19a. LAKE NASSER AND LAKE NUBIA[1]

by

B. ENTZ

Introduction

Lake Nasser forms together with Lake Nubia, the southern part of the huge reservoir, one of the greatest man-made lakes in Africa. This artificial impoundment on the Nile River when full, will extend from the High Dam (HD) at Aswan (Egypt) till the Dal Cataract (Sudan) between the 23°58′ and 20°27′ north latitude and 30°35′ and 33°15′ east longitude. Construction started in 1960, filling in 1964. (Map, fig. 71).

It is unique in its performance because it is situated in pure desert surroundings where the yearly mean precipitation does not surpass 4 mm/year, and a very high rate of evaporation around 3,000 mm/year. The air is very dry and the sky is almost completely cloudless. The only source of water is the Nile River with its inflow in the south. The outflow at Aswan is the continuation of the Nile River towards the north. This vast impoundment is in reality not a typical lake but rather an extremely slow flowing river. Some of the most important morphometric data of the reservoir are summarized in table 1.

As obvious from this table and from Fig. 72 and 73, the lake has a long, narrow shape with often dendritic side areas, called 'khors'. The number of important khors is one hundred, 58 of them being located on the eastern and only 42 on the western shore. The total length of the khor systems in the lake, when full, will be nearly 3,000 km and their perimeter will surpass 6,000 km (Fig. 74). The total surface area of the khors that is areas outside the main valley covered by water, is about 4,900 km^2 = 79% of the total lake surface but in volume they will contain only 86.4 km^3 water (= 55% of the total lake volume).

The mean slope of Lake Nasser is steeper on the generally rocky or stony mountainous eastern shore (14°07′) than on the flatter, more open, wider, often sandy western one (1°51′).

[1] All original data pertaining to Lake Nasser and Lake Nubia were obtained by me as Project Manager – Fishery Limnologist at the FAO/UNDP/SF Lake Nasser Development Centre Project. I am indebted to express my deepest gratitude to the Government of Egypt, especially to the Regional Planning of Aswan and personally to H. E. M. Alwany Governor of Aswan, Mr M. Marei General Director of RPA and Dr. A. F. A. Latif Project Co-Manager, Director of the Lake Nasser Centre of RPA and last but not least to all my colleagues and friends whoser eadiness and permanent help made this work possible.

J. Rzóska (ed.), *The Nile, Biology of an Ancient River*

Fig. 71. Map of the entire basin of the Aswan High Dam (Lake Nasser and L. Nubia); the frontier of the Sudan is near Wadi Halfa. This map contains only the contours at a level of 160 m a.s.l.; now the basin is much broader. Compare with space-photo. After Latif, Entz and other sources.

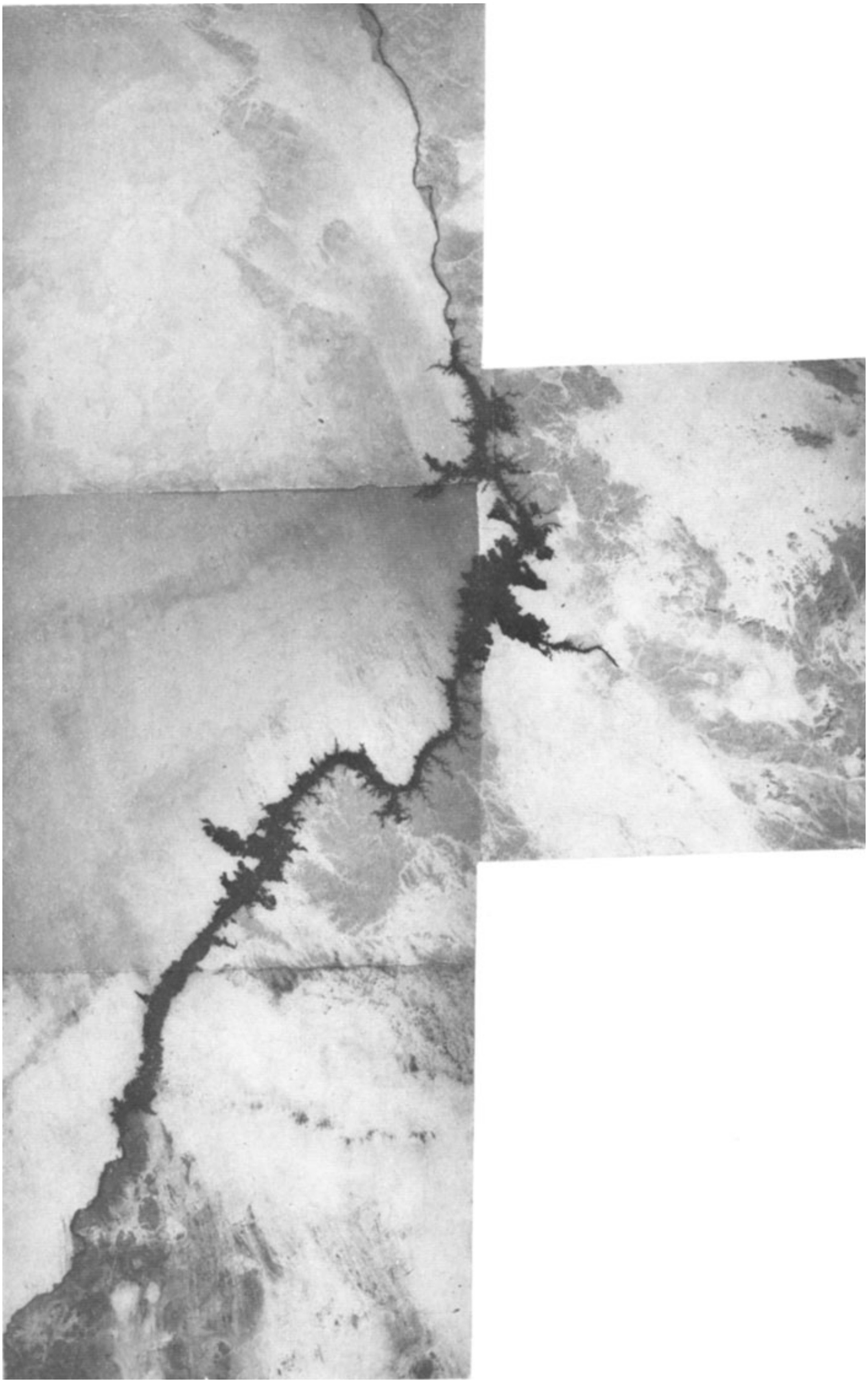

Fig. 72. Combined space-photograph of the Aswan High dam basin; Note the ramifications of the side arms (Khors) representing ancient drainage channels and even extinct rivers; ERTS.

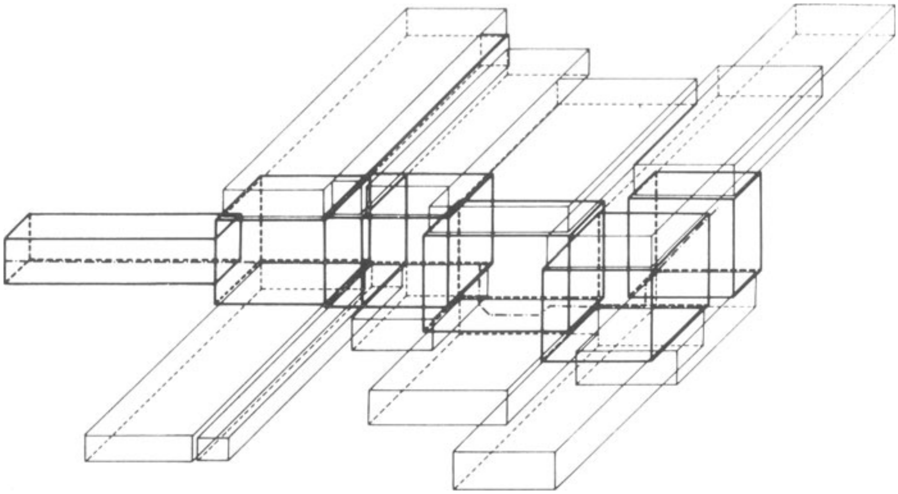

Fig. 73. Schematic representation of the Aswan High dam basin. –.–.– Main axis of the reservoir; —— volumes of central parts of sections 8-1, sections 1 and 2 are combined (thick lines); —— volumes of side areas and khors (thin lines); Entz unpublished.

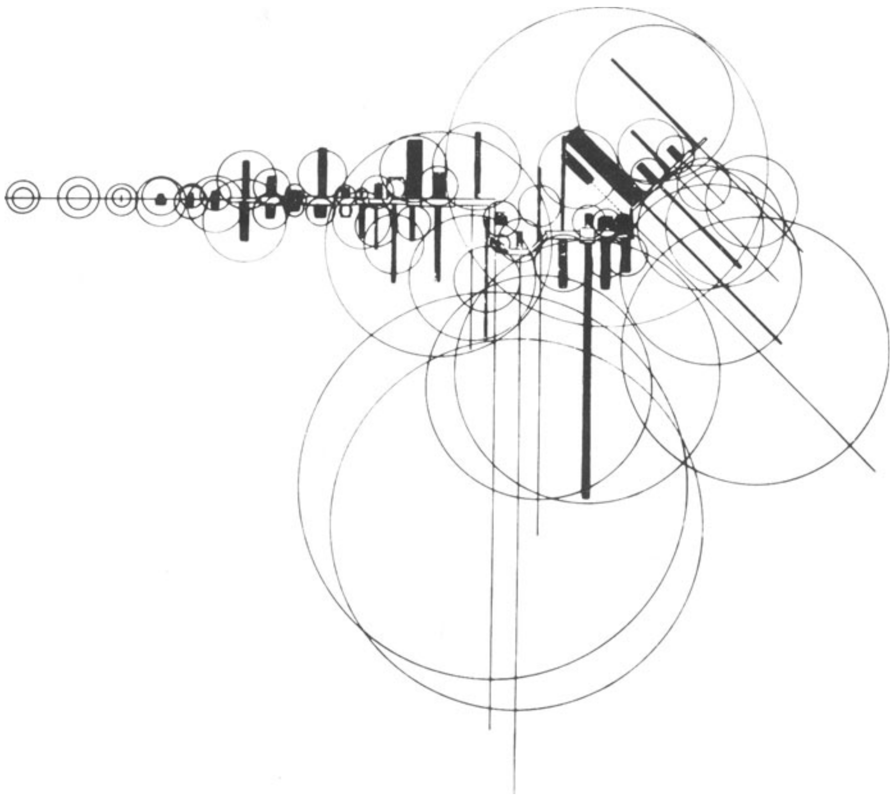

Fig. 74. Schematic representation of the surface and the perimeter of the subsections of the lake. □ surface of central areas; ■ surface of side areas and khors; ○ perimetersof the side areas and khors. Entz unpublished.

Table 1. Morphometric data of Lake Nasser and the total reservoir.

Water level	Lake Nasser		Total reservoir	
	160 m	180 m	160 m	180 m
Length km	291.8	291.8	430.0	495.8
Surface area km^2	2585	5248	3057	6216
Volume km^3	55.6	132.5	65.9	156.9
Shoreline km	5380	7844	6027	9250
Mean width km	8.9	18.0	7.1	12.5
Mean depth m	21.5	25.2	21.6	25.2
Maximal depth m	110	130	110	130

The mean length of the main khor systems is increasing from the south ($\pm$ 1 km between 500 and 360 km from the HD) to the north ($\pm$ 43 km between 80 and 0 km from the HD) because of the northwards declining ancient river bed.

Due to the dendritic form of the lake basin the shoreline development value (D_L according to Hutchinson) is extremely high (33.1!) as compared with usual values of lakes usually ranging between 1.8 and 6.0.

All the khors have a 'U' shaped form in their cross section with a flat sandy central belt and sometimes, especially on the eastern shore, very steep (slope up to 48°) and mostly rocky shores.

Morphology and hydrology

The deepest part of the lake is the ancient river bed with the adjacent strips of cultivated land forming together the original river valley, called the central area of the lake with its bottom elevation between 85 and 150 m a.s.l. The side areas lie between 150 and 180 m above sea level.

The central part can be considered as a flowing river-lake where the speed of the current is fast at the southern end of the Nubian gorge region (100 to 150 cm/sec). This speed is gradually reduced within a few kms to 10–20 cm/sec and in Lake Nasser to 0–3 cm/sec. The mean depth of this central part is gradually increasing from 10 m at the southern end to 70 m in the north. The bulk of the water masses coming from the south is passing through this central part, which forms about half of the total volume of the lake.

The flood, which arrived at Aswan from Khartoum within one month before the High Dam was built, covers now the same distance in not less then 5 but sometimes probably more than 12 months, depending on the lake level and the strength of the flood.

The side arms show usually lacustrine characteristics. Currents if present are weak and are most probably induced mainly by the wind and

Table 2. Characteristics of Lake Nasser and L. Nubia in the different subbasins.

	Subbasins			
	A	B	C	D
Area	Dal-Attiri	Attiri-II Cataract	II. Cataract-El Dirr	El Dirr-High Dam
Distance f. HD km	500–410	410–365	365–200	200–0
Per cent of length of reservoir[1]	18	12	30	40
Per cent of surface of reservoir[1]	1.70	1.34	33.00	63.96
Per cent of volume of reservoir[1]	0.24	0.63	33.77	65.36
Main character during flood	Riverine[2]	Riverine	Semi riverine[3]	Lacustrine[4]
Main character, during low water	Riverine	Semi riverine	Lacustrine	Lacustrine
Approximate speed and main type of current in cm/sec during flood	200–120 turbulent	110–80 turbulent	12–8 laminar	3–0 laminar
Approximate speed and main type of current in cm/sec during low water	100–60 turbulent	50–20 laminar?	5–3 laminar	2–0 laminar

1. All values calculated for 180 m lake level above sea level.
2. High inorganic turbidity, turbulent currents, no stratification.
3. Both inorganic and organic turbidity, stratification weak or of short duration.
4. Dominant organic turbidity, weak laminar currents, long lasting stratification from April to October or December and total circulation from November or January to April.

Table 3.[1] Lake levels between 1964 and 1974, as in a.s.l.

	1964	1965	1966	1967	1968	1969	1970	1971	1972	1973	1974
Maximum (December)	127.8	132.5	142.5	151.1	156.4	161.7	164.5	167.2	165.3	166.7	170.0
Minimum (July)	106.2	116.0	119.3	130.2	145.5	150.7	153.8	159.8	162.6	158.2	161.0

1. Data from the High Dam Authority, Aswan.

far less by the progressing water masses of the central part of the reservoir. According to the current conditions the total reservoir can be divided into four subbasins. Along these, the original riverine conditions are gradually lost and the reservoir resembles more and more a typical lake. Some of these features are summarized in table 2.

The lake's expected high level of 180 m a.s.l. has not yet been reached. The lake was half full in 1969 at about 160 m and the filling process continued up to 1971. At that time influenced by the extremely dry weather along the Blue Nile the filling process was interrupted and the water level dropped in the following period, but the increase was regained again in 1973–1974 (see table 3).

As a consequence of the yearly flood, the maximum lake levels can be measured in December or January and the minimum values in July, just before the start of the new flood period.

With the huge buffer capacity of the lake, the course of the Nile flow below Aswan is basically changed. The one-peak flood of different amplitudes between September and January and the minimum water level in July have been replaced by an almost constant artificial medium water supply between May and June, adequate for irrigation demands for summer crops and by a second lower peak in December for the winter crops besides a fairly constant water level in the remaining periods.

Consequently the amount of water actually entering the Mediterranean is reduced considerably though not completely but the sedimentation of silt load in the delta area is practically abolished.

The three main factors affecting the conditions of the reservoir are air temperature, the yearly flood of the Nile and wind conditions, causing together with biotic factors basic changes in water temperature, oxygen saturation, optical conditions, conductivity, changes in dissolved chemical components and even changes in the fish yield.

The nile flood

Sedimentation of Nile-mud within Lake Nasser and Lake Nubia.

As widely known, the Nile carries a heavy load of mud of about 100 million $m^3 = 0.1$ km^3 per year, consisting of a mixture of sand, silt and clay. This mud was an important source of fertility for Egypt for thousands of years.

During the first years the suspended mud was 'flushed' through the basin of Lake Nasser. But after reaching 150–155 m lake level in 1967–1968, the speed of the current within the lake was reduced so much that the previously dominant turbulent currents were replaced by laminar ones, and a strong sedimentation started within the lake basin. As a visible sign of this process since 1969, the Nile water became permanently green and transparent around Aswan, because of the almost complete lack of suspended silt.

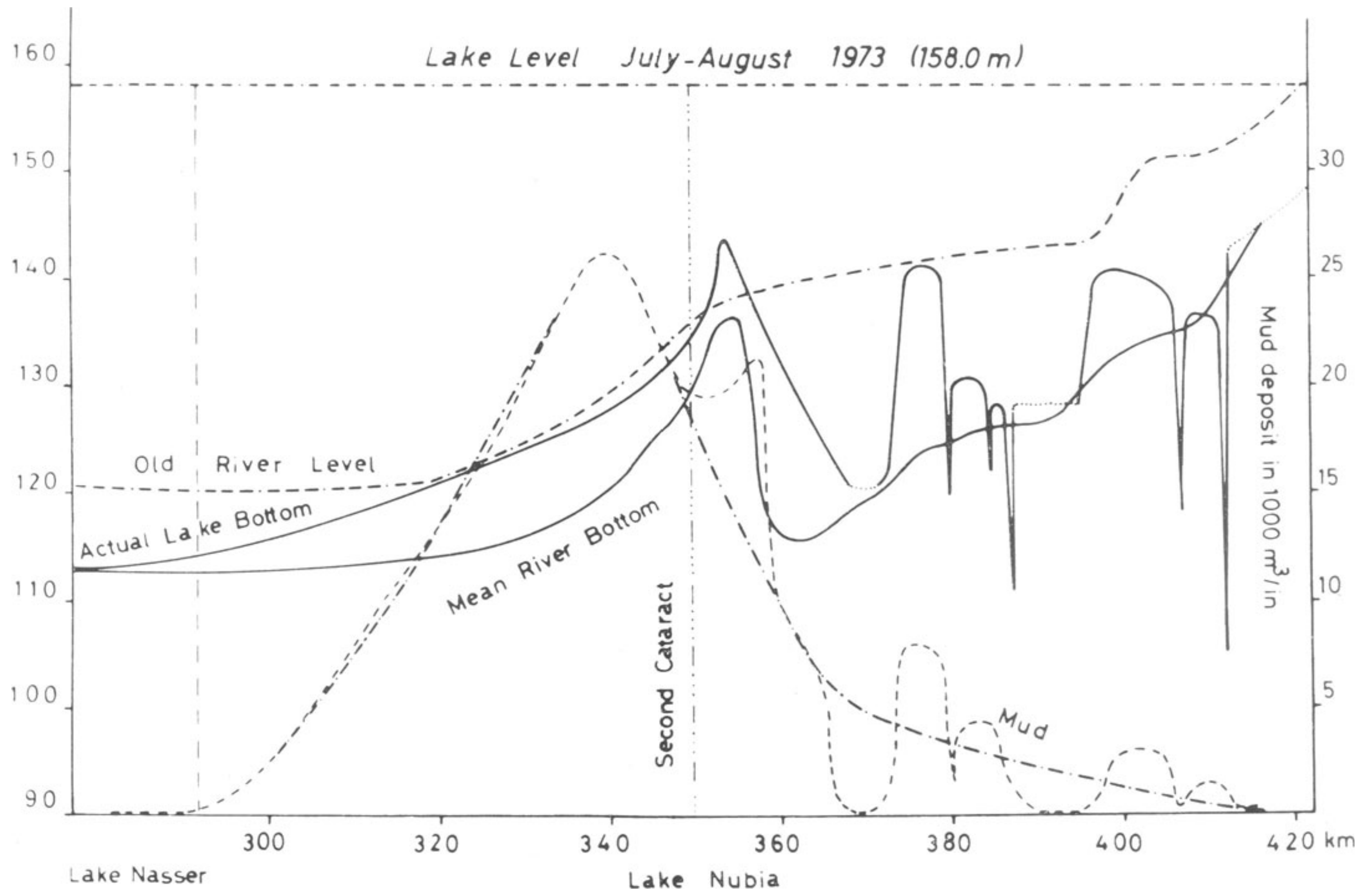

Fig. 75. Sedimentation around the previous Second cataract area in the Sudan. —— mud surface measured; –.–.–.– ideal curve of mud distribution; 90–160 = ordinate in m a.s.l.; 300–420 km = abscisse, distances from High Dam; B. Entz, unpublished.

Following the special shape of the sub-basins, the center of sedimentation is located in the area of the previous II. Cataract, near Wadi Halfa where a very remarkable abrupt slow down of the current takes place with the formation of a new 'delta' (see table 2).

From the point of sedimentation three subsequent sections could be distinguished:

1. Between Attiri and Gomai	(410–365 km from HD)	31.77%[1]
2. Around the 2nd Cataract	(365–345 km from HD)	20.06%
3. Between Wadi Halfa and Abu Simbel	(345–285 km from HD)	48.17%

[1] Foot note: The percentage values given correspond to the proportion of the amount of sedimented material between 1967 and 1974.

In section 1. both thickness and amount of the sediment are very variable along the different localities depending on the width and depth conditions of the lake channel. There are locations where remarkable amounts of sediment have been accumulated but also others without new sediment (Fig. 75). The peak was reached in section 2., where a thick sediment (up to 20–25 meters) covers almost evenly the previously very uneven cataract bottom. In section 3. there is a very smooth decrease both in thickness and the amount of sediment along the main channel beginning with a thickness of about 10 m, to almost nil. The maximum amount of suspended matter within the years 1968–1973 was ranging during the flood between a few hundred mg/l and 8,000 mg/l of perhaps more. The extreme value of 8 g/l has been measured in 1973. This high value never recorded before might be in connection with the exceptional flood of 1972/73 and the newly constructed reservoirs on the Blue Nile and the Atbara.

Future aspects

Naturally new amounts of suspended matter of an approximate amount of 0.1 km^3/year – will be sedimented in the lake. Because of this the lake will undergo in the neighbourhood of Wadi Halfa obviously basic changes in the near future. As suggested the lake will be gradually shallower in this area until it reaches a depth of about 6 to 10 m. This can be promoted or delayed by the tempo of the filling process of the lake and the strength of the flood, until the suggested 'working level' of the lake will be reached. If the supposed 6–10 m river depth will be attained, possibly in 5 to 15 years, the start of a new river channel formation can be expected in this area. Beside the channel the appearance of shallow mud banks is probable, emerging from the lake surface during low water periods. Similar phenomena could be already observed in some areas towards the south, around Attiri and Murshed at 415 and 370 km distance from the High Dam. The new 'delta' will grow continuously northwards and the fertile mud of the Nile will cover the lake shores gradually like during the last years between Attiri and Wadi Halfa, where newly deposited mud appears at low water level on the shores. This new layer is in some calm beaches with flat slopes 1 to 3 m thick, covering step by step the previous riverside vegetation. Its thickness is decreasing inland and is nil at the shoreline of the highest lake level.

This drying mud layer is often covered by sand blown by the wind. The total amount of deposited mud is diminishing towards the north and its last appearance is for the time being around Abu Simbel in the form of a thin mud film. The sedimentation of mud will continue gradually towards the High Dam, but it will take most probably several hundred years until the deposits will approach the Aswan area in remarkable amounts.

TEMPERATURE

The tropic of Cancer crosses the lake; the major part is situated within the tropics and only a small proportion in the northern mediterranean zone. Lake Nasser is a monomictic subtropical lake (Hutchinson 1957) with prevailant lacustrine characteristics and with a single circulation

Table 4. Temperature values of Lake Nasser within the period 1970–1974.

	1970	1971	1972	1973	1974
Minimum water temperature measured °C (February-March)	17.6	16.3	16.1	15.7	15.2
Approximate mean temperature °C (February-March)	18.5	18.4	16.8	16.9	15.9
Lowest temperature °C measured in July-August	19.8	18.6	18.5	18.0	16.7
Approximate mean temperature °C in July-August	25.0	23.2	23.8	22.8	22.9
Volume of water with temperature below 20 °C 'cold water' in July-August km^3	0.02	4.3	7.0	6.2	10.7
Per cent of volume of 'cold water' of total lake volume in July-August	0.1	7.7	12.2	12.3	18.4
Maximum temperature measured in the open water °C	32.2	29.7	34.5[1]	33.0[1]	31.8
Minimum depth under the lake level with temperatures below 20 °C in July-August, m	60	37	37	34	26
Summer stability between 0 and 40 m depth in mkg (mean values) per square meter	157	195	186	208	271
Approximate depth of metalimnion during stratification in summer m	16.0	13.4	18.0	11.1	13.1

[1] Foot note: Temperature values measured in Lake Nubia.

period in winter between November and March. Lake Nubia, and especially its gorge region (Sub-basins A and B) bear mainly semi-riverine or pure riverine features, where the temperature is greatly affected by the current of the inflowing Nile water. Some of the temperature and stability data for the years 1970–1974 are summarized in table 4.

As a result of the falling air temperatures in autumn, the total water mass is cooling down and a complete circulation develops in the winter months. It is worth mentioning that the mean temperatures calculated and the actual minima measured were gradually decreasing from 1970 to 1974. The absolute minimum (15.2 °C) could be observed on 18/2/1974 in deep water near the High Dam (see table 4). The same trend could be observed as decreasing minima in summer time and as an increase of the amount of the 'cold water' during the summer months (table 4). This cooling down of the lake might be continued in the future in some extent mainly due to the low mean ambient temperatures of some cold days in January (± 14 °C), mostly accompanied by increased evaporation induced by sometimes long lasting cold mortherly winds, though lower water temperatures than 13 °C can hardly be expected. Both the amount and the proportion of 'cold water' (15–20 °C) in the deep water layers during the summer stagnation period can still increase significantly in particular under the influence of rising water level. The final picture can be clarified only after several years.

The actually measured maximum lake temperature was 34.5 °C. This could be observed in the open water of Lake Nubia under stratified conditions, just below the surface, at 3 p.m. during a long lasting windless period, which permitted the development of a very heavy Cyanophyta water bloom. The maximum water temperature measured in 1 m depth was still 31 °C, but that in 2 m depth only 29.5 °C.

Accordingly, the range of water temperature does not exceed 20 °C, which is less than the usual range of 22 to 30 °C in shallow temperate lakes and of course much less than the extreme values of the ambient air temperature (—5 to +52 °C). These low surface values are surprising in the 'land of eternal sunshine', and can be explained only by the very high evaporation rates. There are big differences in the circadian air temperature up to 25 or 35 °C a day. But this affects only the temperature of the upper water layers.

The course of the temperature of the whole water mass is mainly influenced by the seasons. There is a rapid increase of the air temperature from April to June followed by that of the water. Near the southern end of the lake under riverine conditions the water is gradually warmed up in all depths to 28–30 °C. A quite different feature could be observed in the lacustrine sub-basins of the lake between the Second Cataract and the High Dam. Here only a slight gradual temperature increment of short duration could be noticed all over the total water mass. After that – usually already in April – a short but rapid increase takes place in the upper 10–15 m water layer resulting in the summer stratification. Although the depth of the metalimnion is changing during the summer seasons and is different in the various localities, it laid usually between 10 and 16 m. Under the influence of the dominant winds and the inflowing river, the depth of the epilimnion is not uniform in the whole lake. As a good example the conditions at the end of September 1970 could be mentioned when the metalimnion was at 15 m in Khor El Birba (9 km from the HD), at 25 m in Allaqi (100 km f. HD), at 30 m around Singari (in the valley bend 180 km f. HD) and at 50 m at Adindan (300 km f. HD).

The slope of the temperature boundary can be well compared with the stability values expressed in mkg/m^2 (Ruttner 1933, 1959). These values reach between surface and metalimnion only about 10 mkg/m^2. The same values are high between surface and 40 m depth as compared with deep temperate lakes (e.g. Altausseer-see 60 mkg/m^2) or even tropical lakes (e.g. Ranu Klindungan in Sumatra 190 mkg/m^2), ranging from 157 to 271 mkg/m^2, but showing extreme values up to 325 mkg/m^2. Between surface and 55 m depth very high stability values could be calculated up to 700 mkg/m^2 or even more. High stability is attained very fast, already in June and July, but from the second half of August it is again decreasing due to the diminishing ambient air temperature and the turbulent water movements caused by the approaching flood. As a result the location of the thermocline drops down in time, especially in the south and disappears completely in October or latest in November. Accordingly the stability values are decreasing until they are reduced to zero under winter conditions (isothermic conditions).

Dissolved oxygen

The oxygen saturation reflects the influence of four important factors: the temperature regime, the wind conditions, aquatic life activities and the desert surroundings.

In winter time there is a total circulation present in the lake. The water is oxygenated from the surface to the bottom and the saturation ranges usually between 60 and 120% as in February (see Fig. 76). The conditions observed during this period were very similar from the neighbourhood of the High Dam through the central section of the lake to the southern gorge region.

Parallel to the rapid increase of the water temperature in April a remarkable increment of the O_2 saturation appears in the upper water layers. This phenomenon is most pronounced within the northern areas of the lake in 1 to 10 m depths where saturation values above 150 or even 200% have been measured. This could happen in a windless period under the influence of a very rich phytoplankton, mostly Diatoms. A similar trend of O_2 saturation could be observed in the central

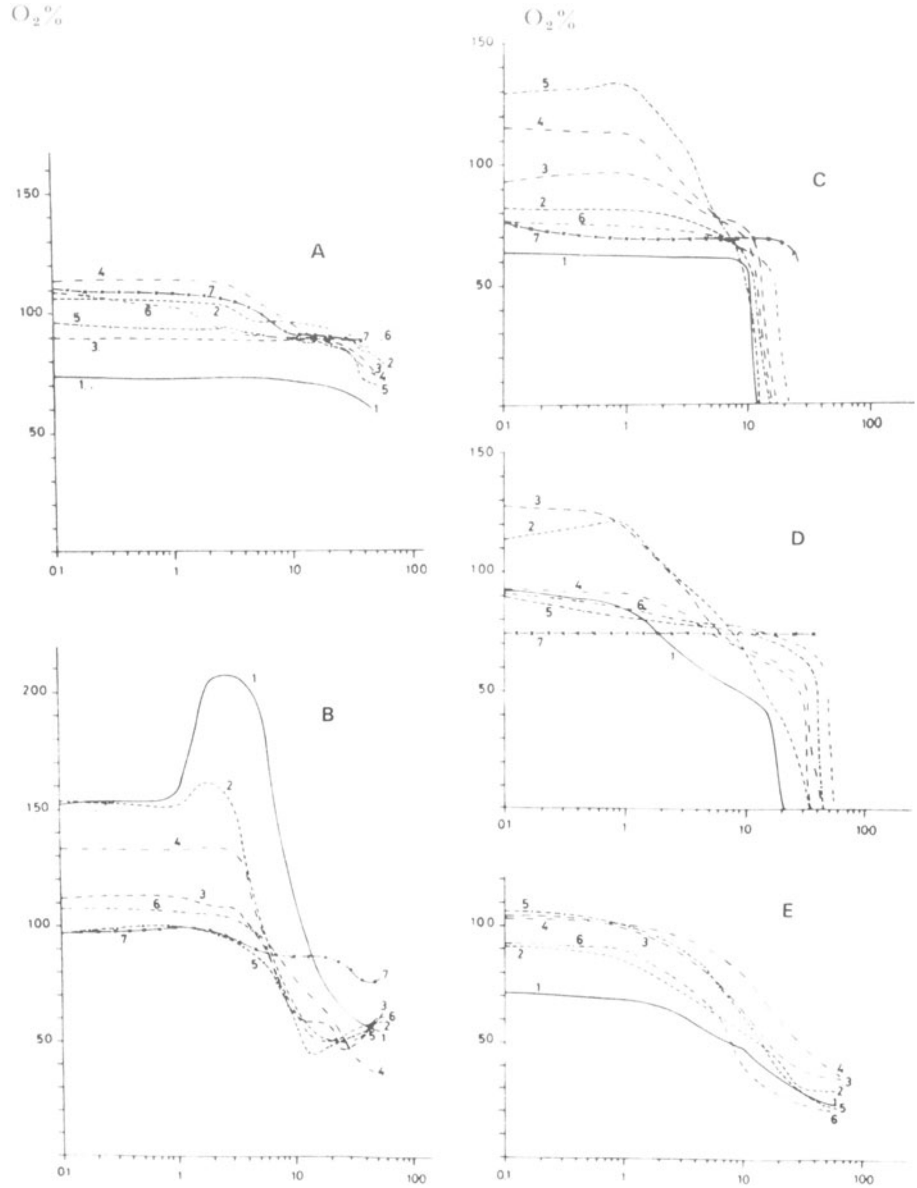

Fig. 76. Oxygen saturation v. depth in m in different seasons and localities of the lake; A. February; B. April; C. July; D. September; E. November; 1. High Dam Area, 0–7 km; 2. El Birba-Allaqi, 9–100 km; 3. Sayala-El Sibu 110–160 km; 4. Shaturma-Kurusku 165–190 km; 5. El Dirr Tushka 200–240 km; 6. Adindan-Wadi Halfa 270–350 km; 7. Amka-Murshed 355–390 km; distances from dam; B. Entz, unpublished.

parts of the lake, although in a smaller estent. Some higher saturation values present in Lake Nubia were caused by heavy Cyanophyta water blooms. During this period the total circulation was already blocked and the beginning of the formation of the metalimnion was obvious. The oxygen saturation drops rapidly from about 5 to 12 or 25 m depth, but grows again in the deeper layers (Fig. 76). The probable explanation of this peculiar slope of these curves is suggested as follows. The oxygen saturation of the lower layers starts to decrease as soon as the total circulation is interrupted. This process is the most vivid just below the zone of the metalimnion under formation, because of the high O_2 consumption by plankton and nekton organisms moving upwards and the rapid decomposition of plankton rain sinking down into the hypolimnion. The bottom of the lake does not consume so much oxygen as usual in lakes because it is mainly formed by desert soil without any remarkable decomposing organic admixtures. The oxygen saturation does not fall anywhere below 50 or 60% saturation in this period.

Quite different are the conditions of the southernmost 'riverine section' of the lake, where all water layers are mixed throughout the year and the oxygen is almost evenly distributed.

During the following weeks a stable stratification is formed by further rise of the temperature. The result is a well oxygenated epilimnion and an oxygen free hypolimnion. During the summer months a remarkable increase in the oxygen saturation takes place in the epilimnion towards the south, most probably due to the masses of Cyanophyta, causing severe water bloom especially in Lake Nubia.

The stratification is abolished gradually in the autumn all over the lake progressing towards the north with declining ambient temperature caused by the winds and the inflowing cooler flood water in the south. A complete total circulation is again reestablished with gradually increasing saturation values during December, January or February.

It is worth mentioning that the oxygen conditions showed no remarkable annual changes during the period 1970–1974. Thus the seasonal results of different years are comparable.

Optical conditions

The transparency of the lake is affected by three important factors: 1. the inflowing turbid water of the Nile River; 2. the development of phytoplankton and; 3. vertical water movements (wind action).

The inflowing Nile water but especially the flood water is very turbid and has a brownish-greyish colour. On the arrival of the flood into Lake Nubia the Secchi transparency can be diminished within a few hours from 70–140 cm to 20–30 cm oı, as in the southern part of it, even to 5 or 10 cm. The border line between flood water and old water is sometimes very sharp as north of the Second Cataract area where the current is

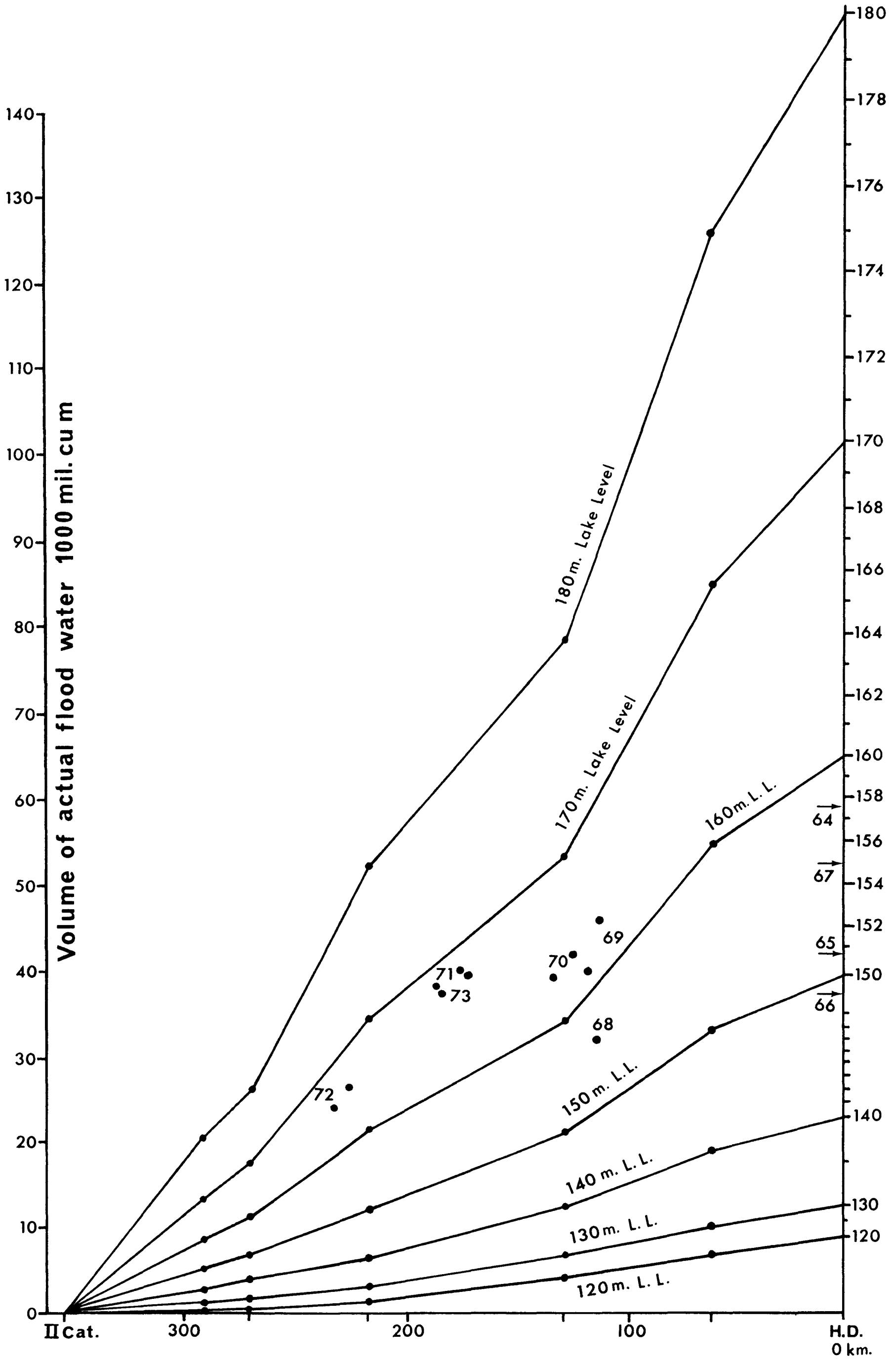

Fig. 77. Correlation between lake levels, volume of flood and the edge of the area reached at New Year by the turbid water; ● actually observed; ○ calculated site; B. Entz, unpublished.

already slow (5–10 cm/sec), but the silt content is still remarkable (100–500 mg/l).

Along the progressing flood a continuous sedimentation takes place within the lake, accompanied by gradually reduced turbidity. Ultimately the optical border line between flood water and old water disappears. By this way the progress of the flood can be followed within the lake by Secchi-disc measurements, but only to a certain distance depending on the hydrological conditions.

The time of flood-water penetration within the lake depends on two factors: 1. the amount of inflowing flood water from the beginning of the flood until the date of observation (straight correlation), and 2. the actual lake level at the beginning of the flood (inverse correlation). If these two components together with detailed morphometry of the lake are known the way of the flood water can be followed in the lake by calculation. Even the actual border line between turbid and clear water at New Year can be calculated by multiplying the volume in question with the empirical factor 0.64. This factor is a result of sedimentation of silt particles during the period considered.

The area of turbid water at this time is of practical importance for this area and is in straight correlation with the distribution and catchability of some semiriverine fish (e.g. *Alestes* spp. and others) in the lake. Based on the above mentioned data the probable amount of catch of the species mentioned can be predicted every year for the next season. The empirical and calculated locations for the border line of the flood water and old water are in good correlation and their position at the New Year are presented for the years 1964 to 1973 in Fig. 77.

In areas where the water masses contain only low amounts of silt i.e. in which the sedimentation has already been completed there is a permanent high transparency in the deeper water layers. It can be suggested that there the Secchi values would exceed all year round 300 to 600 cm or even more. In these areas the transparency of the epilimnion is controlled mainly by the phytoplankton. If the phytoplankton density is poor, as usual from December to February, the transparency ranges between 200 and 400 cm. As soon as a remarkable algal development starts, usually in March or April, the transparency will be reduced to 80–130 cm or as in case of a dense water bloom even to values of 50 to 70 cm.

Under special conditions i.e. strong, long lasting wind blowing from the shore towards the deep water areas of temperature homogeneity, an upwelling current can be formed easily, lifting water masses very poor in plankton to the surface (see Fig. 78). Under such conditions on 18/3/1974 an extremely high transparency of 745 cm could be determined. After a few days of calm weather the transparency dropped because of renewed and rapid phytoplankton development and the conditions became normal again.

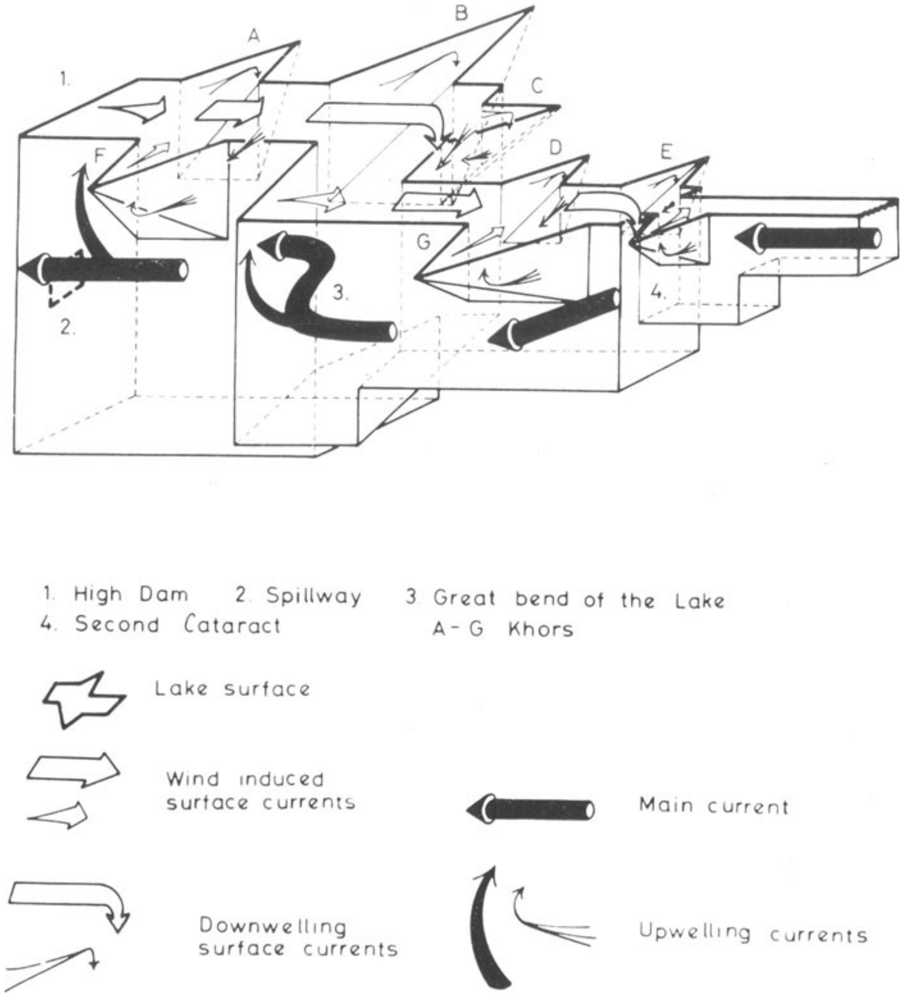

Fig. 78. Current conditions in Aswan High dam basin; B. Entz, unpublished.

In the absence of large amounts of suspended silt, the lake has a green or yellowish green colour. Under such conditions 1% of the surface light reaches only 2–6 m depth. These layers are usually deeper in winter and early spring and shallower in the other seasons. In the brownish or greyish flood water the same light proportion does not reach more than 100 or often only 40 or 50 cm depth.

The wind

One of the major factors affecting the lake conditions is the wind. Based on regular meteorological observations in Aswan and in Wadi Halfa (Omar & El-Bakry 1970) and on our own studies during 1969–1974, the present knowledge on the wind conditions can be summarized as follows. The dominant wind direction is from N–NW (83.3% of windy days), blowing along the main channel or towards the lake centre in the khors of the western side and towards the shore in the opposite eastern khors, causing leeward surface currents in the different areas.

The speed of strong winds reached usually 10–15 m/sec or sometimes 18 to 20 m/sec. Heavy storms well known in several tropical regions have not been noticed in the area during our work. There were stronger winds in wintertime, causing complete circulation. In summer months only moderate winds were common, interrupted frequently by shorter of longer calm periods especially in July or August which promotes a stable stratification. As an average in July 46.4% of the days are calm (Aswan Meteorological Reports 1926–1955). In autumn under cooling weather conditions the wind is helping to destroy the lake stratification.

Moderate but sometimes remarkable wind induced surface currents are detectable in the lake down to 3 or 5 m depth. Their direction in the central channel is from north to south i.e. just opposite the main south-north current of the lake, with a massive flow of water following the Nile valley towards the High Dam (see Fig. 78).

In special localities of the reservoir the existence of wind induced upwelling water movements could be suggested. These were replacing the surface water masses blown away by the wind pressure. Areas with upwelling currents could be characterized by reduced water temperature and oxygen saturation, lower pH values and high, sometimes surprisingly high transparency values of up to 600 or probably 800 cm Secchi values.

Such conditions could be found frequently near the High Dam and sometimes at the southern end of the valley bend near Amada (200 km f. HD), and almost regularly at the end of khors on the western shores. Wind induced sinking water movements were present in other localities resulting in the accumulation of warmer water masses rich in oxygen with high algal turbidity and high primary production. This phenomenon could be observed in erosion littorals e.g. in khors of the eastern shore and in particular in the main channel at the northern end of the bend of Lake Nasser (Singari & Kurusku, 180 km f. HD) as also in the gorge region of Lake Nubia, near the previous Second Cataract (360 km f. HD). Such peculiar conditions diminished the depth of the metalimnion under upwelling and increased it under descending water movement.

The speed of wind induced currents could reach 10 to 35 cm/sec. The above scheduled system of currents covering practically the whole surface of the reservoir (Fig. 78) may be an effective way to avoid any gradual increase of salinity despite the extremely high rate of evaporation.

Another action of wind or even a slight breeze is its remarkable direct cooling effect on the surface water temperature. Wind is enhancing the already high rate of evaporation, under conditions of extremely low relative humidity (of $\pm$ 35% in winter and only 13–21% in summer), to about 3,000 mm/year. These phenomena seem to explain reasonably the relatively low surface water temperature (25–33 °C) under extremely high ambient temperature of the surrounding desert (40–52 °C) in summertime.

Conductivity

It is well known (e.g. Hammerton 1969) that there is a remarkable fluctuation concerning the electric conductivity of the Nile waters. As soon as the flood water appears in Lake Nubia, the conductivity drops down in the area affected from about 280–300 μmhos to 220–230 μmhos cm followed by a more gradual decrease to 210–160 μmhos or even lower.

As mentioned above the total reservoir and particularly its main channel can be considered rather as a very slow flowing river, with predominant laminar currents, than as a typical lake. Accordingly the opportunity arises to study the progress of the flood by fast, simple and exact conductivity determinations, besides transparency observations. Some of our results obtained by conductometry, are shown in Figs 79a and 79b and are calculated as geometric means of the vertical measurements or of all the samples of the cross sections concerned. It is worth considering how the water masses of equal conductivity are moving evenly from September to November 1970 along the main channel, and how far the volume of the lake section concerned and those of the moving water masses are closely correlated. As evident from Fig. 79a, the water masses with 235 μmhos conductivity present at Adindan (280 km f. HD) in September (A) reached Madiq (135 km f. HD) in November (A′). During the same period waters with values of 265 μmhos (A_1) moved from Tushka (240 km f. HD) to Allaqi (110 km f. HD; A_1'), or those of 290 μmhos (A_2) from Singari (185 km f. HD) to Mirwaw (70 km f. HD; A_2'). It could be concluded that during the period in question it took about six months, for the front of the flood to pass through Lake Nasser from Adindan to the High Dam. This suggestion could be confirmed by several biological phenomena.

The data of the flood period 1973–1974 show very similar characteristies (Fig. 79b). During this period the movement of the flood water and as that of the low water can be followed from July 1973 to July 1974 similarly as explained above for 1970, though this time the process is not so clear. The extreme values became reduced in time, and the borders of the different types of waters are not so distinct, most probably due to the meanwhile increased water level.

Conductivity measurements give often useful detailed information concerning the water movement within any selected cross section, such as

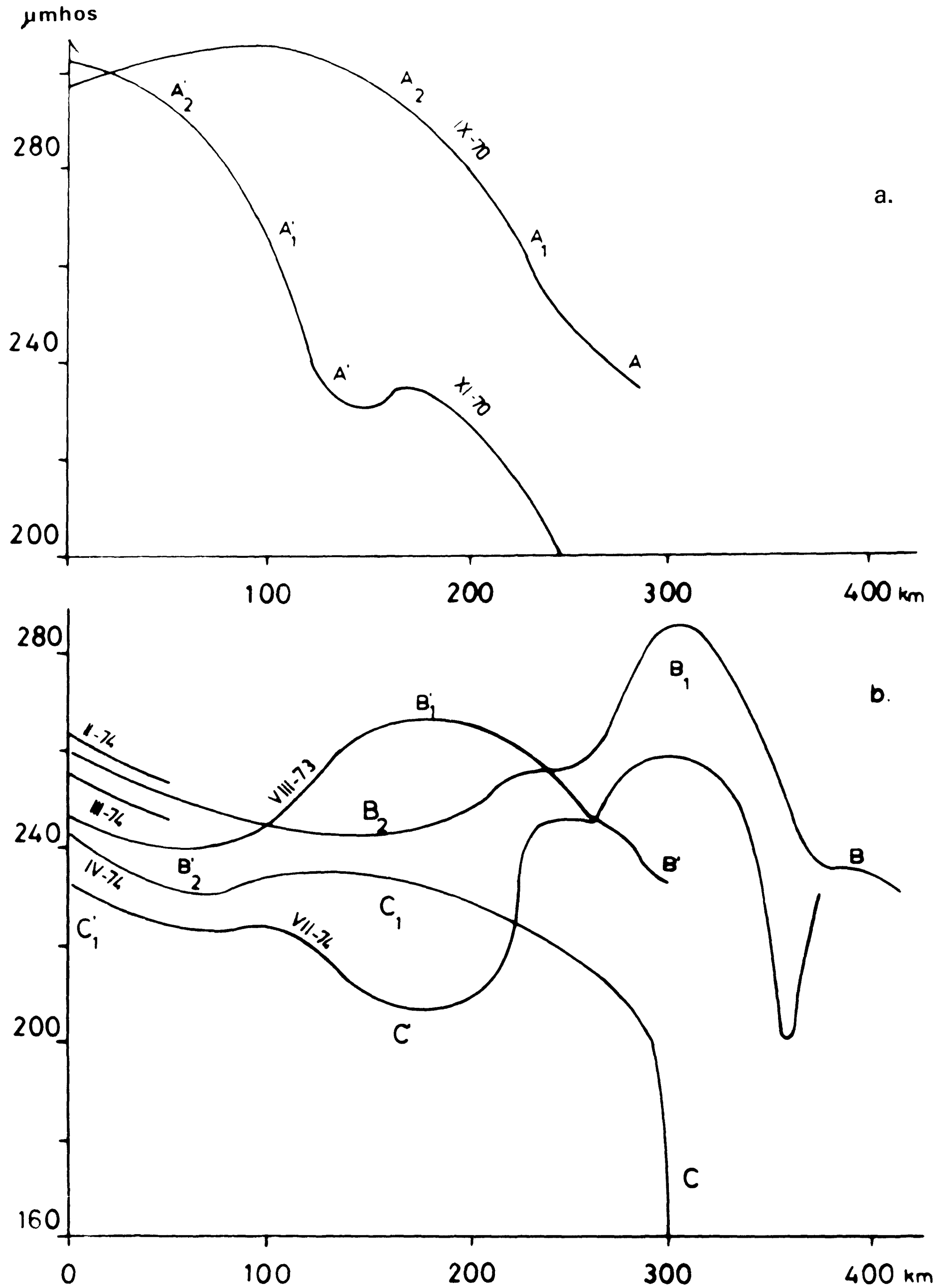

Fig. 79. Conductivity conditions as affected by the flood; a. in 1970; b. in 1973–1974; B. Entz, unpublished.

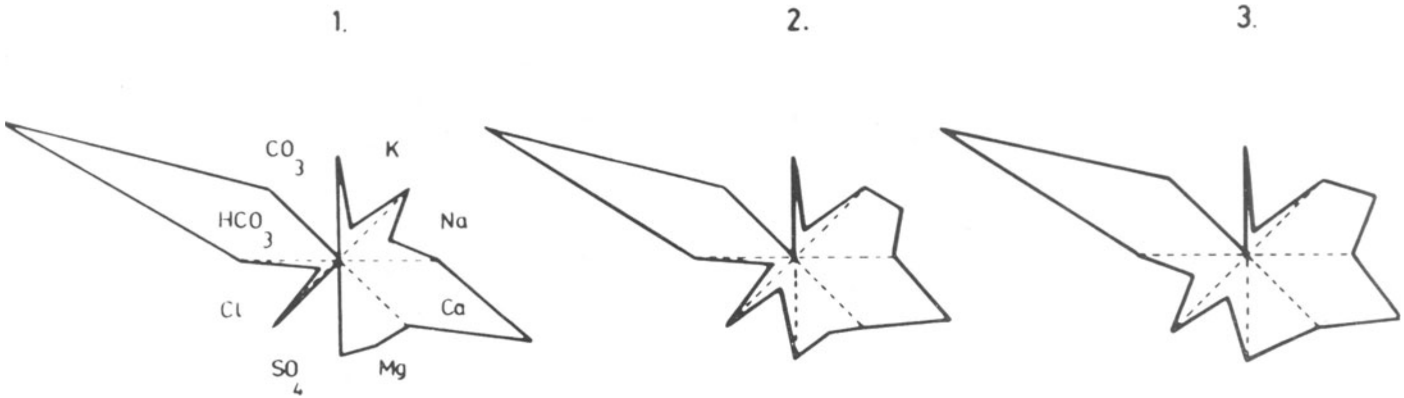

Fig. 80. Chemical composition of Nile water, expressed in 'star diagrams'; 1. Blue Nile from Hammerton 1972, 2. Lake Nasser based on data from Talling (unpublished), 3. Nile at Cairo based on unpublished data from Talling.

vertical and horizontal location of the main current, areas rich or poor in plankton and the water movements in the khors.

Water chemistry

The basic ionic composition of the lake water does not differ from the inflowing Nile water. This can be easily seen in Maucha's star diagrams in Fig. 80 (Maucha, 1948). Within the lake only a slight increase occurs in the Na^+ and Cl^- contents and an almost negligible decrease of the Ca^{++} content from the inflow to the outflow.

The range of pH is wider than in the main course of the river, and due to intensive assimilation processes in the surface layers pH values up to 9.6 are present. According to the studies of Nessiem the phosphate contents together with nitrate are decreasing from the south but a slight increase in nitrite was found (Nessiem 1973).

During the summer stagnation period some H_2S appears in the hypolimnion, detected just below the metalimnion probably due to the decomposing plankton rain, though the S^{--} concentration even here remains below a few tenths of milligrams per litre. The surface of the bottom within the old river channel is brownish in the south, but becomes black in the north during the summer stagnation period, probably because of FeS accumulation. Interesting changes of suspended and dissolved organic matter appear in the Second Cataract area (Entz & Latif 1974), but these features need more detailed investigations.

Biological phenomena

For the settlement and fast development of lacustrine species in the reservoir, it is of high importance to remember that a part of Lake Nasser belonged earlier to Aswan Lake, the lake formed behind the Old Aswan Dam built at the beginning of the twentieth century and heightened in 1933. Although Aswan Lake was flushed year by year by the flood, the opportunity existed for the settlement of several limnophilic organisms. At present very important biological changes occur year by year and stabilized conditions can be expected only after the lake has reached its final working level.

Plankton

The phytoplankton (mainly diatoms and bluegreen algae) gives a fairly high primary production of 3.21–5.23 g C/m^2/day gross production (Samaan 1972). Previous to 1972 water coloration caused by *Volvox* sp. appeared regularly in springtime in several localities. During the present years water coloration and extensive water blooms of Cyanophyta (e.g. *Microcystis aeruginosa*) became common annually for several months before the flood period particularly in the southern areas of the lake between Wadi Halfa and Abu Simbel.

The abundance of zooplankton shows an annual cycle. The peak of its development is not simultaneous all over the lake but shows a longitudinal displacement in time towards the High Dam. As the front of the flood water passes the lake from July to December from the Second Cataract to Aswan, the richest zooplankton development could be noticed always just in front of the flood, in areas not yet affected by the flood water. The highest peaks could be observed in the central sections between 150 and 250 km from the HD. Zooplankton was the poorest usually in the first wave of the flood waters. The khors may play an important role in the repopulation of plankton in the new water masses brought by the flood. The flood water does not intrude into the inner parts of the khors where the rich plankton population remains untouched. The total biomass of the zooplankton was estimated roughly as 100,000 tons (fresh weight).

Littoral areas

The abundance of periphyton all over the littoral zone plays an important role as a nutritive basis for fish either directly for *Tilapia* or indirectly through insects or crustaceans (*Lates*, tiger fish etc.).

As is usual in newly formed reservoirs chironomids developed in enormous numbers. Their larvae were very common down to 3 to 5 m depth during the period 1969–1972. Although chironomid swarms were common on the shores in the evening hours almost all over the year, their peak numbers showed a similar timetable as the zooplankton, appearing always in front of the turbid flood, in water of high conductivity. Their larvae became important as fish food together with water bugs (Coryxidae) similarly widespread in the shallow littoral zone. At that time the biomass of chironomids was estimated around 100,000 tons in the lake. During these years the rocks of the shoreline became covered on their wind protected side by billions of dead chironomids (imagines). This led to an outburst of development of spiders, dragonflies, flies and toads all feeding mostly on the larvae or adults of this insects. In 1973 and even more in 1974 the number of Chironomidae and Coryxidae has been reduced in Lake Nasser considerably. Consequently in 1974 this was followed by the reduction of spiders, flies and even toads around the Lake Nasser. Instead of chironomids snails and shrimps *(Caridina nilotica)* became widespread in Lake Nasser in shallow areas among submerged littoral vegetation (e.g. *Potamogeton pectinatus*, *Najas* spp.). This kind of 'succession' of the littoral fauna could be followed year by year in Lake Nubia in horizontal direction as a consequence of the increasing water level flooding each year new shore areas. But there these features appeared not so obvious as in Lake Nasser because of the semi-riverine or even riverine character of Lake Nubia.

In several localities a fresh water crab *Potamonautes niloticus* (?) appeared in Lake Nasser (see ch. 25). Several new fish speces invaded the area and there were indications even of crocodiles.

Benthos

Before the High Dam has been constructed, a very rich mollusc fauna (Bivalvia) covered the bottom. These mussels did not move out of the river bed when Lake Nasser was formed and died all during the stagnation period because of lack of oxygen. In this area only millions of empty shells are present in the uppermost layer of the mud. The benthos of the old river bed in Lake Nasser is inhabited by a very dense population of *Tubifex* sp. and some scattered chironomids belonging to the '*plumosus*' group. The standing crop of *Tubifex* exceeds in the old river bed 60,000 tons. Benthos is practically absent in the Second Cataract area where the rapid sedimentation of silt prevented the settlement of organisms. In the gorge region of Lake Nubia the original river fauna is present under almost pure riverine conditions.

Starting from 1973 a resettlement of mussels and oligochaetes is going on shallow inlet water, where the oxygen conditions are favourable all year round.

It can be concluded that the reservoir is an eutrophic water body with very favourable physical, chemical and biological conditions. In this way the final development of a very rich flora and fauna can be expected, which gives excellent prospects for the lake fishery. The expected yield is 20,000 tons of fish or perhaps more annually.

Macrovegetation

During the first years of its existence, larger aquatic plants were practically absent from Lake Nasser. The first submerged specimens *(Potamogeton pectinatus)* have been reported in spring 1972 in 0 to 2 m deep water in sandy littoral areas. Most of these stands dried out within the low water period in summer, but recovered again even in larger extent during the next winter and spring. The same happened in the following years and at present *Potamogeton pectinatus* is widespread all over the littoral zone of Lake Nasser.

Later on other species appeared. In summer 1973 *Najas armata* and *Najas minor* could be detected mainly in the northern sections of the reservoir in 3 to 7 m deep water. (Täckholm 1974). They formed in some places in 1974 very dense stands especially near the High Dam. Floating buds or branches of all species mentioned above could be observed in summer 1974 in several open water areas and khors of the lake. All these stands became very rich in periphyton and animal life e.g. freshwater shrimps, insect larvae, fish fry etc. Gradually the macrovegetation may get more abundant and more important as food source especially for young fish in the lake.

Potamogeton crispus, one of the most common vascular plants in 'Aswan Lake,' the lake between the High Dam and the Old Dam, did not spread until now in Lake Nasser although some few specimens were already present in the lake for years, but only in the immediate neighbourhood of the High Dam.

Another type of vegetation is formed in the most remote areas of the khors. Here in very shallow sandy places, very dense stands of *Chara* sp. are present. In shallow localities scattered weak stands of the reed, *Phragmites australis,* are located; probably the extremely strong fluctuation of the water level hindering their massive expansion.

Up to the present there are no floating weeds living in the reservoir, although some of them (e.g. *Eichhornia crassipes, Pistia stratiotes*) play an important but mostly disadvantageous role in some sections of the Nile River system both upstreams and downstreams. Consequently their appearance is possible in the future and has to be watched.

Lake shore vegetation

During the first decade of its existance (1964 to 1974) the lake shore vegetation of Lake Nasser showed four successive stages in its development:

1. Inundation and disappearance of the previous riverside vegetation (1964 to 1968).
2. Temporary appearance of the first settling plants (1969 to 1970).
3. Development of semipermanent or permanent flora between the maximum and the actual water level composed by elements of different origin: A. Desert flora; B. Plants (weeds) from cultivated land and C. Riverside flora (1971 to 1973).
4. Progress of riverside flora around Lake Nasser (1973 to 1974).

The conditions around Lake Nubia were slighly different, because of the slow expansion of the lake above the Second Cataract. In this area there is a gradual withdrawal of the old flora towards the south, which is still going on, and a mixture of old and new flora elements can be observed frequently.

During stage 1. the ancient riverside vegetation (including 500,000 date palm trees) disappeared around Lake Nasser and the shore became completely bare. Seedlings appeared firstly during stage 2. in windprotected bays scattered around the main channel of the lake. Millions of seedlings of *Glinus lotoides* and *Tamarix nilotica,* the two dominant species at that time, were usually arranged in rows following stepwise the borderline of the decreasing water level after the flood. In this process water transport of the seeds may have played an important role.

During the third stage a rapid development of the plant cover could be detected. Beside the two above mentioned species, a third dominant element *Hyoscyamus muticus* enriched the vegetation along the main channel of the lake. Simultaneously several other species appeared. Among the newcomers there were representatives of the vegetation from the previous wadis. These formed often a belt of small bushy plants just at the line of the previous highest lake level (*Fagonia bruguiera*, Cruciferae, Compositae, *Citrullus colocynthis* etc.). These species, except *Hyoscyamus muticus*, were most widespread around the landlocked ends of the khors.

Another spreading centre was in the neighbourhood of the High Dam between the highest and the present water level, where a flora, the richest in species, developed with several mainly bushy plants like *Zygophyllum coccineum*, *Rumex dentatus*, *Rumex vesicarius*, *Phragmites australis* etc. Some of them reached a height over 2 or 3 meters. The vegetation showed in several areas a surprising beauty and transformed the empty desert within 2 or 3 years into a 'park', (e.g. in the surrounding of Khor El Birba, 10 km south from the High Dam of Aswan). Not only sandy places but even stony and rocky areas became covered by dense vegetation during this stage.

It is suggested that the spreading of seeds was favoured by three main factors: a. the prevailing winds, blowing from the northern Nile valley along the river, b. the flood water reaching the area from the south and c. biotic factors such as man and animals, reaching the lake from different directions.

As the water level became more constant, like in 1973–1974 in stage four, the number of some previously predominant species became reduced remarkably (e.g. *Hyoscyamus muticus*, *Glinus lotoides*) and other species became widespread like *Portulacca oleracea*, different grass species etc. These changes may have been promoted by the appearance and very strong development of land insects, especially Orthoptera, grazing on the leaves of the above mentioned bushy plants (*Rumex* spp., *Hyoscyamus muticus* etc.). During this period, especially in summertime, different grasses and *Tamarix nilotica* appeared in large numbers forming dark green spots mainly on flat beeches. Some of the plants mentioned are able to withstand a shorter or longer period of submergence and recover after the flood (e.g. *Tamarix* spp.) but others die very shortly after being flooded (e.g. typical desert plants).

As the lake level has not yet reached its final working level, the final settlement of the new shore flore will take time.

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