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THE DAMMING OF THE NILE RIVER AND ITS EFFECT ON THE HYDROGRAPHIC CONDITIONS AND CIRCULATION PATTERN IN THE SOUTHEASTERN MEDITERRANEAN AND THE SUEZ CANAL

BRANA NA NILU I NJEZIN UTJECAJ NA HIDROGRAFSKE PRILIKE I REŽIM STRUJANJA U JUGOISTOČNOM MEDITERANU I SUESKOM KANALU

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INTRODUCTION

The southeastern part of the Mediterranean Sea was one of the least investigated areas until the last decade. The number of stations in the southern Levant south of 33°N between 1908—1958 were 9 winter stations and 8 summer stations. The work of the Soviet R/V AKADEMIK VAVILOV in the Eastern Mediterranean in 1959 added a few more stations which were located in the southern region of the basin. Later, several cruises were carried out jointly with Egyptian oceanographers including the Egyptian—Japanese expedition aboard SHOYO MARU in March 1959 (Gorgy and Shaheen, 1964), the Egyptian—Yugoslav cruises aboard OVČICA and GOLUBICA in 1959 and 1961, and finally the repeated Egyptian—Soviet cruises aboard ICHTHYOLOG in 1964 (Halim, Guergues and Saleh, 1967) in 1966 (Rzhonsnitsky, 1970; Morcos and Mustafa — Hassan, 1973, 1976) and in 1970—1971 (unpublished).

The information now available on the hydrographic conditions in this area, before and after the damming of the Nile River, permits the determination of the possible effects of damming on the physical and dynamic processes in the area, and to arrive at some conclusions on the effects which have influenced not only the conditions along the Egyptian coast but also in the Suez Canal.

CONTROL OF THE NILE RIVER DISCHARGE BY THE HIGH DAM

Data of the Irrigation Department of the Egyptian Ministry of Public Works indicate that the average yearly discharge of the Nile measured at Edfina (30 km south of Rosetta outlet), and at Damietta (20 km south of Damietta outlet) for a period of 31 years (1912 to 1942) amounted to 62 km^3. In recent years, this discharge was not reached except in 1964. In the summer of 1964, the last normal discharge of the Nile flood into the Mediterranean Sea occurred. It was unusually high, and reached 63.73 km^3. The average total discharge for the preceeding 8 years (1956—1963) amounted to 40.95 km^3. From 1965 on, the discharge remarkably decreased, and the average total discharge during the succeeding 7 years (1965—1971) amounted to 12.75 km^3 (Table 1). From Table 1, it can also be seen that in 1965 the Nile River discharge decreased to about half and in 1966 to about one-fifth of that in 1964. From 1968 on, the annual amount of discharge averages only one tenth of the average value for the period prior to 1964.

Table 1. Annual total water discharge (in km^3) from the Nile River into the Eastern Mediterranean Sea for a period of 16 years (1956—1971).

a. Before the Aswan High Dam

Year	1956	1957	1958	1959	1960	1961	1962	1963	1964
Discharge (km^3)	55.75	34.03	44.55	49.36	38.72	58.52	44.01	43.64	63.73

Average annual discharge — 40.95 km^3

b. After the Aswan High Dam

Year	1965	1966	1967	1968	1969	1970	1971
Discharge (km^3)	36.94	13.24	21.51	5.87	3.60	4.02	4.10

Average annual discharge — 12.75 km^3

Moreover, the annual cycle of the discharge has changed. Before the High Dam, the Nile waters were regulated by a system of dams on its two tributaries, the Damietta and Rosetta branches. The discharge usually occurred from July to August until December or January, and the maximum discharge was observed in September-October with 25 to 30 percent of the total discharge. At present, the discharge is only through the Rosetta mouth, and the maximum is registered in winter. For only two months (January and February), more than 50 percent of the total yearly discharge now flows into the sea.

Thus such a change in both the total amount and the pattern of the discharge affects to a great extent the physical, chemical as well as biological conditions in the southeastern part of the Mediterranean Sea. In the present study, the concern is only with the physical effects and their dynamic consequences.

REVIEW OF HYDROGRAPHIC CONDITIONS AND PHYSICAL PROPERTIES

Temperature and Salinity

It is well known that the water temperature in the studied area fluctuates seasonally across a relatively wide range (8 to 10°C) which is related principally to the annual cycle of the solar radiation (Figure 1). Figure 1 also shows a distinct horizontal and vertical distribution for each season. For instance, the water temperature has great vertical gradients in the layer 50 to 75 m in autumn, while in winter, it is homothermal to the depths of 100 to 150 m, and sometimes even down to the 200 m level, below which the temperature starts to decrease slowly.

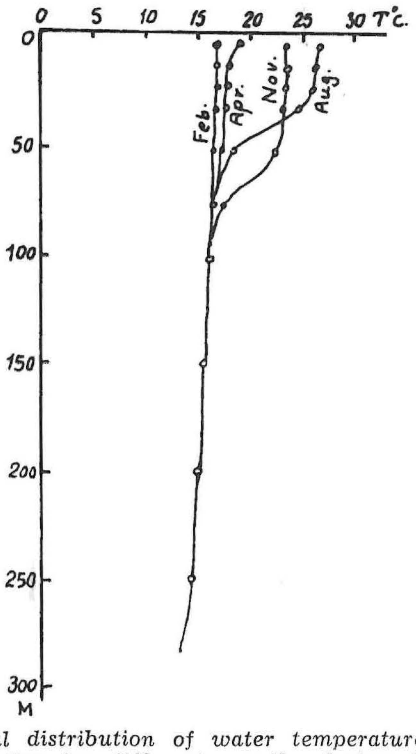


Fig. 1 — Typical vertical distribution of water temperature in the southeastern Mediterranean Sea for different months during 1966 (after Rzhonsnitsky, 1970).

The spring and summer seasons have also their own particular temperature distributions vertically as well as horizontally. The most interesting feature recently observed in the vertical distribution of water temperature, however, is the increase of the thickness of the warmed layer near the coast of the Nile Delta in summer. This warming is due to the improvement in the conditions required for the vertical mixing of water, achieved through increasing the water density on the surface as a direct result of decreasing the amount of the fresh water discharge. This warmed layer extends now to the 100 m level, and anly below that level does the water temperature start slowly to decrease (Figure 2b).

The most pronounced and direct effect of the damming of the Nile River is reflected on the salinity distribution in the southern Levant, particularly

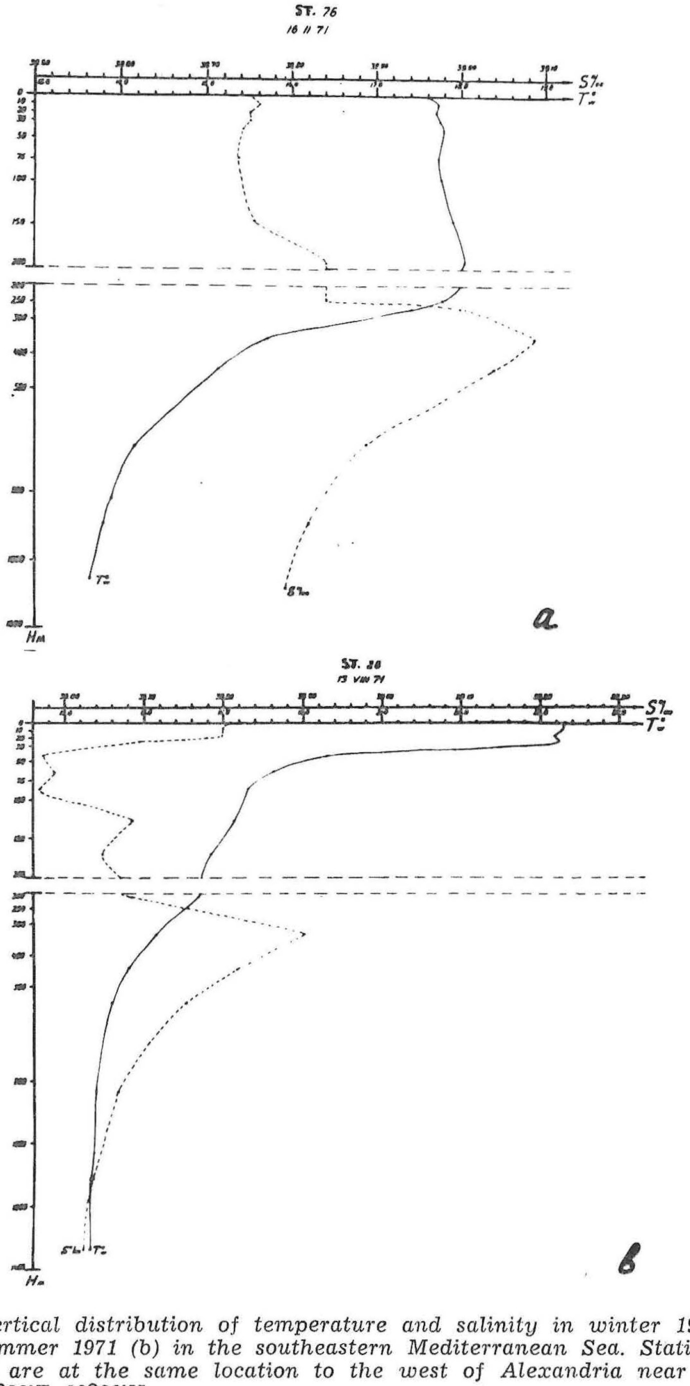


Fig. 2 — Vertical distribution of temperature and salinity in winter 1971 (a) and summer 1971 (b) in the southeastern Mediterranean Sea. Stations 76 and 26 are at the same location to the west of Alexandria near El-Sallum, 25°30'E, 32°20'N.

in the region close to the Nile Delta. The salinity distribution in this region is, however, chharacterized by a great complexity due to the interaction between different factors: the intensive evaporation, the flow of Atlantic water of low salinity ,the existence of Levant water of high salinity, and finally the river discharge. The last of these factors is now of a minor value, and hence any distribution of salinity is controlled mainly by the other factors, and gives a rather different pattern than that known to exist before the damming of the Nile River.

Figure 3 illustrates the surface salinity distribution off the Nile Delta in two comparable autumn months, October 1964 and November 1966, and representing the conditions before and after the damming of the Nile. The figure clearly illustrates the changes in the horizontal distribution of salinity in this region. Furthermore, until the regulation of the Nile River discharge in the studied area at the time of the Nile flood, three zones were distinguished clearly: the freshing zone, within its limits a gradual mixing of Nile waters occurred; a zone of intensive mixing of fresh and sea waters; and finally holistatic zone. Halim, Guergues and Saleh (1967) analyzed the spreading of Nile waters and determined the following values for the physical and chemical characteristics along the border line between the fresh and sea waters: salinity — 38.50‰, density (σ_t) — 26.0 to 26.5; the relative content of dissolved oxygen — 105 percent; concentrations of phosphates and silicates — 0.15 μg at P/L and 7.5 μg at Si/L. In 1964, the river discharge was the greatest since 1956 and the fresh water in October 1964 occupied a large area of the sea, the width of which extended to about 70 km to the north of the Rosetta outlet. The 1966 distribution showed that this freshing zone has greatly diminished relative to the amount of 1964. Mixing of fresh and seawater occurred only near the coast and almost all the investigated region, with the exception of a narrow coastal zone, was occupied by seawater of a salinity higher than 38.5‰ (Figure 3). Only in February 1966, the freshing zone was represented clearly in the eastern part of the region; however, its width did not exceed 16 km.

Density

The considerable decrease of fresh water discharge and the resulting remarkable increase of salinity brings forth a corresponding change in water

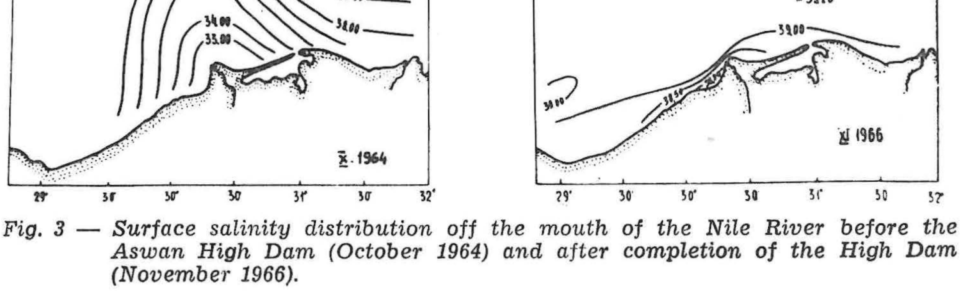


Fig. 3 — Surface salinity distribution off the mouth of the Nile River before the Aswan High Dam (October 1964) and after completion of the High Dam (November 1966).

density, which is dependent on two main factors: salinity and temperature. In the coastal areas, and especially near the river outlets, the dominating influence is that of the salinity factor. Thus, in such areas, the density would change according to any small variation in the salinity value. This, consequently, affects the stability conditions, the mixing processes and the entire current system in the area. These subjects will be discussed in further detail in the next paragraphs of this paper.

Transparency

It is to be expected that the decrease of river discharge would, in turn, greatly influence the transparency of seawater in the area considered. This was shown through a comparative study of the transparency of seawater before and after the regulation of the discharge of the Nile River by the High Dam, based on Secchi disc measurements.

Figure 4 illustrates the distribution of transparency for the months of October 1964 (before the regulation), August 1966, and September 1970 (after the regulation). It is clear that the transparency of water on the continental shelf showed great changes. This was due to two factors, namely, the sharp decrease of the amount of suspended sediments discharged from the Nile River and the change of the phytoplankton population, especially in the coastal area after 1966.

As far as the solid matter is concerned, it was indicated by Shukry (1950) that before the regulation of the Nile, about 57×10^6 tons of suspended sediments were discharged yearly into the Mediterranean Sea. A large amount of the sediment was carried during the flood period; one cubic meter of Nile water contained, at the peak of the flood, up to 4 kg of suspended solid material.

Figure 4a of October 1964, the year of the highest flood, shows that the Nile waters then occupied a large area of the sea, and illustrates that the transparency of seawater to the north of Rosetta, on the line dividing the fresh and seawater, has changed rapidly from 10 m to 35 to 40 m within a distance of only 300 to 500 m. This was not the case after regulation took place (Figure 4b and c).

Water Masses

Generally speaking, the Mediterranean is characterized by three permanent water masses, a mass of low salinity, a mass of high salinity and a deep water mass. In addition, in the summer a surface water mass is formed and characterised by both high temperature and salinity (Wüst, 1959; Lacombe and Tchernia, 1960; Gorgy and Shaheen, 1964; Moskalenko and Ovichinnikov, 1965; Gorgy, 1966; Halim, Guergues and Saleh, 1967; Morcos, 1972). The hydrological structure of the southern Levant was more complicated, mainly as a result of the Nile River discharge.

Halim, Guergues and Saleh (1967) defined five water masses during the flood season of 1964 including:

1. An »epithalassa« of very low salinity and of a high gradient, corresponding to the upper horizontal segment in the T—S diagram shown in Figure 5a.

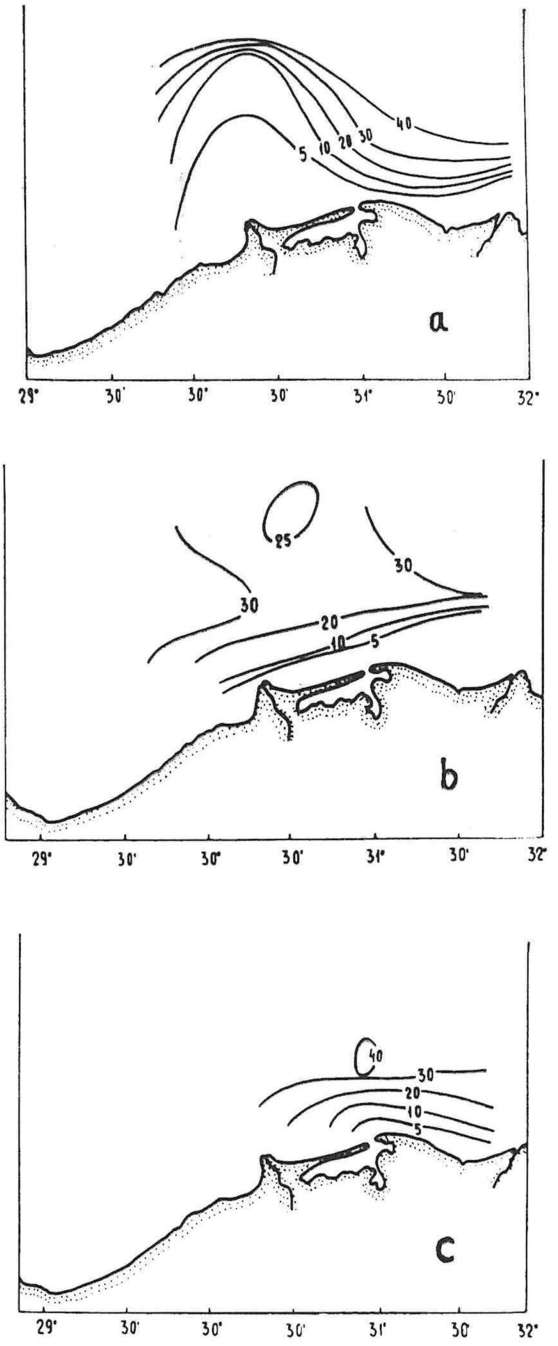


Fig. 4 — Distribution of seawater transparency (Secchi disc. readings in m) off the mouth of the Nile River for October 1964 (a), August 1966 (b) and September 1970 (c).

2. The layer of maximum salinity, corresponding to the zone of flexion in the T—S diagram (Figure 5a). The temperature was slightly lower but showed little variation within this layer.
3. The layer of subsurface salinity minimum, corresponding to that portion of the T—S diagram (Figure 5a) with inward curvature. Salinity decreased slowly while temperature dropped rapidly.
4. Nielsen's »intermediate« layer of salinity maximum, indicated by a slight distinct increase in salinity at about 200 to 300 m.
5. Deep water layer, found below the 400 m level, the characteristics of which did not change throughout the year.

Recent investigations, carried out after the regulation of Nile discharge, showed clearly that the surface water mass, the so-called »epithalassa« layer, mentioned above, completely disappeared (Figure 5b). Now, there are only four water masses during the summer including:

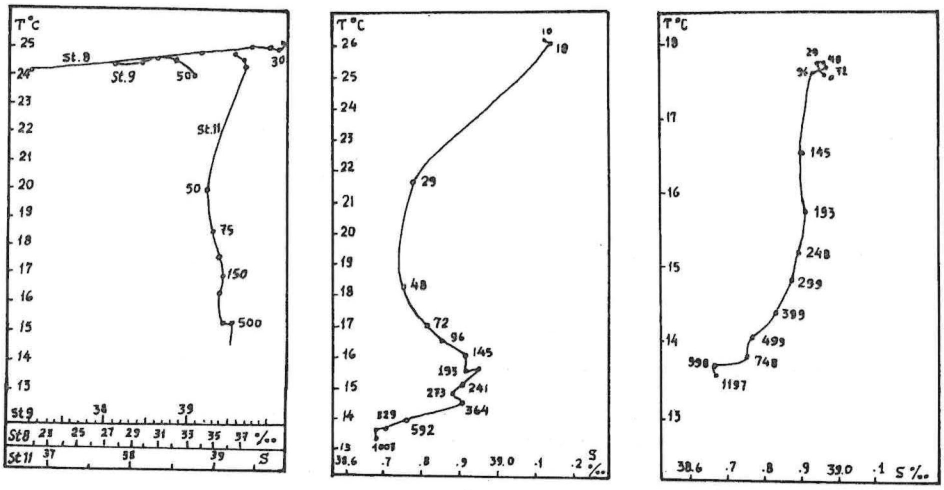
1. The surface water mass which extends from the surface to 30 to 50 m depth and has a temperature range of 22 to 28°C and a salinity of 38.8 to 39.1‰.
2. A water mass of low salinity formed through the transformation of Atlantic water, with a temperature range of 17 to 23°C and a salinity range of 38.6 to 38.8‰. The core layer of this water mass lies at 50 to 75 m.
3. An intermediate water mass of high salinity, at depths from 150 to 400 m with a temperature range of 15 to 17°C and a salinity range of 38.9 to 39.00‰.
4. A deep water mass, below 400 m. Within the limits of this water mass, in the layer 400 to 1200 m, the temperature range is 13.6 to 14.5°C and the salinity 38.68 to 38.87‰.

During winter, due to the decrease of the vertical stability, and the resulting mixing processes, the surface waters sink to great depths and there are only two identifiable water masses (Figure 5c). These can be called the upper and the deeper water masses.

Hydrodynamical conditions

Stability and Mixing Processes. — The considerable increase in salinity after 1965 caused an increase in water density and a decrease in the stability in the upper 10 m layer. This created more suitable conditions for the vertical mixing of water, and the depth of its spread increased in the last few years. This is visibly reflected in the vertical distribution of temperature by the increase of the thickness of the warmed layer near the coast of the Nile Delta. To some extent, this fact may possibly suggest some kind of vertical transportation of biogenous elements from the deeper layers to the upper through convection processes, compensating the loss in the Nile supply of nutrients in the pre-High Dam period.

General Circulation Pattern. — The baroclinicity, the bottom relief and their joint effect, in addition to other factors such as the horizontal pressure gradients resulting from the difference in water level, the tangential wind stress, and the Coriolis force, are the main factors controlling the circulation pattern and the current regime in any open or closed sea. In the case of the Mediterranean Sea, the most important factors are the joint effect of baroclinicity



(a) (b) (c)

Fig. 5 — T-S diagrams for the southeastern Mediterranean Sea near the coast of Egypt before regulation of Nile discharge (a) (after H a l i m, G u e r g u e s and S a l e h, 1967), and after regulation during summer (b) and winter (c).

and bottom relief, the horizontal pressure gradients and the wind stress (G e r g es, 1976). The other factors have been shown to be of minor importance. In the coastal region of the southern Levant, the current regime would be sensitive to any alteration in the density field and/or in the sea level.

The general features of circulation in the southern Levant before the High Dam have been well reviewed by G o r g y (1966) and H a l i m, G u e r g u e s and S a l e h (1967). The water discharge from the Nile caused a rise in sea level at the coast, particularly near the river outlets. The water slope led to a rise in the horizontal pressure gradient toward the north, which helped the waters from Rosetta to be moved in a nortwest direction and spread by its own momentum in that direction to an area about 50 km from the outlet, before being deflected eastward by Coriolis force. Thus, the »Nile Stream« was formed which in its way eastward received more flood water from Damietta. This influx reinforced the stream and increased its velocity to 3.2 knots (H a l i m, G u e r g u e s and S a l e h, 1967). Conditions at Damietta were somewhat different from Rosetta. The Damietta branch was directed northeast, and its output usually amounted to about half that of Rosetta branch. The flood water did not spread as far seaward and there was no sharp change in direction. The stream moved further to the east remaining close to the coast and then ultimately became directed nortward, but its salinity was still very low (34.2‰). While the stream proceeded northward, highly saline waters off Israel and Lebanon were set into a surface countercurrent which converged with the stream, producing a cyclonic anticlockwise vortex, characteristic for the circulation in this region.

At present, the Nile waters do not cause such a rise in the water level near the coast. As a result, the horizontal pressure gradients are much less, and the Nile stream has practically disappeared. For the same reason, the current velocities in the Delta region decreased considerably. Based on some measurements of currents in the area during the last cruise of the R/V ICHTHYOLOG in the southern Levant in 1971, the total current velocity rarely exceeded 0.5 knots.

The present circulation pattern shows a permanent current flowing in summer very close to the coast from west to east. It is observed between the coast and the 50 to 75 m isobath. In winter, there is an indication of a westward current north of 32°N Latitude and water flow to the west was observed. This was confirmed in a recent study of the circulation in the Eastern Mediterranean in the winter season (Gerges, 1976).

The Damming Effect on the Suez Canal.

In a previous study by Morcos and Gerges (1968), it was shown that the distribution of water masses in the Suez Canal in September 1966 gave quite a different picture than those observed in the month of September in the previous sets of sections taken in 1923—1924, 1934—1935 and 1954—1955 (Morcos, 1967). Comparison of two recent longitudinal sections along the canal taken in September 1964 (typical for the conditions known to exist before the damming) and September 1966 (taken after the damming), showed a clear shift of almost all the water masses of the canal towards the north in 1966 (Figure 6). This suggests a northward current towards Port-Said, the Mediterranean end of the canal, at that time of the year in which a strong southward current toward Suez was previously observed. An attempt was made to investigate the effect of all the physical factors encountered in the phenomenon, namely, the mean sea level, the atmospheric pressure, the wind, and the water density (Morcos and Gerges, 1974). The latter was shown to be the most influencing factor. A noticeable change in the water density at Port Said was observed in September 1966, as compared to the density values in previous Septembers. This affected the current regime in the Canal in 1966, and explained the absence of the reversed southward current in this year. In spite of all the scientific arguments about this interpretation (Morcos, 1967, 1973; El-Sabh, 1968, 1969), there must be no doubt that the drastic decrease in the Nile River discharge in 1966 led to an increase in the salinity of seawater at Port-Said, hence a decrease in its specific volume and in the water level sloping which previously favored the domination of a southward current from 15 August to 15 October. Because of the lack of information about the present conditions in the Suez Canal the permanency of the observed changes cannot be confirmed. However, evidence that that is happening is accumulating. Morcos and Messieh (1973) in a more recent study showed that, contrary to all preceeding observations in 1924, 1934, 1954 and 1964, no increase in salinity was observed in Suez Bay during summer 1966. This confirms the previous suggestions that a change in the current regime in the Suez Canal took place in 1966 just after the completion of the Aswan High Dam as a result of the vast reduction in the amount of water from the Nile into the Mediterranean.

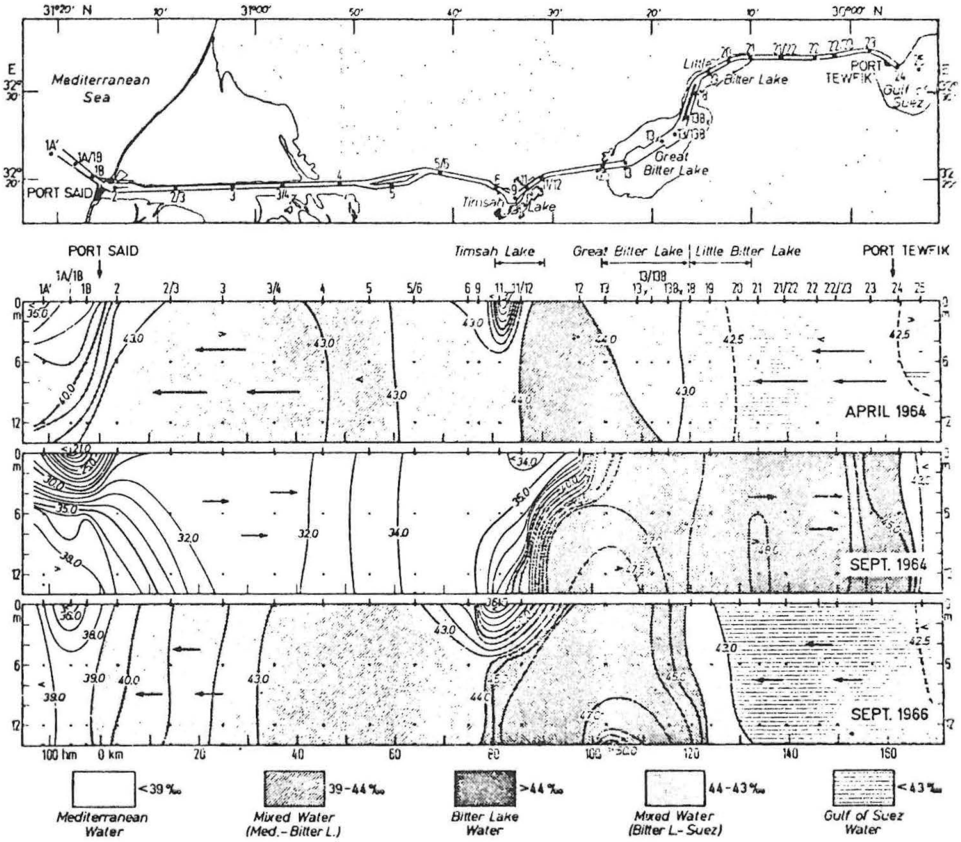


Fig. 6 — Salinity distribution along the Suez Canal for April 1964, September 1964 and 1966 (from M o r c o s and G e r g e s, 1972).

SUMMARY

The psysical effects and dynamic consequences in the Eastern Mediterranean and the Suez Canal resulting from thee damming of the Nile River have been determined. Changes in temperature, salinity, density and transparency have been noted. The number of water masses has been reduced from five to four and changes in the circulation pattern have been noted. A change in the current regime in the Suez Canal occurred after damming of the Nile River.

ACKNOWLEDGEMENTS

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BRANA NA NILU I NJEZIN UTJECAJ NA HIDROGRAFSKE PRILIKE I REŽIM STRUJANJA U JUGOISTOČNOM MEDITERANU I SUESKOM KANALU

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KRATAK SADRŽAJ

Analizirani su podaci o dotoku Nila i hidrografskim prilikama u Levantinskom bazenu prije i poslije izgradnje Asuanske brane. Poslije 1968. dotok Nila je smanjen na jednu desetinu u odnosu na razdoblje 1954—1964. S time u vezi je drastično promijenjena transparencija vode ispred delte. Znatno je promijenjen i salinitet kao i njegove sezonske fluktuacije. Minimum se sada pojavljuje zimi umjesto u kasno ljeto i ranu jesen, kako je bilo prije izgradnje brane. Te promjene utječu na stabilitet, pa je povećano vertikalno miješanje i spuštanje toplog gornjeg sloja. Osim u obalnom području, promjene se osjećaju i u južnom Levantinskom moru. Pretpostavljeno je da su se promijenili smjer i brzina strujanja. Promjene se također osjećaju u području Sueskog kanala, gdje je uočeno da se režim strujanja u rujnu 1966 izmijenio, a to je mjesec u kojem su ranije nastupali maksimumi dotoka Nila.