A NOTE ON THE WATER BUDGET OF LAKE NAIVASHA, KENYA

– especially the role of Salvinia molesta Mitch and Cyperus papyrus L

BY
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ABSTRACT. The water budget of Lake Naivasha, a fresh water lake at the bottom of Kenya's Rift Valley, just south of the equator at an altitude of c. 1885 m a.s.l. is discussed. It is suggested tentatively that the water budget of the lake to a large extent depends on groundwater flow to and from the lake. The latter point is very crucial, as the lake has no visible outlet. The water budget studies show that the potential evaporation is c. 2–3 times the amount of the annual precipitation over the lake. However, no studies so far have been made on the role that *Salvinia molesta* Mitch and *Cyperus papyrus* L, which cover a great part of the lake, play in the water budget. This study indicates that the evaporation and transpiration from samples of the floating fern *Salvinia* approximately equal the potential evaporation from a free water surface under similar conditions. For *papyrus* the corresponding figure is about 200–250 %. The introduction of *Salvinia* in the 1960's has therefore hardly increased the water loss from the lake, whereas the influence of *papyrus* on the water budget of the lake can not be disregarded. Nevertheless, the water budget studies and studies of the chemistry of the lake give strong support for the theory suggesting the existence of an underground outlet of the lake.

Introduction

The bottom of Kenya's Rift Valley (or Gregory Rift Valley as it is sometimes called after one of the early explorers) contains several lakes like L. Turkana (Rudolf), L. Baringo, L. Bogoria (Hannington), L. Nakuru, L. Elementaita, L. Naivasha and L. Magadi (cf. Fig. 1). Some of these lakes are highly alkaline; for L. Nakuru and L. Magadi the pH-values are in the range of 10–11, whereas L. Turkana, L. Baringo and L. Naivasha have pH-values around 7–8, i.e. only slightly alkaline. Except for L. Nakuru, the 'lake of the flamingoes', Lake Naivasha is probably the best known of these lakes, which is due to its easy reach from Nairobi (c. 80 km). However, knowledge of the lake is spread over quite a number of various institutions as far apart as the Botany Department of the Kenyatta University, Nairobi, the Zoology Department of the University of Leicester, U.K. and the Geography Department of the University of Stockholm.

Where is the outlet of Lake Naivasha?

For decades, the fact that Lake Naivasha is a fresh-water lake but does not have a visible outlet, has been puzzling people. Many underground outlets have been proposed and there is hardly any source of fresh water in the Nairobi area that has not at some time been suggested to emanate from Lake Naivasha. According to the present author, the most probable direction of an assumed ground water outlet is towards the south (i.e. towards L. Magadi, where there is an obviously abundant supply of freshwater although the lake itself is highly alkaline). However, to try to trace an assumed underground outlet for Lake Naivasha is in a way premature before it has been proven that the lake really has an underground outlet.

There might, of course, be another explanation for the freshwater of Lake Naivasha, as was suggested long ago by E. Nilsson (1932, pp. 72–73) namely that during periods of low water level, a stratum of salt is deposited, which is, in its turn, covered by sediment during the succeeding rainy season. Citing G.K. Gilbert and I.C. Russell, who in the late 19th century studied saline lakes in Utah and Nevada Nilsson states that this would finally result in formation of a stratified deposit consisting of salts and saline clays in alternating layers. Nilsson's theory can not be disregarded, as the present author has found some crystals of salt in a dried sediment sample from about 1 meter's depth in the sediments outside Fisherman's camp in the southern part of Lake Naivasha.

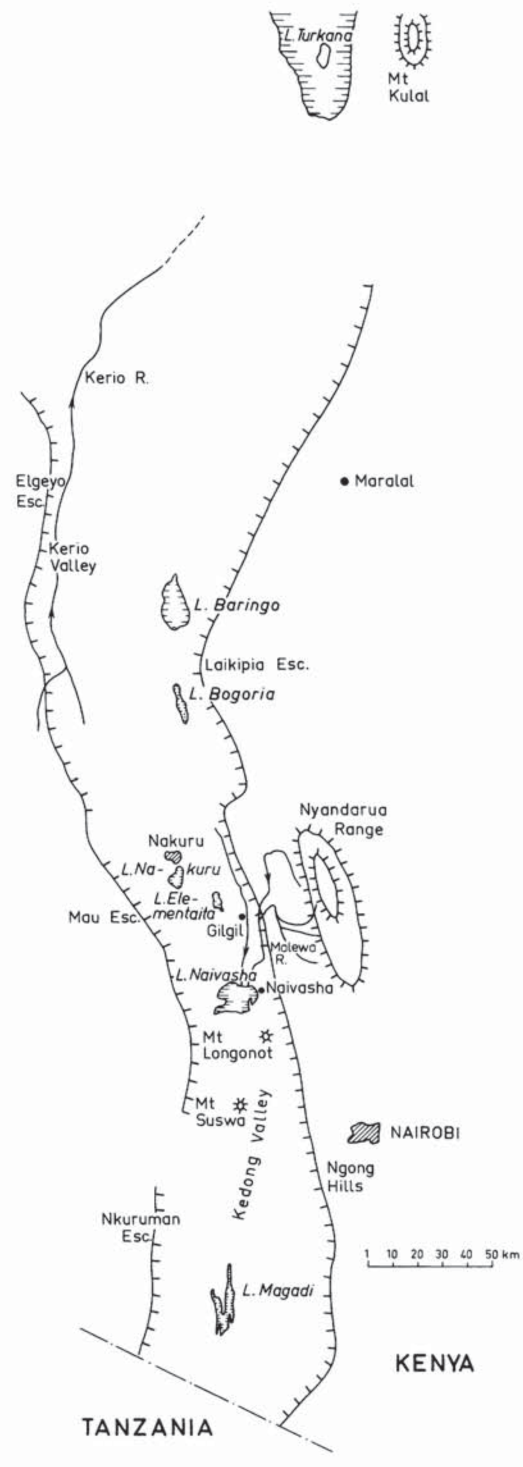

Fig. 1. Map showing the Rift Valley of Kenya and its lakes.

Water level variations of Lake Naivasha

To try to solve the problem concerning whether or not there is an outlet at Lake Naivasha, we will first turn to the water level variations of the lake during the last century.

Reading of water level have been made at three different places along the lake, namely at Lake Hotel, at Crescent Island and at Korongo (cf. the map Fig. 6). Data from Lake Hotel and Crescent Island have been obtained from the Ministry of Water Development in Nairobi, whereas the data from Korongo were obtained from Mr. Roger Mennell. The data from Lake Hotel cover the time from 1962 onwards. The data from the gauges here seem to refer to a correct Datum according to levellings that were carried out by the present author to a bench mark at 6215 feet c. 1 km SE om Naivasha Railway station. The data from Crescent Island and Korongo refer to another 0-point situated 3.61 m above the 0-point of the readings at Lake Hotel. The readings from Korongo show a very good correspondence with those at Lake Hotel if this correction is used. For the readings at Crescent Island, this correction seems to be applicable back to 1959.

Mennell's own readings at Korongo cover more or less daily observations from 1964 until his death in 1983. Before that time he also presented observations from Naivasha Staff Gauge Records for the years 1936–1964. Mennell has corrected for a change of Datum of 2 feet that took place in 1959. During the period between 1933–1958 the figures obtained from Mennell give a reasonable correspondence with those at Crescent Island if the latter figures are given a correction of +2 feet or 0.61 m. Normally, the correspondence is within a few centimeters; only in 1933 and 1935 is the discrepancy about 0.25 m. As the Korongo data (Mennell) show a good continuation over the 'crucial' period 1958–1960, his data (with the addition of the Lake Hotel data after 1982) have been used for the construction of the diagram Fig. 2 after the correction mentioned above with 3.61 m. Back to 1933 we find that these data are in good agreement with other data. (The symbol M in Fig. 2 stands for the lake level in 1959, obtained from the topographic map 1:250 000 Nyeri. As this level is only given in full feet, i.e. 6181, it must be considered to be in good agreement with the diagram, especially as the map figure probably just refers to one or a few occasions).

The records from Crecent Island kept at the Ministry of Water Development start in 1933. Before this the figures seem to be more uncertain. The diagram kept at Korongo states that the readings 1911–1935 were 'weekly observations but frequent interpolations'. Data from this time are presented by Thompson and Dodson (1963, p. 10), by Parker (1974, Fig. 2) and by the present author (Åse) in 1982 and 1986. Thompson and Dodson do not state their original, Parker's original is a drawing from the Ministry of Works (44606) that I have not been able to trace. My own original is the diagram from Korongo, which when it comes to 1909–1982 is identical with Fig. 2 except for the correction of the zero-level, i.e. 3.61 m. It is difficult to say which of the three presentations is the more correct one. There is, however, one possibility to check the data from 1927, at least. A comparison between a depth map from November 1927 presented by Thompson and Dodson (1963, p. 9) and a corresponding map from Oct. 1983 (Sernbo in Åse *et al.* 1986, p. 19) shows that the values for the depth of the lake was appproximately 2 m higher in Nov. 1927 than in Oct. 1983. (The depth contour for 30 feet in 1927 shows reasonably good correspondence with the 7 meter contour of 1983.) As the water stood around 1886 m above sea level in Oct. 1983, the corresponding figure for Nov. 1927 should

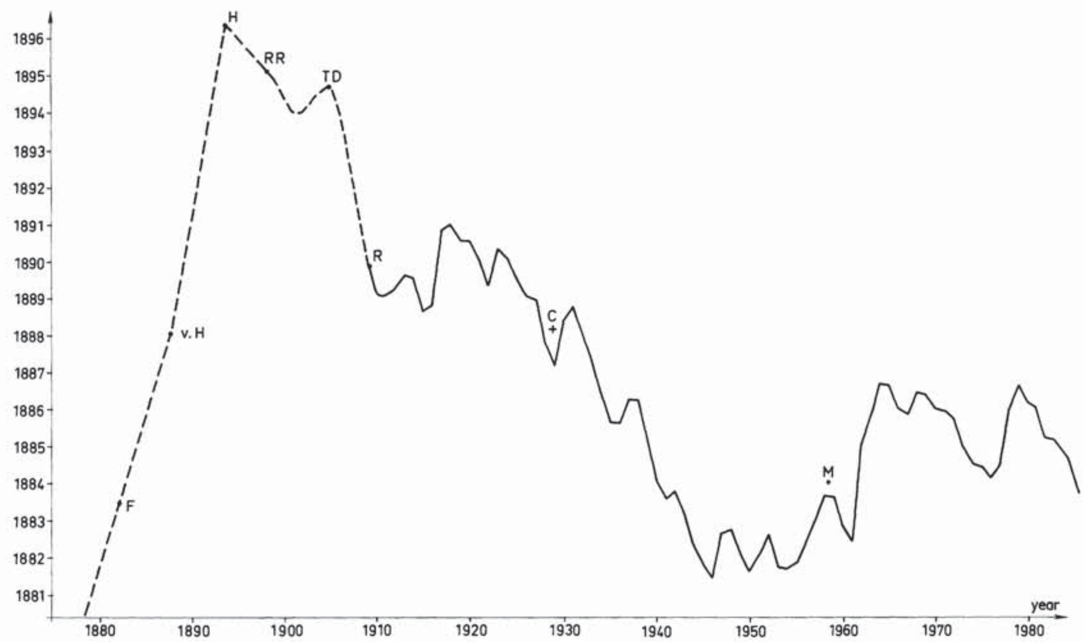

Fig. 2. Diagram showing the water level variations of Lake Naivasha 1880–1980. Symbols: F = Fisher, v.H. = von Höhnel, H = Hobley, RR = Railway records, TD = Thompson & Dodson, R = Records start, C = comparison between two maps, M = Map value. (Cf. text).

have been c. 1888 m. Thompson and Dodson give a figure of about 6205 feet, i.e. c. 1891 m for Nov. 1927. The corresponding figure given by Parker can be calculated to c. 1892 m. Mennell's original figure for Nov. 1927 is 6207.52 feet, which (multipled with 0.3048) corresponds to 1892.05 m. With the (0-point) correction of −3.61 m the figure becomes 1888.44 m, which obviously agrees better with the comparison between the two depth maps. I have therefore considered it most appropriate to use the (0-point corrected) Korongo data even for the time interval 1909–1932.

For the time before 1908 only occasional observations are available. These observations are treated by Sikes (1930) and by myself (Åse in Åse *et al.* 1986, pp. 32–34). Some new information has been obtained through fieldwork in 1985 and 1986 and is added in the following description. The highest natural point of the isthmus between Crescent Island and the mainland is c. 1883.3 m a.s.l. Thus, in 1883 the water level must have been below this figure because at the time of Fisher's visit in June 1983 Crescent Island was a peninsula. This value is a minimum figure for 1888, when Teleki and von Höhnel visited the lake. A more realistic figure is c. 1888 m a.s.l., as the (very small scaled) map of von Höhnel (1892) shows a lake contour slightly below the 6200 feet contour of the topographic map. In 1894 Hobley (cited by Sikes) could not pass between the cliff, where the railway now runs, and the lake. The lowest part of the cliff SE of Naivasha railway station is situated around 1896 m a.s.l. according to a levelling by the present author in Oct. 1985. The Railway Survey of 1898 indicates a water level at that time of 6214.72 feet on September 14th and 6214.56 on November 19th, i.e. around 1895.5 m. Thompson and Dodson's diagram (1963, p. 10) indicate a rising lake level from c. 1898–1906, which seems reasonable as most of the years during that time had rather high precipitation. It is difficult to give a good figure for the presumbly high water level around 1905, but the figure given by Thompson and Dodson is c. 6216 feet or 1894.6 m, which seems realistic.

For the construction of the part of the diagram Fig. 2 that covers the time between 1880–1908, the data mentioned above have been considered. The broken line during this time interval indicates that the data are very uncertain and of sporadic nature.

Keeping the discussion above in mind, if we now turn to the information that appears in Fig. 2, we find the range of the water level variations during the last century to be c. 15 meters. Even the variation during the last decade (cf. Fig. 3) is quite impressive. After the heavy 'long rains' in 1977 the water level rose up to mid 1979 by c. 3 meters. After some regression a new peak occurred after the heavy rains in April-May 1981. The drought in 1982–1984 resulted in a dropping lake level, which is now (Nov. 1986) at about 1884 m a.s.l. Thus, on the whole the general trend of the water

Fig. 3. Water level records read at Lake Hotel, Naivasha. Data from Ministry of Water Development, Nairobi. Altitude in meters over Kenyan Datum.

level variations is in accordance with what could be expected from the climatic factors, especially the precipitation. When turning to the monthly variations (see Fig. 3 and Fig. 4) the picture is not so clear. After the normal drought at the beginning of the year, the water level normally starts to rise during the long rains in April-May. The drought during the middle of the year (cf. Fig. 5) is not evident, however, in the water level variations of the lake. To some extent, this might be due to reduced evaporation during the cloudy months of June-August, but as appears from Fig 5 this can

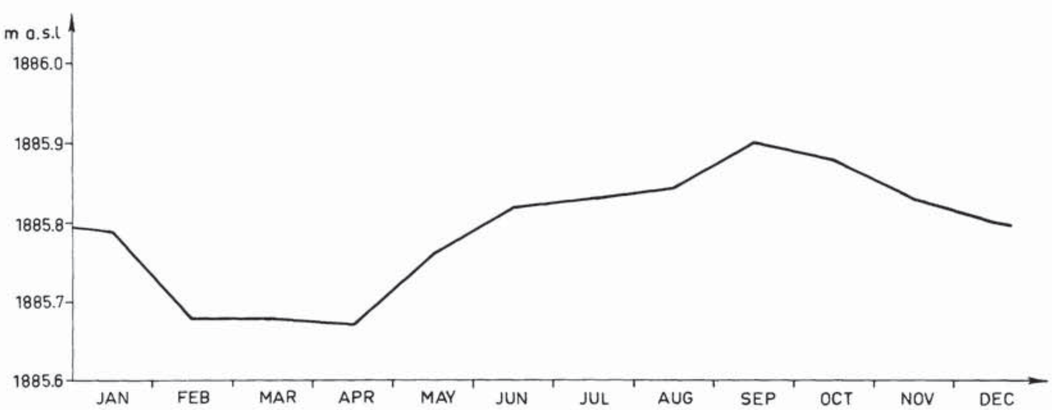

Fig. 4. Monthly variations of water level of Lake Naivasha 1911–1980.

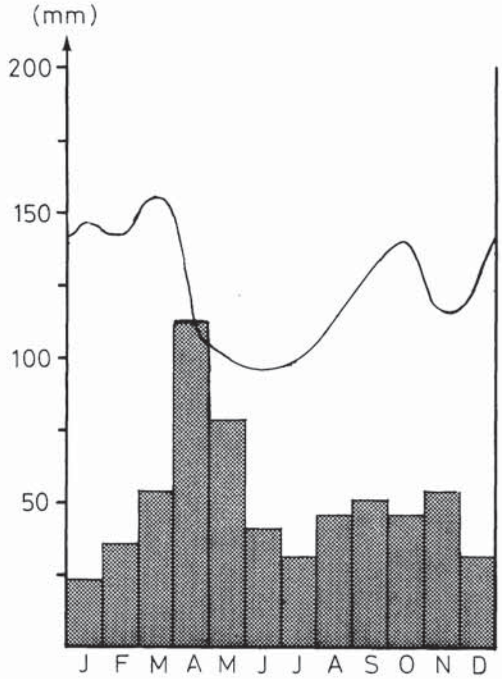

Fig. 5. Average precipitation and potential evaporation (E_O) at Naivasha D.C. 1965–1980. The panfactor used is 0.80. From Syrén in Åse *et al.* 1986, p. 51.

not be the main reason, as evaporation figures during June-Aug. are well above those of precipitation. Even during September and October, which are often bright and dry, the water level normally continues to rise. This gives us a first hint that the water level variations of the lake are to a great extent influenced by the flow of ground water.

The water budget of Lake Naivasha

The water level of Lake Naivasha is given the symbol L_N, and is due to the following factors:

$$L_N = L + P + I - E - ET \pm S \qquad (1)$$

where L is a previous water level, P the precipitation during the time between L and L_N, I the surficial inflow to the lake during the same time, E the evaporation from the free surface of the lake and ET the combined effect of evaporation and transpiration from the vegetation of the lake. Normally, the symbol S stands for water storage, but in this case S should equal the difference between the assumed underground inflow and outflow to and from the lake. Syrén (pp. 63–70 in Åse *et al.* 1986) and Åse 1982 (pp. 163–164) present figures for these parameters. Table 1 shows the figures for the period 1936–1976.

Table 1. Hydrological data for Lake Naivasha 1936-1976. (Åse 1982, pp. 163-164)

Inflow to the lake (from Maleva and Gilgil) equalling a rise of lake level	+91.45 m
Precipitation over the lake equalling a rise of lake level	+26.21 m
Evaporation from the lake (pan factor 0.8) equalling a drop of level of	-67.94 m
Real drop of lake level	- 1.5 m
Rest factor (probably underground outlet) equalling a drop of lake level of	
(91.45 m + 26.21 m - 67.94 m - 1.5 m = 48.2 m)	-48.2 m

The precipitation (P) and evaporation (E) figures have been obtained from Naivasha D.C. (see Fig. 6) and the figures for the surficial inflow (I) have been obtained from observations of the water discharge of the two major rivers flowing to Lake Naivasha, i.e. the River Malewa and the River Gilgil. Table 1 supports the theory of the existence of an underground outlet, as there is a considerable rest sum that can hardly be explained through errors in the calculations. The use of water for irrigation purposes (cf. Anonymus 1987) might influence upon the water budget during the last few decades but not on the overall picture given by Table 1.

Even another attempt has been made in this connection. Periods with very little inflow to the lake have been selected. The factors P and I in equation (1) can now be more or less excluded. Under these conditions the lake could be considered a huge evaporation pan, although a leaking one if there is an underground outlet. The following periods were selected for the test: January 1968, March 1973 and January 1975. During these three mounts, there was less than 5 mm of precipitation registered at Korongo farm or Naivasha D.C. (see Fig. 6). A little run-off occurred in the catchment, but as is evident from Table 2 the lake level changes due to this surficial inflow only corresponded to c. 0.02 m rise of lake level.

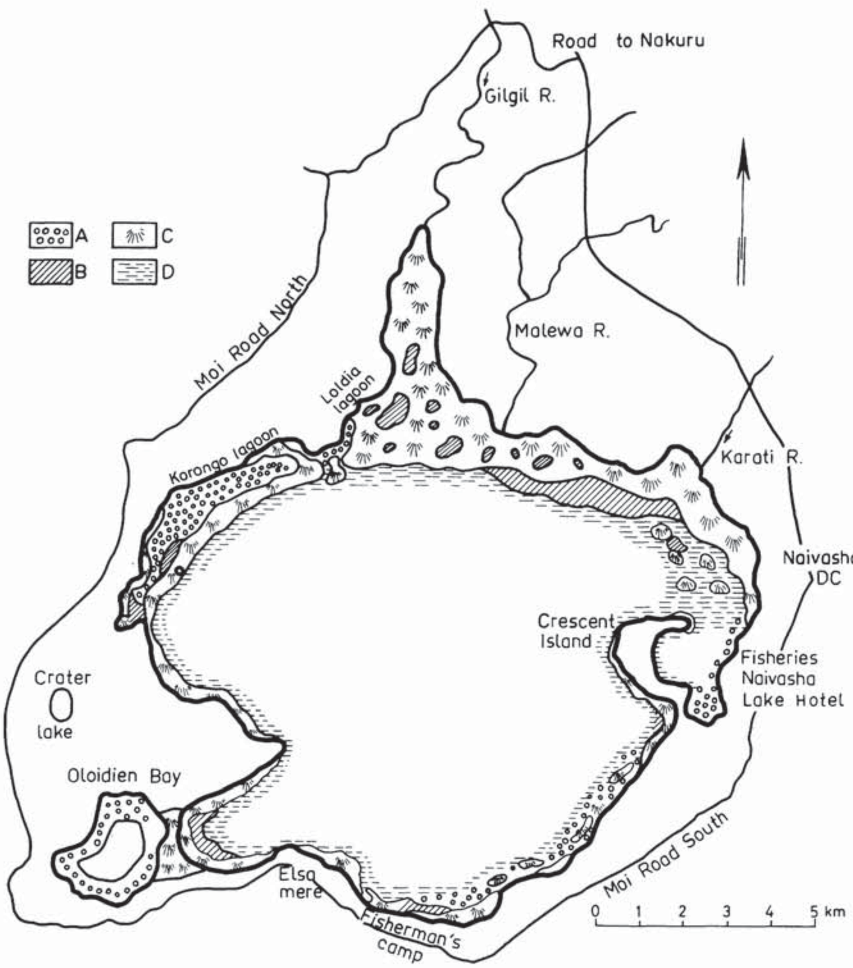

Fig. 6. Map showing the vegetation of Lake Naivasha 1974–1975. (After Jutta Dietrichs 1976 and N. Tarras-Wahlberg 1981). Key: A = water lilies, B = *Salvinia*, C = *Papyrus*, D = submerged vegetation.

Ther potential evaporation was registered at Naivasha D.C. and multiplied with a pan factor of 0.8. The water levels were registered at Korongo Farm or at Naivasha Hotel (see Fig. 6). The test was originally made to check the significance of the pan factor. As such, the test was useless, as the figures in column (5) and (6) of Table 2 vary so much, as do the ratio figures of column (7). Indirectly, however, the study gives another good reason for the assumption that the flow of groundwater to and from the lake are important factors in determining the water level of the lake.

Table 2. Calculations of evaporation from Lake Naivasha. (Åse et al. 1986, p. 52)

(1) Period	(2) Inflow	(3) Calculated lake level change due to inflow	(4) Actual lake level change	(5) Computed potential evaporation	(6) Actual potential evaporation	(7) Ratio (6)/(5)
Jan 1968	$3.4 \cdot 10^6$ m^3	+0.021 m	−0.250 m	2/1 mm	209 mm	0.77
Mar 1973	$2.8 \cdot 10^6$ m^3	+0.018 m	−0.110 m	128 mm	235 mm	1.83
Jan 1975	$2.9 \cdot 10^6$ m^3	+0.020 m	−0.150 m	170 mm	203 mm	1.20

The influence of the vegetation

There is, however, one factor that could jeopardize all the calculations mentioned above. The intelligent reader has certainly found that the factor ET in equation (1) has not been considered at all so far. In fact, the lake has been assumed to have a surface totally free from vegetation, which, as appears from Fig. 6, is obviously not the case. In fact large areas are covered by vegetation. Since the mid 70's, when the map in Fig. 6 was constructed, the submerged vegetation and the water lilies have disappered, but *papyrus* and the floating fern *Salvinia* still cover large parts of the lake. A rough estimate based on Fig. 6 is that c. 15% of the area of the lake was covered by *papyrus* and c. 5% by *Salvinia*. According to Gaudet (1977), *papyrus* covered 11% of the lake surface. Rich and Harper (1987) citing Gaudet & Falconer (1983) state that after the 1978–9 rises in water level, *Salvinia* spread to cover an area of up to 20% of the lake surface. Njuguna (1983) estimated that in 1983 *Salvinia* also covered 20% of the lake's surface, but this might refer to an occasion when *Salvinia* temporarily had spread due to special wind conditions, over large parts of the lake.

If the uptake of water by *Salvinia* and *papyrus* is higher than the potential evaporation, it could explain the rest factor of Table 1 and the whole discussion about an underground outlet of the lake would make no sense.

Cyperus papyrus L and *Salvinia molesta* Mitch

To study the role of *papyrus* and *Salvinia* in the water budget of Lake Naivasha some experiments were carried out (see below). Before we turn to these experiments a few words should be mentioned about these plants and their occurence on Lake Naivasha.

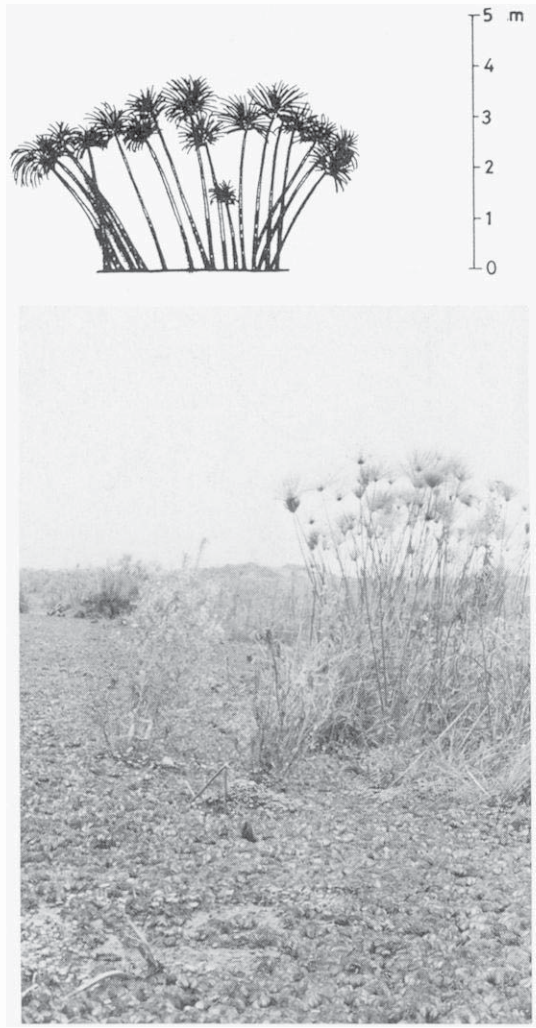

Fig. 7a. Drawing and photograph of *Cyperus papyrus* L. Photo: N. Tarras-Wahlberg.

Cyperus papyrus L is a plant belonging to the sedge family *(Cyperaceae)*. In Lake Naivasha it often reaches the size of c. 4 m and occurs both as rooted vegetation along the shores of the lake and as floating rafts (cf. Fig. 7a and Gaudet 1977). It might have spread to East Africa from the Nile area. At the time of Gregory (1896, p. 101) it was obviously already abundant at Lake Naivasha, but in the early part of this century, when the water level was rising, the amount of *papyrus* decreased (A. Hopcraft of Loldia Farm and M.D. Carnelley of Fisherman's Camp, pers. comm.). In the time of diminishing water level between c. 1930 and the early 50's the areas covered by *papyrus* increased again, as it colonized mud flat areas (Gaudet 1977, p. 36). The rise of the water level in 1977 should (according to Gaudet's discussion) make the distribution of *papyrus* decrease, but, on the contrary, *papyrus* really became a problem to the landowners around the lake in the early 80's (R. Mennell of Korongo Farm, pers. comm. in July 1981). However, since that time, *papyrus* seems to have decreased in number.

Salvinia molesta Mitch is a floating fern about the size of 2–3 cm. The leaf is covered by hairs (see Fig. 7b) that in air pictures make the *Salvinia* mats look bright (see Fig. 8). Like all ferns, *Salvinia* lacks roots. What looks like roots are actually leaves that have been converted to organs that can take up water and nutrient salts. Like *papyrus*, *Salvinia* normally multiplies asexually. In the case of *Salvinia* buds are given off which develop into new plants. The genus *Salvinia* originated in South America. Various species have spread to other parts of the world like Asia, Australia and Africa, where they have become weeds that make

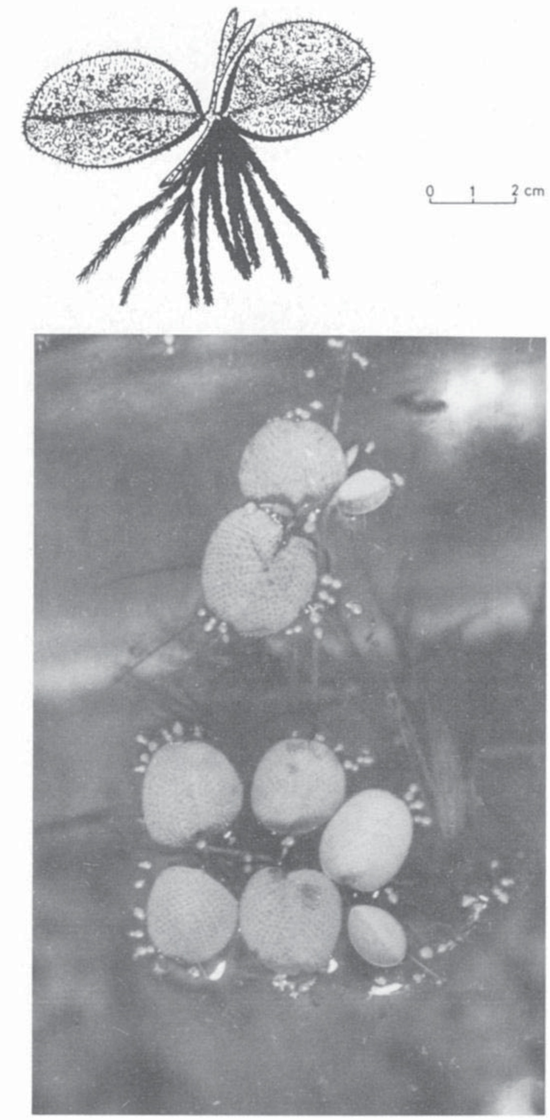

Fig. 7b. Drawing and photograph of *Salvinia molesta* Mitch. Photo: N. Tarras-Wahlberg.

ponds and lakes clog up. The *Salvinia* species of Lake Naivasha (earlier thought to be *Salvinia auricularia* but now described as *Salvinia molesta* Mitch, cf. Tarras-Wahlberg 1987) was introduced in aquaria shops in Nairobi in the 1950's (S.Njuguna 1983, p. 14). It escaped to ponds and rivers in the Nairobi area, and, possibly spread by water birds, came to L. Naivasha in the early 1960's (probably in 1962 according to Njuguna). Within 10 years it has spread to all parts of the lake and appeared in great mats, especially in the northern part of the lake. The *Salvinia* mats prevented the hatching of *Tilapia spp*. in the lake and the fishing of *Tilapia* dropped tremendously during the 1970's. Efforts were made by the Fisheries' Department in Nairobi and Naivasha to get rid of the weed and even the herbicide Gramoxone was spread over parts of the lake, but the result of the efforts was not very impressive. As stated above, in the mid 70's *Salvinia* covered c. 5% of the surface of the lake and in 1983 the *Salvinia* mats had turned into sudds, where other pants like *Hydrocotyle sp.* had started to grow. The thick *Salvinia* mats are to some extent a menace for the boating on L. Naivasha.

Experiments to study the evapotranspiration of *Salvinia molesta* Mitch and *Cyperus papyrus* L

To study the role of Salvinia and papyrus in the water balance of L. Naivasha the following experiments were conducted in October 1985 (cf. Figs. 9–11). In the first experiment three aluminum pans with a diametre of c. 30 cms were placed on the volcanic soil of a garden without shade from trees at Elsamere Conservation Centre. One of the pans was filled with water up to a cut mark in order to measure the potential evaporation, another pan was loaded with *Salvinia* so that the plants covered the whole surface and water was then added up to the cut mark. In the third pan, which was established only during the later part of the observation periods, the upper part of a cut *papyrus* stalk was placed in the pan and water added up to the cut mark. Every morning around 8 a.m. the pans were filled up to the mark and the volume added was registered and recalculated to mm. Precipitation was taken into account through simultaneous readings by Mr. John Carver, warden at Elsamere. If possible, temperature readings were made around 3 p.m. but sometimes interpolation for this time had to be made. In Fig. 11 the figures obtained through interpolation are put in parenthesis and do not have a decimal.

In the second experiment evaporation balances (cf. Fig. 10) were put on the tree stump in the shade of yellow fever trees at Elsamere. One of the balance cups was loaded with young *Salvinia* plants, the other was just filled with water to the 0-level of the scale. Readings were made every morning at 8 a.m. This experiment had to be watched very carefully, as birds wanted to drink from the balance cups and on one occasion (1985 10 21) the readings were jeopardized by colubus monkeys. In the first experiment with the three pans disturbances of a 'zoological' nature were prevented by the garden fence.

Another similar set of experiments was carried out 23.10 to 1.11 1986 at Fisherman's camp, also on the southern shore of L. Naivasha. Here a small 'meteorological site' was established in the

Fig. 8. Air photo (March 1984) showing the distribution of *Salvinia* (bright) and *papyrus* (dark) in the SW part of the main lake and adjacent parts of Oloiden Bay. Approximate scale: 1:20 000.

Fig. 9. Photo showing the pans used for the studies of evaporation, transpiration and water uptake. (Cf. text and Fig. 11). Photo: N. Tarras-Wahlberg.

shade of yellow fever trees (cf. Fig. 12). The site was fenced by thorny *Acacia* branches to prevent disturbances from various animals (especially dogs and cattle). At the site the following observations were made: Continuous registration of temperature and relative humidity (R.H.) by a

Fig. 10. Photo showing the balances used for studies of evapotranspiration from *Salvinia*. Photo: N. Tarras-Wahlberg.

calibrated thermohygrograph. Observations four times a day of solar radiation using an Esselte Pyranometer $\frac{113 \text{ mV}}{1 \text{ kW} \cdot \text{m}^2}$. Observations five times a day (normally at 6 a.m., 9 a.m., 12 noon, 3 p.m. and 6 p.m.) of transpiration from cut *papyrus* stalks put in a measuring cylinder filled with water and a thin oil film to prevent evaporation (cf. Fig. 12). On every occasion the water level of the cylinder was raised to the 0-level by adding water with a graded pipette. To study the transpiration of *Salvinia* and *papyrus* and at the same time measure the potential evaporation, three green plastic pans with a diameter of about 40 cms were prepared. One of the pans was equipped with a young stand of *papyrus,* including its roots, and then filled with water up to the 0-level. Another pan was equipped with living *Salvinia,* like the *papyrus* collected at the shore of the lake below Fisherman's camp. The third pan was just an ordinary evaporation pan filled with water, of the same material and diametre as the two other ones. Towards the end of the period a new '*Salvinia*-pan' was established. All the pans were inspected and refilled up to the 0-level every morning around 9 a.m. Precipitation records were obtained from the 'top camp' at Fisherman's through Mr. M.D. Carnelley. Unfortunately however, these records are not directly comparable to those at our site, where the interception of the trees must have been considerable, but fortunately, measurable

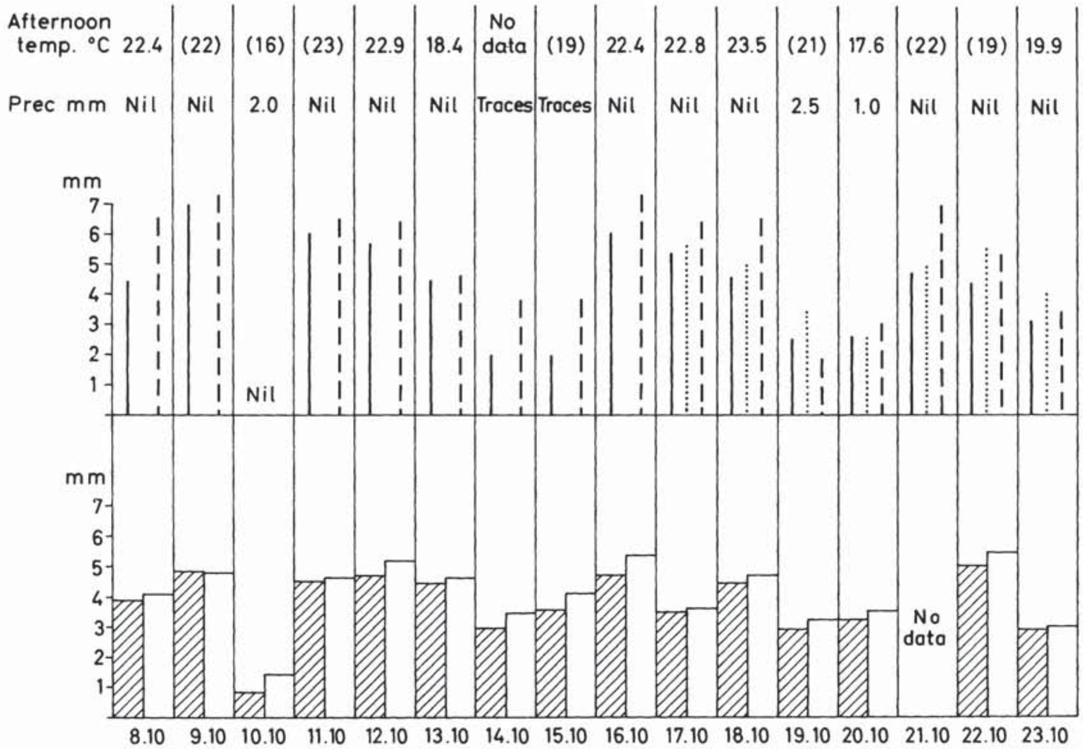

Fig. 11. Diagram showing the results of the studies at Elsamere in Oct. 1985 of evaporation and evapotranspiration from the pans (upper diagram) and the balances (lower diagram). Upper diagram: Filled bars = *Salvinia*, dotted bars = *papyrus*, broken bars = potential evaporation. Lower diagram: Shaded bars = *Salvinia*, unfilled bars= potential evaporation. For further information see text.

amounts of precipitation only occurred on one occasion during our stay at Fisherman's camp. Wind observations were made of both direction and speed. The direction was determined by compass, while observing the direction of the waves; the wind speed was estimated using the Beaufort scale. (M = Moderate stands for Beaufort 4, F = Fresh for 5 and S = Stong breeze or Beaufort 6 on the 12-graded Beafort scale.) The observations appear in Table 3. Records of transpiration, evaporation and precipitation taken in the morning are referred to the previous day in Table 3.

Results

It is quite obvious that the observations at Elsamere (Fig. 11) and Fisherman's camp (Table 3) are not directly comparable although the weather conditions during the two observation periods were quite similar. Even comparisons with other studies give rather confusing results.

Concerning *Salvinia,* the results from my own studies are very puzzling. The experiments carried out at Elsamere indicated c. 10–20% *less* evapotranspiration from a *Salvinia*-covered surface than from the pan for measuring potential evaporation. However, the experiments at Fisherman's camp indicated a c. 20% *higher* evaporation from the *Salvinia* pan. A possible explanation might be that *Salvinia,* being a fern, becomes stressed in a non-shady environment. This hypothesis is to some extent supported by observations made by several people that many *Salvinia* individuals seem to die when forced by wind to float over the surface of the lake. However, the balance experiment at Elsamere was carried out in a reasonably shady environment, but it might be that the young *Salvinia* plants used for this experiment have less

Fig. 12. Photo showing the 'meteorological site' used for observations in Oct. 1986 at Fisherman's camp. The two *Salvinia*-pans appear in the foreground together with the papyrus-pan. The child is holding a *papyrus*-stalk used for the studies of transpiration. Photo: L.E. Åse.

transpiration than old ones due to anatomic and/or physiological reasons. Or, could the brass of the balance cups have a poisoning effect?

Turning to the *papyrus* experiments, it must be assumed that the experiment at Elsamere only showed the shading effect that the top of the *papyrus* stalk had on the evaporation. Obviously, no transpiration occurred from the cut *papyrus*. The observations at Fisherman's camp seem to be more useful. The pan observations registered evapotranspiration from about 20 young stalks of *papyrus*. Every day they consumed about a liter of water, compared to 0.4–0.5 l that correspond to the potential evaporation. The transpiration from the three cut *papyrus* straws averaged c. 30 ml a day (cf. Fig. 13). 20×30 ml equal to 600 ml, which make this figure similar to the difference between evapotranspiration from *papyrus* and potential evaporation from the pan or tank experiments.

The figures do not completely agree with data

Table 3. Records from temporary "meterological site" at Fisherman´s camp 23.10 - 1.11 1986. (See also text and Fig 12)

Datum	Max Solar Radiation	Max temp	Temp 9 a.m.	Min temp	Max RH	RH 9 a.m.	Min. RH	Afternoon wind	Pot Ev mm	ET Salvinia mm	ET Papyrus mm	Prec.
23.10 -86	-	24°	19.3°	-	-	71%	62%	NE F	(1.7)	(0)	(4.0)	(9.7 mm)[x)]
24.10 -86	-	25.5°	18.2°	17°	92%	82%	30%	NE F	1.7	3.7	8.9	
25.10 -86	-	26°	18.5°	17.5°	85%	69%	28%	NW F	3.5	3.7	5.9	Tr
26.10 -86	0.017 mV	27°	18.5°	16.5°	86%	68%	28%	SE F	2.3	2.1	8.9	Tr
27.10 -86	0.082 mV	24°	18.1°	19°	88%	72%	30%	NE S	5.7	6.1	10.1	
28.10 -86	0.030 mV	24°	17.7°	17°	88%	71%	30%	NE S	4.3	5.6	8.9	
29.10 -86	0.091 mV	26°	18.2°	18°	82%	72%	42%	NE S	4.3	5.6	8.1	
30.10 -86	0.041 mV	22°	19.0°	18.5°	80%	66%	48%	NE S	3.9[xx)]	3.3	8.1	
31.10 -86	0.086 mV	23.5°	18.0°	16.5°	85%	72%	30%	E M	3.9	4.7	8.4	
1.11 -86	-	-	18.0°	16.5°	88%	71%	-	-	-	-	-	
								Total	28.7	34.8	67.3	
								%	100	121.0%	235.0%	

x) Recorded outside site
xx) Estimated value: 3.0

found in the literature. Penman (1963) states that on the basis of available references and his own experiments the transpiration from *papyrus* and evaporation from an open lagoon are nearly equal. Migahid (1952), who carried out experiments in the 'Sudd' region in the late 40's, deducted from tank experiments that although the results varied depending on climatic conditions, there was on the whole c. 10% less evaporation from the open water tanks than from those with *papyrus*. One of Migahid's experiments was carried out on the deck of a steamer and checked with

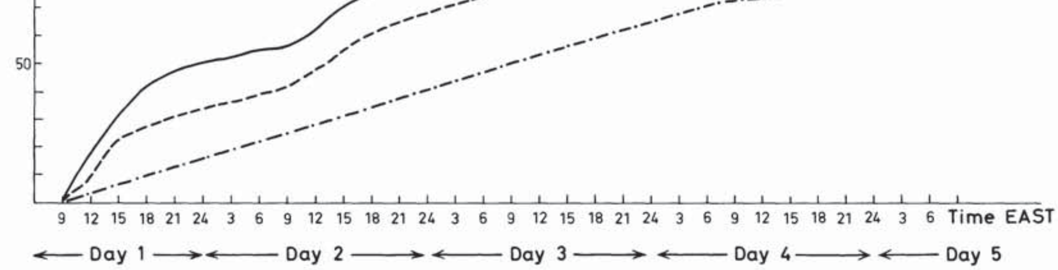

Fig. 13. Cumulative curves showing the transpiration of two sterile (I_s and II_s) and one fertile (III_f) stalks of *papyrus*. (Cf. text.)

Table 4. Comparison of atmospheric conditions, water temperature, evaporation and transpiration outside and inside the papyrus swamp. (Migahid 1952, p. 7)

Position	Water loss mm./day		Temperature °C			Rel. hum. %	Wind vel. km/hr	Light intens. foot candles
	Water tank	Papyrus tank	Air	Water: Water tank	Water: Swamp water			
Outside papyrus (on deck)	6.53	8.35	27.5	28.8	-	79.3	6.5	3194
Inside papyrus (in swamp)	1.20	7.85	27.5	-	28.6	81.4	0	278

experiments from tanks inside a *papyrus* swamp (Table 4, from Migahid 1952, p. 7). Under shady conditions a very much (c. 6–7 times) higher water loss occurred from the *papyrus* tank than from the water tank. Hurst (1952) reports on experiments with large (10 m^2) tanks in which an 'evaporation' rate of 1.25 occurred in the *papyrus* tanks, as compared with the Piche evaporimeter outside the tank.

When passing the c. 500 km long 'Sudd' area in southern Sudan the White Nile loses about 50% of its water (Talling 1957, p. 74). Rzóska (1976) gives the mean annual discharge of the White Nile at the Lake Albert (Mobutu) exit to 23 billion m^3 and at Lake No, i.e. below the Sudd region, to 10 billion m^3. He concludes, however, (1976, p. 151) that the enormous loss of water in the Upper Nile swamps 'is not caused by the permanent papyrus stands but probably by spillage and evaporation of the temporary grasslands'. The conclusion does not seem very well founded; my personal viewpoint is that most of the water is lost through transpiration in the papyrus' swamp of the Sudd.

Except for the tank studies, a more theoretical study has been made by Rijks (1969). For a *papyrus* swamp in southern Uganda, he estimated from formulae given by Penman (using figures of temperature, relative humidity, air pressure and solar radiation) 'evaporation from an old stand of papyrus' to be 60±15 per cent of Penman's estimates of evaporation from open water' (Rijks 1969, p. 613).

Rijks' value has been used by Gaudet (1979, p. 955) to estimate the evapotranspiration of the *papyrus* swamps in northern L. Naivasha. To the present author, this assumption does not seem very relevant. Rijks' measurements were carried out in an old *papyrus* stand that was burnt by fire six years before the experiments were carried out. Moreover, the calculations were made in a semi-theoretical way, which might make them of less value for practical purposes.

Naturally, one must be very careful in extrapolating even my own experiments to all the *papyrus* of L. Naivasha. Nevertheless, to me it seems probable that a surface covered by *papyrus* consumes about 2–3 times as much water as a free water surface. *Nota bene,* if water is available. Whether transpiration decreases if water is not available is an open question that might be studied in a different way.

For the water budget calculations only very rough estimates of the influence of *papyrus* and *Salvinia* can be made. If we assume that *papyrus* covered 10% of the surface of the lake during the period 1936–1976 (cf. Table 1), and transpiration from the *papyrus* swamps was three times that of evaporation from a free water surface, this means that instead of a pan factor of 0.8 a factor of 0.96 or say 1 should have been used. The evaporation from the lake would in this case equal c. 85 m instead of 68 m and instead of the rest factor of 48 m, the rest factor would be c. 31 m. As *Salvinia* occurred only during a small part of the period 1936–1976 and its influence on the water budget obviously is much less than that of *papyrus,* it can be neglected in this connection. More important is whether the pan factor 0.8 is really realistic. It was observed during the stay at Fisherman's camp that both transpiration and evaporation increased considerably during the windy days from the 27th–30th of Oct., especially on the 27th, when the evening and following night were also windy. If the pan factor is converted to lake conditions and the *papyrus'* transpiration is assumed to convert it to 1.2 rather than 1.0, we find that another third of the rest factor disappears, i.e. the very existence of the rest factor can be questioned.

As in so many other investigations, more questions are raised than answered. Which is e.g. the influence of the wind on the water budget of L. Naivasha? Can the absorption of nutrients by the *papyrus* swamps in the northern part of the lake, where the major tributaries enter, explain the low conductivity and the fresh water of the lake? Are salts deposited in the sediments of the lake? Which influence does the irrigation carried out around the lake have on the water budget? These questions and many others can be asked and be the objects for further investigations.

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