Level at beginning of period (m)	1133.63	1133.82	1135.34
Change in level over the period (m)	+0.19	+2.02	-1.19
Change in level (mm year^{-1})	+17	+505	-99

Now consider the water balance obtained from over-lake precipitation and evaporation and land runoff:

Mean annual data	*1950-1960*	*1961-1964*	*1965-1976*
Rainfall (mm)	1641*	1944*	1763
Evaporation (mm)	1594†	1594†	1594†
Land runoff (mm)	328*	368*	345
Outflow (mm)	320*	567	589
Balance (mm)	+55	+151	-75

* *From de Baulny & Baker (1970).*
† *Assumed to be the same as for 1970-1974 since these are the only data available.*

The water balance for the last period is fair, but for the other two periods the balance is poor. It seems that a simple water balance cannot explain the rise in lake level.

The third step in the investigation of the possible natural causes of changes in lake level was to run a monthly lake routing model using over-lake precipitation and evaporation data and land runoff data to estimate lake levels and lake outflows.

By inputting these data the estimated lake levels obtained as output can be compared with the recorded lake levels. Figure 4 shows

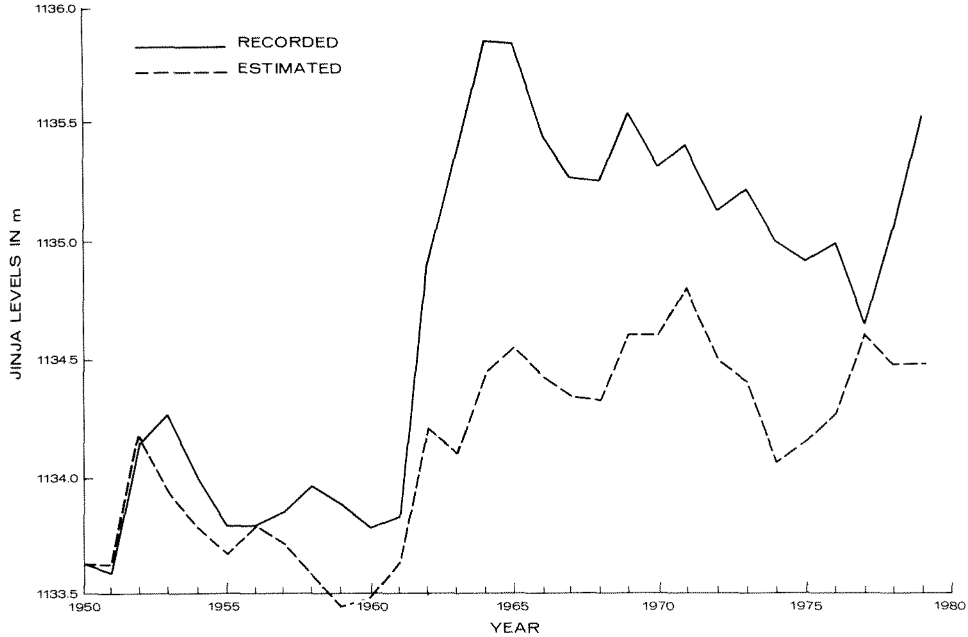

Fig. 4 *Lake Victoria beginning-of-year levels, recorded vs. estimated.*

this comparison for the years 1950-1980. It is immediately apparent that, although the estimated levels show the same pattern as the recorded levels, the model has not reproduced the sharp jump in lake levels recorded in the early 1960's.

Since neither a simple water balance nor use of a mathematical model can duplicate the observed rise in lake level it is necessary to reconsider the input data. Over-lake precipitation is very difficult to estimate; the Hydrometeorology Project has used, from 1970 onward, a weighted average of data from lake shore stations supplemented by data from island stations when available. The accuracy of this method is said to be ±10%. Before 1970 the data are scarcer, the island stations non-existent, and the accuracy must be much less.

Land runoff data are also very scarce. Out of the total of 30 years used, runoff was measured for only 16; for the remaining 14 years the annual land runoffs were estimated by regression on Kagera River annual runoffs. This is a doubtful procedure since although the Kagera accounts for around 50% of the total annual runoff into Lake Victoria, the other 50% comes from regions which may have different climate patterns. Monthly land runoffs were then estimated from the annual figures using the within-year distribution of flows obtained as an average of the observed data for 1970-1977.

Evaporation data are the least accurate. For the years 1970-1974 monthly evaporation rates have been computed by a heat budget method, with an accuracy said to be ±20%. For the years 1977, 1978 and 1979 evaporation data from Kishanda station alone have been used, whilst for all other years the average of 1970-1974 figures have been used.

Using the mathematical model the effects of various changes in precipitation and evaporation data on lake levels were investigated. Figure 5 shows the results of a particular experiment. The dotted

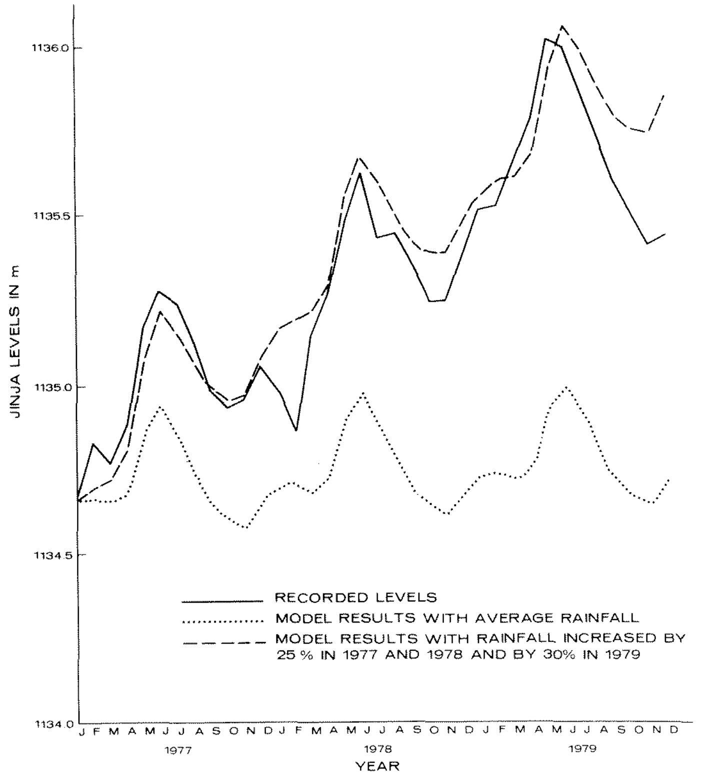

Fig. 5 Lake Victoria beginning-of-month levels at Jinja.

line shows simulated levels at Jinja using average meteorological conditions; the dashed line, which follows the solid line of the recorded levels very closely, shows model result using rainfall data increased by 25% in 1977 and 1978 and by 30% in 1979.

What has been shown by this use of the model is that the rise in lake level between 1977 and 1980 could have been caused by precipitations between 25 and 30% greater than those recorded.

CONCLUSIONS

During the period 1961-1964 the level of Lake Victoria rose by around 2.5 m; over the period 1977 to 1980 it rose by around 1.5 m. These rises are unusual given the normal small variation of such a large lake but are confirmed by independent gauges on all sides of the lake. Further confirmation is given by similar rises at the same times on other lakes in East Africa.

The only possible manmade cause of rises in the level of Lake Victoria is the Owen Falls Dam on the River Nile at Jinja. It has been shown that the effect of this dam on Lake Victoria levels over the period 1957-1980 has been to raise the lake level by 0.03 m.

The greater parts of the observed rises in lake level must therefore be due to natural causes. However, neither a simple water balance nor use of lake routing model have been able to pinpoint the exact cause. This is believed to be because estimates of over-lake precipitation and evaporation cannot be made accurately from measurements at a small number of point locations given the tropical pattern of very heavy and localized thunderstorms.

Use of a lake routing model has shown that the most recent rise in lake level can be simulated very closely if the observed precipitation volumes are increased by between 25 and 30%. This suggests that observed data may be underestimates of the true precipitation.

Rapid change in lake levels and river flows such as those described here render the use of long term average statistics unreliable for design purposes, since estimates of future lake levels and river flows are of extremely doubtful accuracy. Lamb (1966) has suggested that climate statistics (and, by inference, lake levels) for the period prior to 1895 may be more relevant for the next few decades than the statistics of any period between 1900 and 1950. This is doubtful, however, since, firstly, statistics prior to 1895 are rare and of uncertain reliability and, secondly, the directions and timings of future steps in the time series would still not be accounted for.

Salas *et al.* (1979) have shown that simulation models using a mean which shifts by a random factor at random intervals are capable of reproducing statistics such as those noted by Hurst (1957) in the River Nile flows. Possibly such models could be used as aids in determining likely ranges in levels and flows for practical purposes.

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