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# Salt Content and Water Budget of The Suez Canal

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Abstract. The water body in the Suez Canal is a combination of waters from different sources. Hence, its exact hydrographic structure is very difficult to define. Three main water masses are identified along the Canal on account of their salinity values: Levantine water mass I, the Suez Bay water mass II, and the Bitter Lake water mass IV, in addition to a number of mixed types III. The monthly water volume and salt content of the main water masses and Canal sectors are determined using empirical relationships. The monthly variations of salt content, water volume, sea level, temperature, salinity and density for each main water mass were discussed. The ratio between the salt content of the different water masses in one month follows nearly the ratio between their masses that is slightly different from the ratio between their volumes. The total amount of salt in Levantine water mass (I) is less than 500 million kilogram from January to June, then a rapid increase is observed to September followed by a sharp decrease to January. In the Suez Bay water mass (II), the total amount of salt remains nearly constant between January and April, decreases sharply in May and June and becoming zero between July and September. In the Bitter Lakes water mass (IV), the total amount of salt shows an exceptional pattern, where a sharp increase is found from the minimum in April-May to the maximum in summer, then a decrease to the minimum in April. The dilution by River Nile water and the slow current in summer months may help greatly in the increase of the salt content in that area.

## Introduction

Since the opening of the Suez Canal (Fig. 1) for navigation in June 1869, few studies have been carried out on its environment. Its waters are of mixed type from different sources: the Mediterranean, Red Sea, and River Nile. The exact structure of the medium is complex as a result of the influence of the salt bed at the floor of the Bitter Lakes. Earlier works on the Canal followed the seasonal change in the distribution of these water masses using their salinity values as the main indicator. The present work goes beyond that to investigate the variation in volume, water mass, and total salt content of the water mass in the Canal as well as its salt budget.

## *Background on Distribution of Salinity and Salt Content along the Suez Canal*

A basic representation of the hydrographic conditions in the Suez Canal is given in Fig. 2 (after Morcos, 1960a), based on his observations of 1953-1955. Through different works on the Suez Canal (Fox, 1926; Wüst, 1935; Morcos, 1960a,b and 1975; Morcos and Gerges, 1974; Morcos and Messieh, 1972; El-Sabh, 1968; El-Sharkawy and Sharaf El-Din, 1983; Miller and Munns, 1974; Sharaf El-Din, 1974; Soliman *et al*., 1988; Soliman and Morcos, 1990), the hydrographic feature of its water showed a specific pattern which is seldom noticed in other areas in the world.

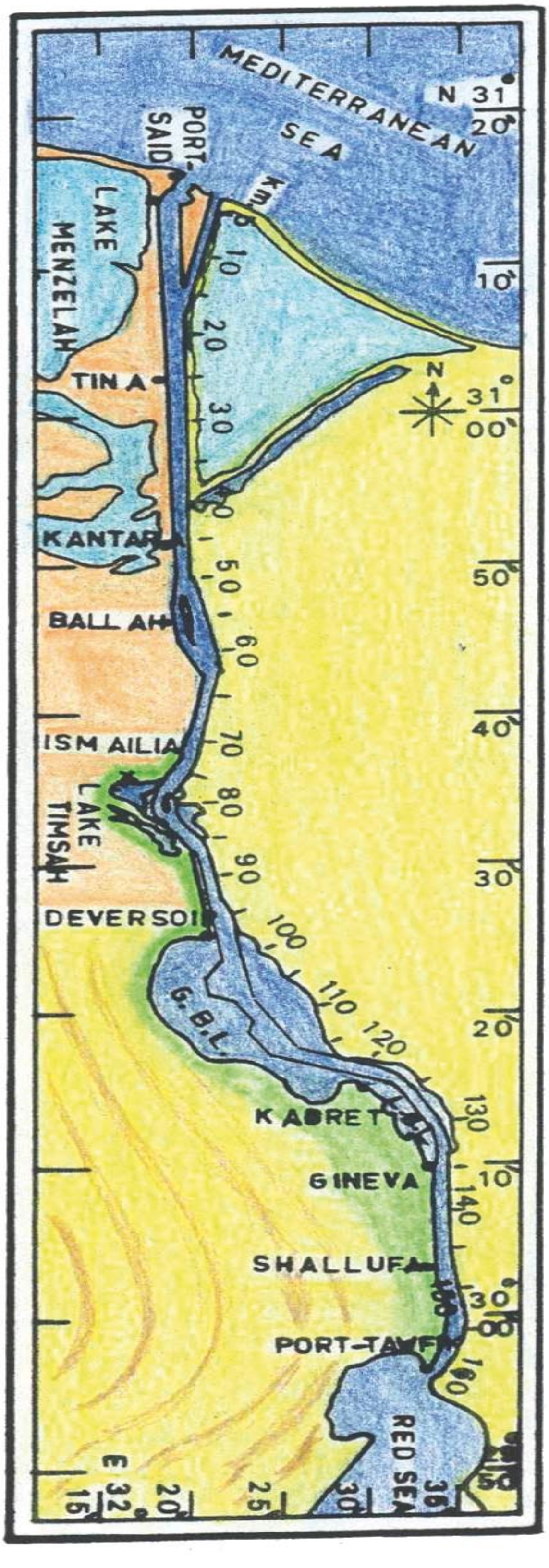

FIG. 1. The Suez Canal map.

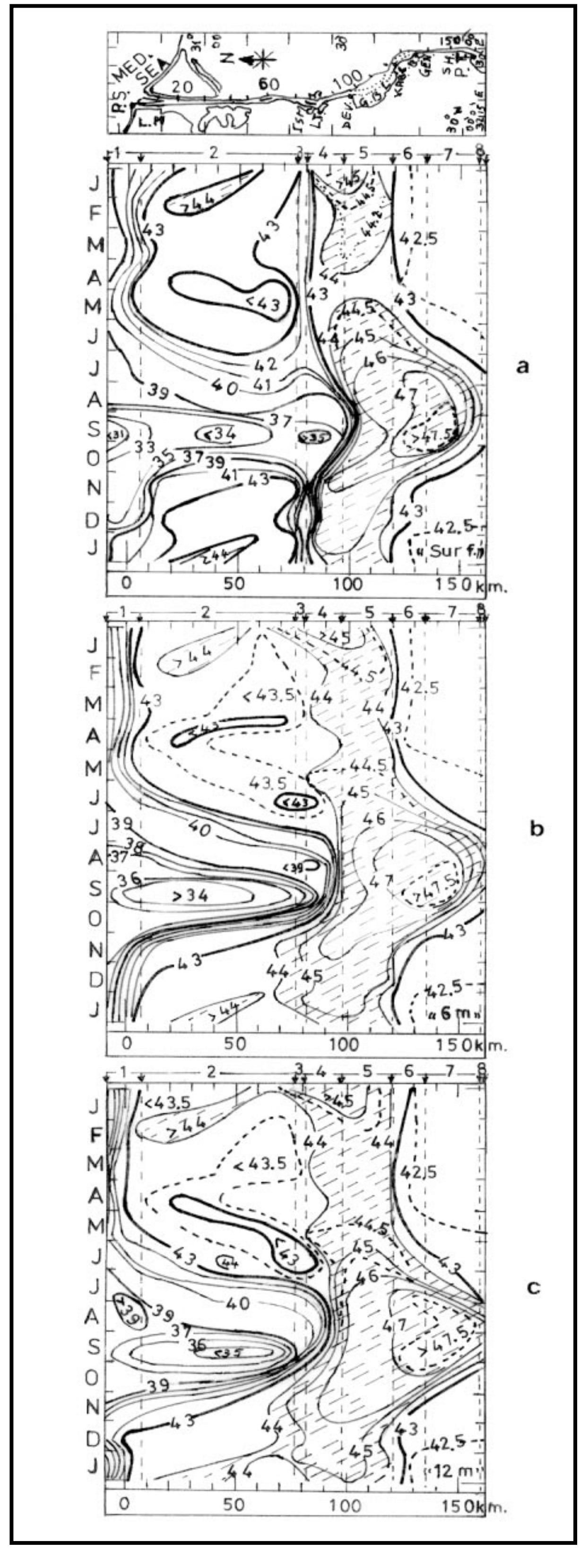

FIG. 2. Monthly distributions of salinity along the Canal at surface, 6 m and 12.

The distribution of salinity at surface, 6 and 12 m depth levels along the Canal is given in Fig. 2. The distributions of mean salinity, temperature and density (over depth) for the same period are given in Fig. 3. It is worthy to mention that the Mediterranean water (< 39) is defined by the isohaline 39.0, while the Gulf of Suez water (Suez Bay water with salinity < 42.5) is described by the isohaline 42.5.

The 44.0 isohaline in the southern canal shows the influence of the southward current in moving the high salinity water (> 44) in the Great Bitter Lake (G.B.L) towards the Suez Bay (S.B.). The 44.0 isohalines in the north and the south can be looked at as the outer circumference of a body of water that starts to build up in April, increases with time in volume and salinity to reach its maximum from July to October and then starts to decrease regularly and disappears at surface in April. The 44.0 isohaline and circumference of this body contain isohalines of higher values of concentric form with the 47.5 isohaline as the nucleus of the body in September (August-October). Starting with 44.0-45.0 on the bottom in the nucleus in the period from February to May, the salinity increases gradually to 47, reaching a maximum of 47.5 in September before starting to drop to minimum in February-March.

The structure of this water body suggests that it had a "radiating" source of salt coinciding with the maximum salinity in the center of the nucleus, which decreases gradually by passing from the center to the outer shell of this concentric body. It is noticed that the decrease in salinity takes places also from the bottom to the surface indicating that the source of salts lies on the floor of the G.B.L.

### *The Salt Content in the Canal*

From the observations taken over the two years (1953-1955) along the Suez Canal, one could conclude that salinity in the Canal changes with space and time. Accordingly, an accurate estimate of the monthly average salinity and density for the whole Canal is difficult. In estimating the salt content along the canal, the earlier investigations did not take into consideration the cross-sectional area of the canal. The present study is a new approach in introducing this factor. As a result, the significance of increase salinity of the Bitter Lakes is multiplied, particularity if we take into account that the G.B.L. is about 10 times the volume of the Canal proper. Not only the calculation of the salt content of the whole Canal is important but also in its individual parts and water masses. This can be done by summation of the salt content of the water masses lying between every two successive isohalines, according to the following equation:

$$S_c = S_{c1} + S_{c2} + S_{c3} \quad (1)$$

Salt contents is defined by the following relations:

$$S_c = M * S = V * \rho * S \quad (2)$$

$$S_{ci} = M_i * S_i = V_i * \rho_i * S_i \quad (3)$$

Where:

$S_c$ : is the total salt content of the Suez Canal,

$M$ : is the mass of water in the Canal,

$V$, $\rho$, and $S$ : are the volume, average density and average salinity of water in the Canal,

$M_i$ : is the mass of water between two successive isohalines,

$S_{ci}$ : is the salt content of a water mass between two successive isohalines,

$V_i$, $\rho_i$, and $S_i$ : are the volume, average density and salinity of a water mass between two successive isohalines.

Every water mass is suggested to be divided into three layers, Surface, Middle, and Bottom at depths 0, 6, and 12 m.

According to Equation (1) we have:

$$S_c = (V_1 * \rho_1 * S_1) + (V_2 * \rho_2 * S_2) + (V_3 * \rho_3 * S_3) \quad (4)$$

and

$$V = V_1 + V_2 + V_3 \quad (5)$$

If $\rho_i$ varies slightly, then:

$$\rho = (\rho_1 + \rho_2 + \rho_3) / 3 \quad (6)$$

and

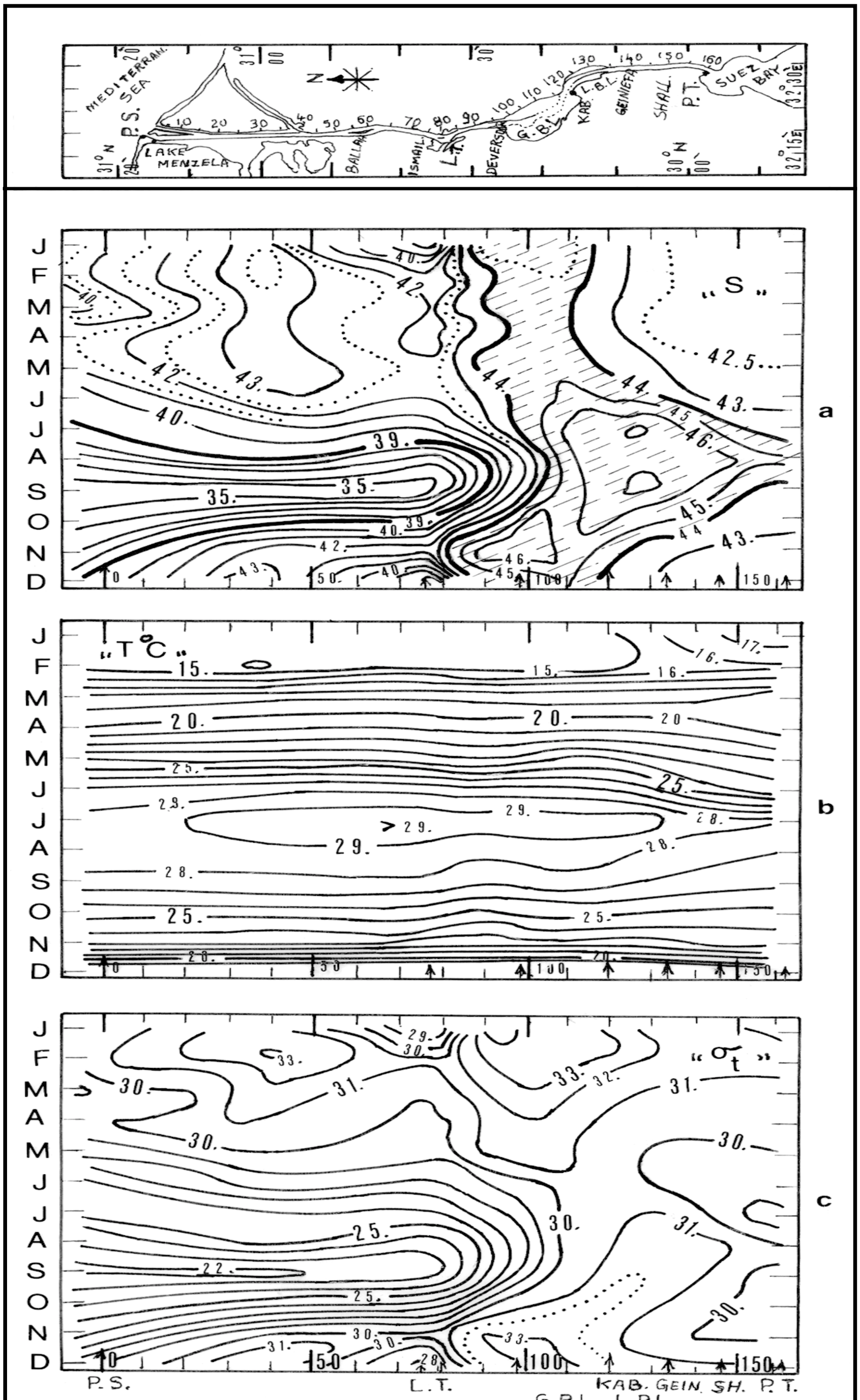


FIG. 3. Monthly distributions of mean salinity, temperature and sigma T along the Canal.

$$S_c = (V_1 * S_1) + (V_2 * S_2) + (V_3 * S_3) * \rho \quad (7)$$

Equation (5) can be written as:

$$V = a * d = a_1 * d_1 + a_2 * d_2 + a_3 * d_3 \quad (8)$$

and

$$a = a_1 + a_2 + a_3 \quad (9)$$

where:

- a : is the average area of the cross section of the water mass,
- $a_i$ : are the corresponding terms to the surface, middle and bottom layers.
- d, $d_i$ : are the average distance and the corresponding terms on the main axis between the two isohalines enclose the water mass.

By determining the average cross-sectional area of the Canal proper, a factor (f) can be determined for every sector of the Canal or lakes according to the following equation:

$$a = f * A \quad (10)$$

or

$$f = a/A \quad (10')$$

where

A: is the area of the average wet cross-section of the Canal proper.

Therefore,

$$a = f * A = (f_1 + f_2 + f_3) * A \quad (11)$$

and

$$V = a * d = (f_1 * d_1 + f_2 * d_2 + f_3 * d_3) * A \quad (12)$$

Using equation (7), then:

$$S_c = (f_1 * d_1 * S_1 + f_2 * d_2 * S_2 + f_3 * d_3 * S_3) * A * \rho \quad (13)$$

$$= f * d * S * A * \rho \quad (14)$$

Equations (13 and 14) are used in determining the monthly salt content of the Canal sectors and its main water masses based on data obtained in eleven monthly cruises (Nov. 1953-Nov. 1955).

## Methodology

The method of determining the terms in equations (13 and 14) and the procedure of calculation are described in the followings:

### *The Cross-sectional Area A*

In the Canal proper, a number of profiles of cross-sections (scale 1:500) are taken to represent the different sectors of the Canal proper (Reunion, 1955). In Port Said (P.S.) and Port-Tawfik (P.T.) regions the Canal is wider at its two openings in the Mediterranean and Gulf of Suez. From the charts used, it was found that the cross-sectional areas between km 1 and 5 and km 160 and 162 are nearly three times as large as the average cross-sectional area of the Canal proper which is composed of three parts (representing only 9.24% of the total volume of the Canal). They are the northern part (NP) from km 5 to 76, the central part (CP) from km 81 to 97 and the southern one from km 135 to 160. The average cross-sectional area is taken as 1280 $m^2$ for calculating the salt content of the Canal proper.

Figure 4 represents the cross-sectional area of Lake Timsah, the Great Bitter Lake, and the Little Bitter Lake along the axis of the Canal. The cross-sectional areas in the lakes were calculated on the axis every 500 m in Lake Timsah (L.T.) between km 76 and km 81, and every one-kilometer in the Bitter Lakes except between km 101 and km 115 and between km 122 and km 126 where the calculation was made every two kilometers (with respect to level 17.80 m according to the scale used by the Suez Canal Authority). The cross-sectional area is divided into three parts ($a_1$, $a_2$ and $a_3$ corresponding to salinity $S_1$, $S_2$ and $S_3$).

### *The Determination of $f_1$, $f_2$ and $f_3$ along the Axis of the Canal and Lakes*

In the lakes, the values $f_1$, $f_2$ and $f_3$ were determined according to the relation (10') by dividing the values of $a_1$, $a_2$ and $a_3$ by 1280 (the average cross-sectional area of the Canal proper in square meters).

In the Canal proper, P.S. and P.T. regions (which represent 13.12 % of the capacity of the whole Canal), the values $f_1$, $f_2$ and $f_3$ are considered to be the same ($f_1 = f_2 = f_3 = f/3$). The computation took also in consideration that the Canal doubled by the Ballah Branch between km 51 and km 60.4.

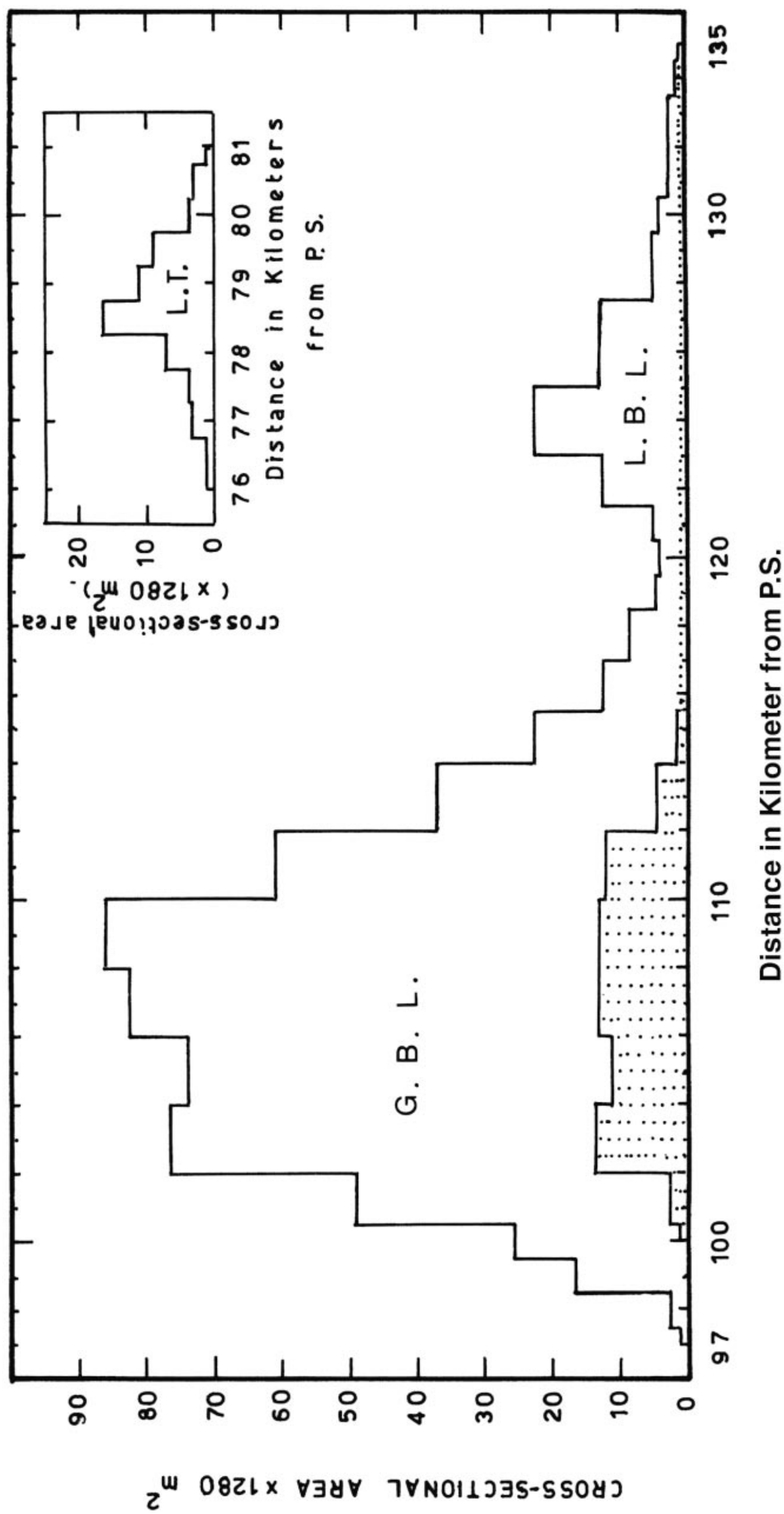


FIG. 4. The cross-sectional areas along the Great Bitter Lake (km 97-km120), Little Bitter Lake (km 120-135) and Lake Timsah (km 76-81). The shaded area represents the area of the cross section under 9 meters in the G.B.L.

### *The Determination of $d_1$, $d_2$ and $d_3$*

These values were determined from the longitudinal sections of the distribution of salinity as the distance between two successive isohalines at 0, 6 and 12m levels.

### *The Determination of Salinity $S_1$, $S_2$ and $S_3$*

These values were determined from the longitudinal salinity distribution of the hydrographical sections in the Canal, as the mean salinity value between two successive isohalines.

### *The Determination of Density ρ*

The density ρ is determined for the regions of the Canal (Fig. 5) and for the main water masses of salinities < 39.0, 39.0-43.0, 43.0-44.0 and > 44.0 (Fig. 6). It is determined as a function of S and T of a certain water mass. Mean salinity for each sector is given by:

$$S = \frac{(f_1 * d_1 * S_1 + f_2 * d_2 * S_2 + f_3 * d_3 * S_3)}{(f_1 * d_1 + f_2 * d_2 + f_3 * d_3)}$$

## Results and Discussions

### *The Relative Distribution of the Main Isohalines in the Canal*

Figure 2 shows that, due to the hydrographic and meteorological conditions in the Canal region as well as the changes in sea level and the inflow of the fresh water of the Nile flood, salinity changes widely along the Canal from one season to another and illustrates a clear reversal of the current pattern in the Canal.

#### *From July to October*

a – A southward shift of the main isohalines, pushing the 43.0 isohalines south of km 162 (Fig. 2 and Fig. 5h).

b – A remarkable decrease in salinity of P.S. region and the northern part of the Suez Canal (Fig. 2 and Fig. 5a-b).

c – A remarkable increase in salinity of Bitter Lakes, southern part (SP) of the Canal and P.T. region (Fig. 2 and Fig. 5e-h)

#### *From November to June*

a – A northward shift of the main isohalines resulting in the disappearance of the 39.0 isohalines north of Port-Said at Hektometer 100 at depths of 6 and 12 m (Fig. 2).

b – An increase in salinity of P.S. region and the northern part of the Suez Canal (Fig. 2 and Fig. 5a-b).

c – A decrease in salinity of Bitter Lakes, the southern part of the Canal and P.T. region (Fig. 2; Fig. 5e-h)

Hence, an opposite image between the southern and northern parts of the Canal is observed. In summer, the decrease of salinity in the northern part of the Canal is accompanied by an increase in its southern part (Fig. 2). The reverse is taking place in winter, an increase in the north and a decrease in the south. Is there a sort of balance in the two cases? One may be led to believe that the salt content of the Canal is constant on the assumption that: the decrease in the salt content in one part of the Canal is compensated by the increase in another part. In other words, the increase in volume and salinity of a water mass takes place at the expense of another water mass. Table 1 is based on the assumption that the salt content of the Canal is constant over one year. This does not take in consideration the decrease in the salinity of the Suez Canal since its opening in 1869.

### *Characteristics of the Water Masses Defined in the Area*

Four water masses are defined along the Suez Canal (Fig. 2) on account of their salinity values as:

#### *Levantine Water (I)*

The water in front of P.S. is originating from the Levantine Sea having salinity < 39.0. This water is subjected to the Nile flood in summer (July-October), while during the rest of the year more saline water is flowing out of the Canal to the Mediterranean.

#### *Suez Bay Water (II)*

The water of the northern part of the Gulf of Suez is found in the vicinity of P.T. most of the year with salinity 42.0-43.0 which could be traced north in the Canal to km 120 in winter and spring. In May, June and July this water began to withdraw in the southern direction until it disappears

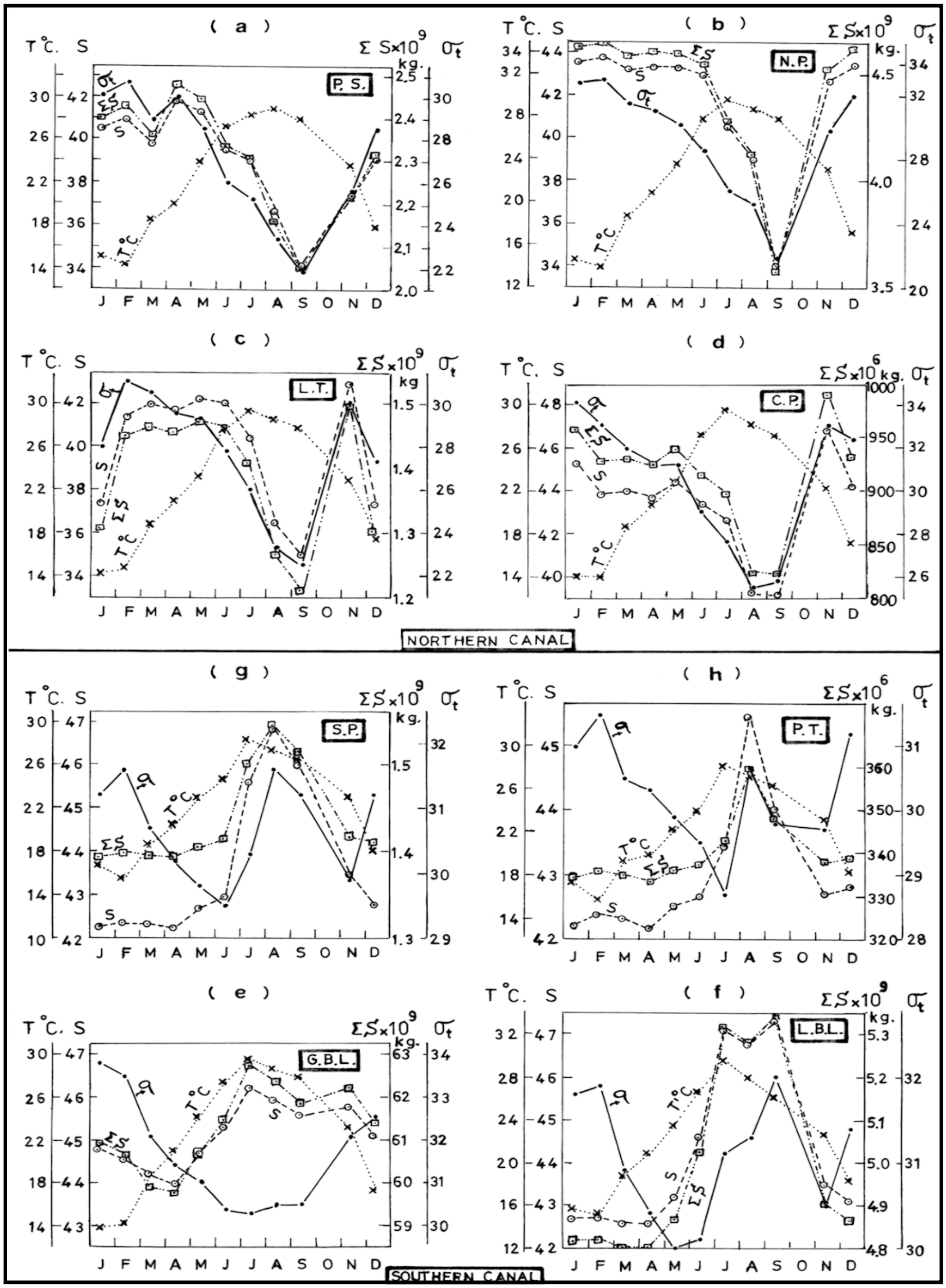


FIG. 5. Monthly changes in salinity, temperature, sigma T and total salt content in different regions:

a – In Port Said Region (P.S.).
b – In the northern part of the Canal (N.P.).
c – In Lake Timsah Region (L.T.).
d – In the central part of the Canal (C.P.).
e – In the Great Bitter Lake Region (G.B.L.).
f – In the Little Bitter Lake Region (L.B.L.).
g – In the southern part of the Canal (S.P.).
h – In Port Tawfik Region (P.T.).

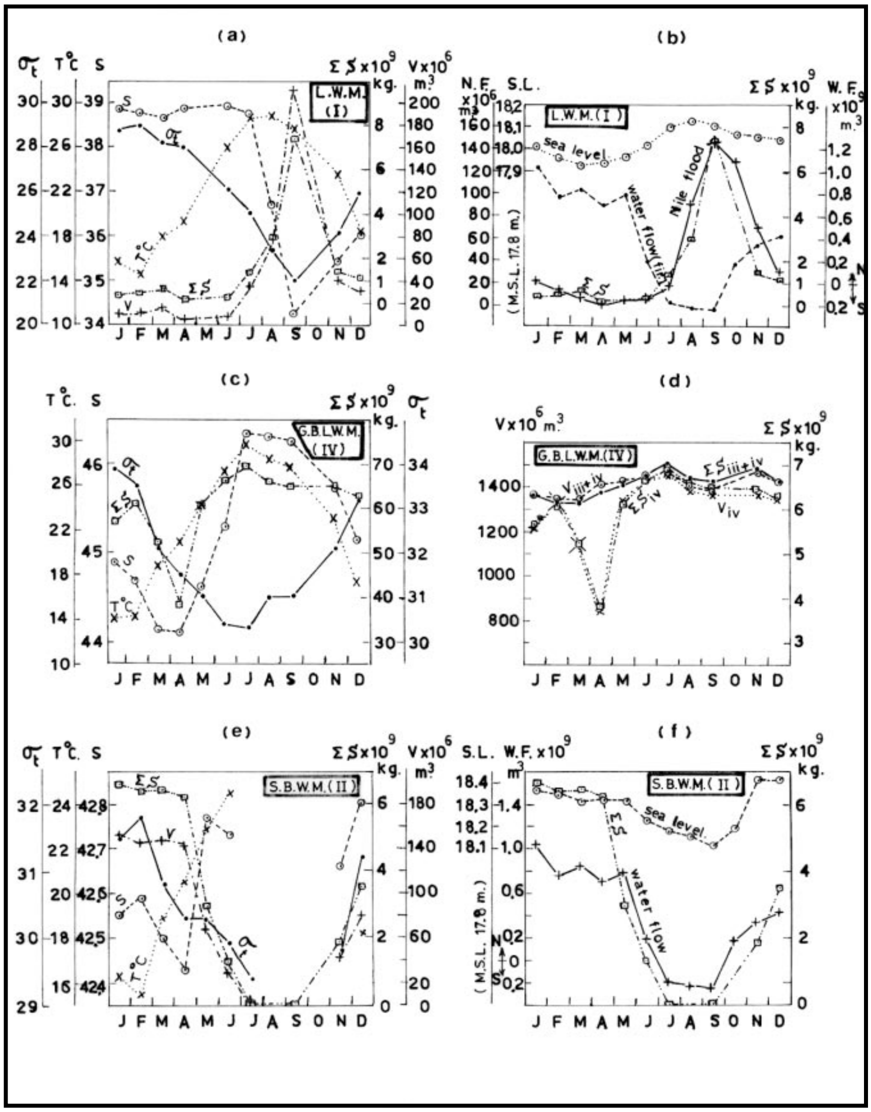


FIG. 6. Monthly changes in different parameters of the different water masses:

a – Monthly changes in salinity, temperature, sigma T, water volume and total salt content in the Levantine Water Mass (LWMI).

b – Monthly changes in water level, amount of Nile flood at Damietta, flow of water at Firdan and total salt content in the Levantine Water Mass (LWMI).

c – Monthly changes in salinity, temperature, sigma T and total salt content in the Great Bitter Lakes Water Mass IV (GBLWMIV).

d – Monthly changes in water volume and total salt content in the Great Bitter Lake Water Mass IV (GBLWMIV) and that of water mass (III + IV).

e – Monthly changes in salinity, temperature, sigma T, water volume and total salt content in the Suez Bay Water Mass II (SBWMII).

f – Monthly changes in the water level, water flow at Firdan and total salt content in the Suez Bay Water Mass II (SBWMII).

TABLE 1. The difference in total salt content between successive months in the different regions and the Canal.

| Month | Regions | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | P.S. | Northern part | L.T. | Central part | G.B.L. | L.B.L. | Southern part | P.T. | Total |
| I-XII | 85 | 10 | 5 | 27 | – 471 | – 7 | – 16 | – 5 | – 412 |
| II-I | 28 | 22 | 143 | – 29 | – 293 | 4 | 3 | 2 | – 120 |
| III-II | – 69 | – 62 | 17 | 1 | – 721 | – 17 | – 3 | – 1 | – 854 |
| IV-III | 121 | 16 | – 11 | – 6 | – 162 | – 6 | – 3 | – 1 | – 52 |
| V-IV | – 33 | – 8 | 18 | 15 | 941 | 69 | 14 | 2 | 1018 |
| VI-V | – 115 | – 48 | – 7 | – 24 | 776 | 160 | 8 | 1 | 749 |
| VII-VI | – 31 | – 273 | – 59 | – 17 | 1254 | 285 | 87 | 6 | 1252 |
| VIII-VII | –141 | – 157 | – 142 | – 74 | – 366 | – 32 | 45 | 17 | – 849 |
| IX-VIII | – 157 | – 540 | – 52 | 0 | – 527 | 60 | – 30 | – 12 | – 1257 |
| XI-IX | 209 | 950 | 288 | 166 | 393 | – 435 | – 100 | – 10 | 1462 |
| XII-XI | 104 | 88 | – 200 | – 59 | – 824 | – 41 | – 5 | 1 | – 937 |
| Total | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |

even from P.T. region in August, September and October and is replaced by the Bitter Lakes water due to the southward current (Fig. 2).

### *Bitter Lakes Water (IV)*

This water is found mainly in G.B.L. and occupies the L.B.L. and the southern part of the Canal in late summer and early autumn with salinity > 47.5. It decreases in salinity during the rest of the year to values between 43.0 and 44.0 and tends to move northward, reaching Lake Timsah in some winter months (Fig. 2).

### *Mixed Waters*

These waters are composed of one or more of the above water masses that may be specified as the followings:

a – In the Southern Canal, water mass of salinity 43.0-44.0 ($III_b$), which is the result of mixing of the Suez Bay water mass (II) and the Bitter Lakes water mass (IV).

b – In the Northern Canal, the water of the Bitter Lakes in its flowing to the Mediterranean in winter and spring is subjected to dilution through mixing with the Levantine water invading the Canal in summer, or by the inflow of fresh water from irrigating canals and drains especially in L.T.

Therefore, different water masses in different regions of the Northern Canal are identified according to their degree of dilution as:

a – Water mass with salinity < 39.0

b – Water mass with salinity 39.0-43.0

c – Water mass with salinity 43-44 in the immediate vicinity north of the G.B.L($III_a$).

These three water masses can be taken as transitional stages between the two main water masses: the Bitter Lakes water mass (IV), the Levantine water mass (I).

Salinity was taken as the only factor defining the water mass, since temperature does not differ appreciably along the whole Canal at one time. These definitions of water masses in the Canal are empirical to help studying the changes taking place in the salt content of the Canal with space and time.

### *The Monthly Changes in the Water Masses*

To follow up the water masses in the Canal with time, the monthly values of the average salinity, density and volume of the different water masses are used to estimate the salt content in each water mass. The calculations made with respect to the regions (Fig. 5) or to the different water masses

(Fig. 6) are based on the assumption that the level of the Canal is constant. The total volume of water in the Canal was estimated as $1681 \times 10^6$ $m^3$ (from Hektometer 100, 0.1 km north of Port-Said, in the Mediterranean to km 162 at P. T.).

***Levantine Water Mass (I)***

Fig. (6 a-b) represents the monthly change in salinity, temperature, density, volume and salt content of the Levantine water mass (I). It shows the followings:

a – The salinity values lie between 38.5 and 39.0 from January to July then decrease abruptly to less than 37.0 in August and to the minimum in September (34.29) due to the fresh water discharged to the Mediterranean during the Nile flood (July-October). It then starts to increase but remains less than 37.0 in November and December to reach 38.5 again in January.

b – The water temperature increases from the minimum in February (14.45ºC) to maximum in August (28.83ºC). The diurnal changes in temperature are not taken into consideration. Generally, it is noticed that the seasonally change of the temperature does not differ very much from one mass to another (Fig. 3).

c – The density is low in summer and high in winter (due to the influence of temperature), showing a minimum in September (1.0218) and a maximum in February (1.0341).

d – The volume of the water mass changes markedly from one month to another. It remains less than $10 \times 10^6$ $m^3$ most of the time from January to June. In May, this water mass disappears completely, being pushed north of Hektometer 100. The volume increases twenty fold from June to the maximum in September (210.7 * $10^6$ $m^3$), when it starts to decrease.

e – The total amount of salt $\Sigma S_c$ is less than $500 \times 10^6$ kg (from January to June). A rapid increase (to more than 15 times its value in winter) is observed from June to September (7383.7 * $10^6$ kg) followed by a sharp decrease from September to January.

The change in the total amount of salt in the water mass follows very closely the monthly change in its volume. The total salt content ($\Sigma S_c$) increases in summer months although the salinity of the water mass decreases sharply during this period. The maximum of $\Sigma S_c$ coincides with the minimum of salinity in September. This means that the change in the volume of the water mass is more influential in changing its total salt content than the change in its salinity. Therefore, it is expected that the ratio between the salt content of the different water masses in one month follow nearly the ratio between their masses, which is slightly different from the ratio between their volumes. The difference in the values of the average densities is comparatively small to make a notable difference in the percentage composition by volumes or by weight.

***The Suez Bay Water Mass (II)***

Fig. 6 shows the monthly changes taking place in the Suez Bay water mass II, which is expelled south of km 162 from July to September. The figure also shows the followings:

a – The average salinity varies between 42.40 and 42.80, which is low in February and March and high in May, June and December. This condition is maintained by the seasonal change in the tidal current in the Southern Canal. In winter, the flood current is greater in magnitude than the ebb current and the resultant current is dominantly northward. In summer, the reverse conditions prevail with the resultant current favoring the transport of the Bitter Lakes waters towards the Suez Bay (Table 2; after Morcos, 1960b).

b – The density is a maximum in February and is followed by a continuous decrease towards the minimum in summer.

c – The volume of this water mass remains nearly constant (140-150 * 106 $m^3$) between January and April decreasing during May and June and reaching zero values between July and September.

d – The total amount of salt ($\Sigma S_c$) follows nearly the same trend of the volume. It remains nearly constant between January and April (335 * $10^6$ kg), decreases sharply in May and June and becoming zero between July and September.

***The Bitter Lakes Water Mass "B.L.W.M." (IV)***

The monthly changes in the B.L.W.M. (IV) are represented in Fig. (5 c- d) which shows:

a – The salinity has a minimum value in March (44.12), followed by a continuous increase to the maximum in July-September (46.28), and then starts to decrease again reaching the minimum in March.

TABLE 2. The monthly average of maximum velocities of currents in cm/sec (after Morcos, 1960).

| Month | Shallufa (km 146) | | | Genifa (km 134) | | | Kabrit (km 120) | | |
|---|---|---|---|---|---|---|---|---|---|
| | North | South | Difference | North | South | Difference | North | South | Difference |
| January | 107.09 | 47.14 | 59.95 | 100.65 | 43.75 | 56.90 | 13.39 | 11.22 | 2.17 |
| February | 90.95 | 58.34 | 32.61 | 87.98 | 57.95 | 30.03 | 14.75 | 12.28 | 2.47 |
| March | 102.37 | 57.53 | 44.84 | 95.06 | 54.56 | 40.50 | 15.36 | 11.03 | 4.33 |
| April | 97.73 | 74.51 | 23.22 | 92.56 | 70.48 | 22.08 | 19.25 | 11.70 | 7.55 |
| May | 96.26 | 70.87 | 25.39 | 90.54 | 66.78 | 23.76 | 19.08 | 12.42 | 6.66 |
| June | 94.67 | 85.34 | 9.33 | 89.01 | 80.12 | 8.89 | 20.75 | 16.08 | 4.67 |
| July | 93.98 | 97.76 | – 3.78 | 87.95 | 89.37 | – 1.42 | 20.58 | 16.47 | 4.11 |
| August | 90.12 | 98.62 | – 8.50 | 84.84 | 91.84 | – 7.00 | 21.36 | 17.53 | 3.83 |
| September | 78.67 | 98.23 | **– 19.56** | 74.01 | 92.90 | **– 18.89** | 20.64 | 16.50 | 4.14 |
| October | 94.95 | 86.78 | 8.17 | 88.17 | 84.31 | 3.86 | 20.14 | 15.70 | 4.44 |
| November | 98.12 | 68.78 | 29.34 | 95.06 | 62.45 | 32.61 | 21.06 | 15.17 | 5.89 |
| December | 101.09 | 67.90 | 24.19 | 94.84 | 74.37 | 20.47 | 18.64 | 13.81 | 4.83 |

b – Both the temperature and salinity show an increase in summer. They have opposite effects on density, and hence slight changes would be expected in density. In spite of the considerable increase in salinity in the summer months, density values show a remarkable decrease from winter to summer.

c – The volume of this water mass shows a sharp increase from the minimum in April and May to the maximum in July (Fig. 6c). A slow decrease is observed from August to December.

d – The increase in volume of the B.L.W.M. (IV) in summer months is explained by the slow current in that time of the year in the Lake, thus allowing longer contact of water with the salt bed. Due to the accumulation of salt, the salinity increases at the center of the water mass followed by an increase in its volume. The slight decrease in its volume in August and September is explained by the effect of the Nile flood beginning at the end of July and reaching a maximum in September. The diluted waters carried by the southward current invading the northern part of the G.B.L., decrease the surface salinity below 44 south of km 97 in August and September.

The mean salinity of the three water masses ($III_a$ + IV + $III_b$) shows a smooth decrease from November (44.25) to the minimum in February (43.86) then starts to increase slightly to reach maximum in July (44.42). The volume of the three water masses ($III_a$ + IV + $III_b$) is presented in Fig. (5d). It is less in August and September (1085 and 1069 * $10^6$ $m^3$ respectively) than in July (1139 *$10^6$ $m^3$) due to:

i – The diluted southward current (by the Nile flood) affects the surface layer in the northern part of the G.B.L. in August and September and not in July and November.

ii – From July to September the most southern 43.0 isohaline disappears completely from the Canal. Therefore, an unknown volume of the water mass ($III_b$) is expelled south of km 162. These unknown values should be added to the apparent values of ($III_b$) to get the real values of ($III_b$) for July, August and September.

iii – The salinity at P.T. (km 162) at 12 m depth in July was 42.34 compared to 44.70 in August. Thus the 44.0 isohaline shifts not only south of km 162 but further south of km 164.8 in the open waters of the Suez Bay.

iv – In November the volume of the water mass IV is nearly the same as in September (1370.049 and 1367.953 * $10^6$ $m^3$ respectively). In November the current is set in a northward direction, thus pushing the higher saline water mass IV already accumulated south of the G.B.L. in the preceding months towards the north. Since the current is stronger than the summer months, thus allowing shorter time of contact between the water and the salt bed, the values of September and November are very close. This is because the G.B.L. is supplied in November with water having remarkably higher salinity than in the following months when northward current prevails.

v – The monthly change in the total quantity of salts in the water mass follows nearly the same trend of the change in volume in case of B.L.W.M. (IV) or the three water masses ($III_a$ + IV + $III_b$).

### *Mixed Water Masses*

The mixed water masses between the two main water masses, the Levantine water mass (I) (< 39.0) and the Bitter Lakes water mass IV (> 44.0) can be easily noticed from Figure (2):

1 – In summer, as a result of the southward current, the Levantine waters diluted by the Nile flood dominates the Canal north of the Bitter Lakes water mass (IV) with different salinity values in a sequential set of mixed water masses from north to south.

2 – During the rest of the year the Bitter Lakes waters dominate the northern part of the Canal by the prevailing northward current.

Generally, during the winter and spring seasons the mixed water masses prevailing in the Canal are composed mainly from the Bitter Lakes waters IV than from the Levantine water. Hence, it is more convenient to say that the Canal is of a salt productive type. This means, it yields salt to both seas during most of the year.

## Conclusions

i. Assuming that the total salt content during the period from January to April represents mostly the dominant characteristics prevailing in the Canal under normal conditions, the difference of the calculated values from the mean value of the period (Jan.-Apr.) could be estimated (Table 3). The positive values mean that more salt is produced in each region either through evaporation or by dissolution of salt from the salt bed. Meanwhile, the negative values indicate a drop in the salt content as a result of dilution by fresh water.

ii. The Bitter Lakes and the southern part of the Canal are mostly of positive character reaching the peak during the summer period (July- Sept.), which indicates a gain of salt. On the other hand, the central part, Lake Timsah and the northern part have a negative character during the same period showing a drop in their salt contents in August-September through dilution.

TABLE 3. Mean values of $\Sigma S_c$ during the period January to April and monthly deviation form the mean.

| Month | Regions | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | P.S. | Northern part | L.T. | Central part | G.B.L. | L.B.L. | Southern part | P.T. | Total |
| Mean (Jan.-April) | 24150.79 | 4613.50 | 1419.22 | 935.15 | 60312.25 | 4809.30 | 1396.15 | 334.76 | 76236.10 |
| I-Mean | – 17.05 | 10.49 | – 113.34 | 22.66 | 620.76 | 7.17 | – 0.65 | – 0.35 | 529.69 |
| II-Mean | 11.48 | 32.53 | 30.00 | – 6.63 | 327.95 | 10.58 | 3.24 | 1.10 | 410.22 |
| III-Mean | – 58.06 | – 29.58 | 47.21 | – 4.88 | – 394.00 | – 5.92 | 0.31 | 0.33 | – 444.19 |
| IV-Mean | 63.63 | – 13.44 | 36.15 | – 11.15 | 555.11 | – 11.83 | – 2.90 | – 1.08 | – 495.73 |
| V-Mean | 30.14 | – 21.88 | 54.20 | 4.24 | 386.11 | 57.09 | 10.65 | 1.54 | 522.09 |
| VI-Mean | – 84.60 | – 69.44 | 46.30 | – 20.31 | **1161.48** | **216.38** | 18.81 | 2.72 | **1270.98** |
| VII-Mean | – 116.17 | – 342.70 | – 12.61 | – 37.32 | **2415.85** | **501.24** | **106.10** | **8.40** | **2522.78** |
| VIII-Mean | – 256.43 | – 498.97 | – 154.10 | – 111.11 | **2049.27** | **469.74** | **150.76** | **24.90** | **1674.06** |
| IX-Mean | ***– 4.14.17*** | ***– 1038.45*** | ***– 205.87*** | ***– 111.24*** | **1522.48** | **530.04** | **121.03** | **13.10** | 416.99 |
| XI-Mean | – 205.13 | – 87.91 | 81.35 | 55.32 | **1915.89** | 94.65 | 21.30 | 3.14 | 1878.62 |
| XII-M | – 101.44 | 0.08 | – 188.32 | – 4.35 | **– 1092.12** | 53.53 | 15.67 | 4.18 | 941.46 |

iii. The fresh water invading the G.B.L. in spring and early summer in addition to the southern weak current increases the accumulation of salt in the Bitter Lakes rate, hence increasing their salinity and consequently their total salt content. As the current flows to the south during summer, part of the surplus salt is transported to the L.B.L., to the southern part of the canal and further south to the Suez Bay. When the speed of the southern current increases in late summer (September), more salt is removed from the G.B.L. to the Gulf until the current reverses its direction in October, pushing this water mass northward and hence the surplus salt to the Mediterranean. The reverse conditions prevail in winter when the predominantly northern current accelerate the removal of the high salinity water of the Bitter Lakes to the northern part of the Canal and eventually to the Mediterranean where salinities higher than 39 are observed in front of Port Said.

iv. The total amount of salt in the Mediterranean water mass I is less than 500 million kg (from January to June). A rapid increase is observed from June to September (7383.7 million kg) followed by a sharp decrease from September to January, which follows very closely the change in volume. The change in the volume of the water mass is more influential in changing its total salt content than the change in its salinity. On other hand, the ratio between the salt content of the different water masses in one month follows nearly the ratio between their masses, which is slightly different from the ratio between their volumes.

v. The total amount of salt of the Suez Bay water mass II follows nearly the same trend of its volume. It remains nearly constant between January and April (between 6000-7000 * $10^6$ kg), decrease sharply in May and June and becoming zero between July and September when it is driven out of the Canal. This is followed by an increase in November and December to reach 6619.73*$10^6$ kg in January.

vi. The existence of the salt bed at the floor of the G.B.L., which is considered as the main source of high salinity in the G.B.L water body, finds support in the very interesting phenomena of the very regular monthly change of salinity or total salt in this water mass from the maximum between July and October to the minimum in April.

vii. The strong northward current in winter allows less contact between the water passing in the G.B.L. and the salt beds while the resulting feeble southward current prevailing in summer allows longer contact between the waters of the Lake and the salt beds resulting in a considerably high salinity than the winter months.

viii. The presence of the salt bed and the nature of the current result in this "nuclear structure" of water body both in space and time, a very special character rarely found in nature.

ix. The fresh water invading the G.B.L. in early summer beside the influence of the current may greatly help the accumulation of salt in the G.B.L.

x. The annual change in the total quantity of salt is nil both in the different regions and in the different waters masses, consistent with the assumption that the salt content of the canal over the year is constant over short periods of time.

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# المحتوى الملحي وميزانية المياه في منطقة قناة السويس

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٢٨٢٠٤ كنتون لين ، *سانتا كلاريتا – كاليفورنيا* (٩١٣٥٠)
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*المستخلص .* لقد لوحظ أن المحتوى المائي لقناة السويس يتكون من مصادر مختلفة من المياه ، لذلك فانه يصعب معه التحديد الدقيق لتكوينها الهيدروجرافي . ومن خلال توزيعات قيم الملوحة أمكن التعرف على ثلاث كتل مائية أساسية وتشمل: الكتلة المائية التي تنتمي إلى شرق البحر المتوسط (I) ، الكتلة المائية التي تنتمي إلى جونة السويس (II) ثم الكتلة المائية التي تنتمي للبحيرات المرة (IV) ، بالاضافة الى عدد من النوع الخلطى (III) . وقد تم تعيين حجم المياه والمحتوى الملحي للقطاعات المختلفة والكتل المائية الأساسية باستخدام بعض المعادلات التي تم استنباطها لهذا الغرض . كما نوقشت العلاقات بين المحتوى الملحي – حجم المياه – مستوى سطح المياه – درجة حرارة المياه – ملوحتها – وكثافتها لكتل المياه الثلاث الأساسية . وقد وجد أن النسبة بين المحتوى الملحي لهذه الكتل المختلفة في شهر واحد تتماشى مع النسبة بين كتلها ولكنها تختلف قليلا عن النسبة في الحجوم . وقد أظهرت النتائج أن كمية الأملاح الكلية في الكتلة المائية (I) تقل عن ٥٠٠ مليون .كجم خلال الفترة يناير – يونيو ، ثم تزداد بسرعة حتى شهر سبتمبر تتبعها انخفاض حاد إلى شهر يناير . أما في الكتلة المائية التي تنتمي لجونة السويس(II) . فان كمية الأملاح الكلية تظل ثابتة في الفترة من يناير إلى أبريل ثم تنخفض بشكل ملحوظ خلال شهرى مايو ويونيو إلى أن تنعدم في الفترة من يوليو إلى سبتمبر . وفى الكتلة المائية الخاصة بالبحيرات المرة (IV) فان كمية الأملاح الكلية توضح خصوصية منفردة حيث تزداد كمية الأملاح بشكل ملحوظ من الحد الأدنى لها خلال شهرى أبريل ومايو إلى الحد الأقصى في الصيف تتبعها انخفاض إلى الحد الأدنى مرة أخرى في أبريل . والى جانب تأثير البخر ، فانه تعزى الزيادة الحدية في كمية الأملاح الكلية في منطقة البحيرات المرة إلى التخفيف الذي يحدث في مياه الجزء الشمالي والأوسط للقناة بواسطة مياه نهر النيل أثناء الفيضان وانخفاض سرعة التيار حيث تساعد على تراكم الأملاح في البحيرات المرة .