Bull. Nat. Inst. of Oceanogr. & Fish., A.R.E. 1995, Vol.(21) No. 1: 35 - 66

THE INFLUENCE OF THE LAST WIDENING AND DEEPENING OF THE SUEZ CANAL ON ITS TIDAL MOTION

By

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Key words : Suez Canal, tidal motion.

ABSTRACT

The tidal motions in the Suez Canal and its lakes have been numerically investigated using the depths distribution as processed from the Admiralty Chart No. 2431 of 1967, and a recent bathymetric chart which was essentially produced in December 1994 to carry out the present study. The canal has been divided into six segments which are treated in consequence for each time step. Linear and quadratic friction terms were used according to the type of each segment. Friction coefficients of $2.5 * 10^{-2}$ for the quadratic relationship and $6.0 * 10^{-1}$ sec^{-1} for the linear relationship, were considered.

The results obtained using the old depths distribution are in good agreements with observations. The strongest tidal current of about 35.0 cm/sec was found in the region between Port-Tawfik and Genifa near shalloufa. The tidal volume of the Bitter Lakes is very large compared with the tidal volume of the southern part of the canal, so that the currents are relatively high between Port-Tawfik and Genifa. The tidal range was found to decrease linearly between Port-Tawfik and Genifa and between Port-Said and Lake Timsah.

The maximum speed of ebb and flood current occurs about 50 minute after the low and high water at Port-Tawfik and Port-Said, while it is out of phase in the Great Bitter Lake.

The amplitudes and phase angles of the M2-tide and tidal current for the present canal showed an increase in the southern part of the canal

(maximum speed of 45.0 cm/sec) and the Bitter lakes, while slight decrease was traced in the northern part of the canal. This reveals that changes mainly occur in the southern part of the canal and the Bitter Lakes.

The increase in the tidal current after the last enlarging may add some difficulties for navigation in the southern part of the canal, which can be overcome by adjusting the time of departure of super tankers from Suez to Great Bitter Lake and vice-versa.

Generally, the model is succeeded to determine the tide-constants along the Canal as well as the type of the tidal waves. They are of progressive type in the northern and southern parts of the canal, while in the Great Bitter Lake the tidal wave is of a standing type. In addition, it gives the co-ranges, co-tidal-lines and current patterns all over the canal region.

INTRODUCTION

The Suez Canal appears as consisting of a simple longitudinal narrow channel connecting the Mediterranean and the Red Seas. It extends between Lat.29° 56' 14" N., Long, 32° 33' 47" E at Suez in the south on the Gulf of Suez and Lat. 31° 15' 45" N, Long 32° 18' 51" E at Port-Said in the north on the Mediterranean Sea. Therefore, the tidal motion in the canal is strongly influenced by the tidal motions of the adjacent basins, and hence can be considered of co-oscillating type. Its vertical or horizontal motions are still not well defined and need more studies. Few investigators (Goby, 1951; Morcos, 1960; Shukry, 1968) have discussed the water elevation at certain points along the canal through the available water observations and the current measurements recorded at few spots. Meanwhile, others have used the data to investigate the variability of monthly mean water level and its relationship to the current system along the canal (Morcos and Gerges, 1974; Sharaf El-Din, 1974 and 1975). During the last two decades more information are available from eleven tide-gauge stations along the Canal, that increases the possibility to carry out more studies about the tidal motion in the canal (Soliman ***et al.***, 1988; and Eid ***et al.***, in press).

As a result of the intensive development along the two banks of the canal and its last enlarging, more studies are required to analyze and understand the influence of widening and deepening on the water movements. The application of numerical methods is an efficient tool that help understanding the tidal and non-tidal processes in the canal. These methods are applied in the present study on the tidal processes to investigate the influence of enlarging the canal on such motions.

The Mathematical Model.

As mentioned above, the Suez Canal is apparently simple in its shape. The crossing of the canal through the lakes (Bitter Lakes in the south and Lake Timsah in the north) makes the water movements relatively complicated. The vast surface area of the Bitter Lakes convert them to a big reservoir which damp greatly the vertical movements of the tidal waves that propagate from both ends of the canal towards the lakes.

It is clear from the Suez Canal Map (Fig.1) that the area under investigation is composed of simple longitudinal channels and two-dimensional basins of different sizes. Therefore, the model used was constructed to work on one dimensional system for the channel type using equations 1-3, and as two dimensional system for lakes using equations 4-7.

1- The hydrodynamical differential and continuity equations.

i- The equations of motion and the numerical model

The hydrodynamical differential equations for the two systems are given by the following equations:

a- One dimensional system:

$$\delta u/\delta t = - \delta p/\delta x + \nu\, \delta^2 u / \delta z^2 + X \quad \text{....... (1)}$$

$$\delta p/\delta z = - \rho g \quad \text{........ (2)}$$

The continuity equation is given by:

$$\delta u/\delta x + \delta w/\delta z = 0 \qquad \text{....... (3)}$$

b- Two dimensional system:

$$\delta u/\delta t - fv = - \delta p/\delta x + \nu\, \delta^2 u / \delta z^2 + X \qquad \text{....... (4)}$$

$$\delta v/\delta t + fu = - \delta p/\delta y + \nu\, \delta^2 v / \delta z^2 + Y \qquad \text{....... (5)}$$

$$\delta p/\delta z = - \rho g \qquad \text{........ (6)}$$

The continuity equation is given by:

$$\delta u/\delta x + \delta v/\delta y + \delta w/\delta z = 0 \qquad \text{....... (7)}$$

By integrating vertically the equation systems (1-3) and (4-7) from the bottom Z=H to the free surface $Z = -\zeta$, then :

a-

$$\delta u/\delta t = - \delta\zeta/\delta x + - \tau_x{}'^{b} + X \qquad \text{....... (8)}$$

$$\delta\zeta/\delta t + \delta U/\delta x = 0 \qquad \text{....... (9)}$$

b-

$$\delta u/\delta t - fv = - g\, \delta\zeta/\delta x - \tau_x{}^b + X \qquad \text{....... (10)}$$

$$\delta v/\delta t + fu = - g\, \delta\zeta/\delta y - \tau_y{}^b + Y \qquad \text{....... (11)}$$

$$\delta\zeta/\delta t + \delta U/\delta x + \delta V/\delta y = 0 \qquad \text{....... (12)}$$

where:

$$U = \int_H^{-\zeta} u\, dz$$

$$V = \int_H^{-\zeta} v\, dz \qquad \text{......... (13)}$$

x, y : cartesian co-ordinates in the north and east directions respectively,
t : time,
ζ : water elevation of the free surface,
u, v : components of the depth mean current in the x- and y-directions respectively,
H : total water depth,
f : coriolis parameter,
k : coefficient of bottom friction in the linear form,
r : coefficient of bottom friction in the quadratic form,
ν : vertical eddy viscosity,
$\tau_x{}^b, \tau_y{}^b$: components of frictional forces at the bottom in the x- and y- directions respectively,
$\tau_x{}'^b$: frictional force at the bottom in linear form in the x - direction,
g : acceleration due to gravity,
X, Y : components of the tide-producing force in the x- and y- directions respectively.

The initial and boundary conditions were taken as follows:

i- <u>Initial conditions</u>

The motion was suggested to start from rest, i.e.

$$u = v = 0 \quad \text{at} \quad t = 0 \quad \text{..........} \quad (14)$$

ii- <u>Boundary conditions</u>

At the boundary, the normal component of the depth mean current has to vanish, i.e.

$u = 0$ along the meridional boundary,
$v = 0$ along the lateral boundary .... (15)

At the open boundaries of the two entrances, the observed water levels were assumed as periodical oscillations according to the following relation:

$$\zeta = A * \cos(\sigma t - \varphi) \qquad \text{............ (16)}$$

where:

A : is the amplitude of the penetrating oscillation at the opening which was taken as 11.7 cm at Port-Said and 56.1 cm at Suez.

σ : is the frequency of the oscillation which corresponds to M2-tide.

φ : is the phase of the penetrating oscillation at each location.

iii- Frictional forces

In order to damp growth of waves with time, bottom friction was taken into consideration either as linear form for the channels (17), or quadratic form (18) for lakes i.e:

Linear frictional force in the x -direction = k * u

.... (17)

Linear frictional force in the y -direction = k * v

or

Quadratic frictional force in the x -direction = $r * u * (u^2 + v^2)^{1/2}/2H$

.... (18)

Quadratic frictional force in the y -direction = $r * v * (u^2 + v^2)^{1/2}/2H$

with $r = 5 * 10^{-2}$ and $k = 6 * 10^{-1}\ sec^{-1}$

The Finite Difference Scheme:

A finite difference scheme with grid systems as given below was used:

a- Grid system for lakes

A grid system was constructed such that each grid has u-points on the y-directed sides denoted by (+) sign, v -points on the x-directed sides and denoted by (x) sign and ζ-points at the middle of the grid (Fig. 2a).

b- Grid system for channels:

At each grid, u-points with (+) sign were selected on the y-directed sides and ζ-points at the middle of the grid (Fig. 2b).

A relatively simple explicit finite difference scheme was used or applied to estimate ζ, u and v at time $t + \Delta t$ from the known values already computed at time t with forward time difference and central differences for space derivatives.

iv- Stability conditions

The stability criteria of a simple wave (Friedriches-Lewy Criterion) is given by :

$$\Delta t \leq \Delta x/(2g\, H_{max})^{1/2} \qquad \text{for } f = 0 \quad \text{.......(19)}$$

and

$$\Delta t \leq r / f^2 \qquad \text{for } f \neq 0 \quad \text{........ (20)}$$

Depth Distribution

After the reopening of the Suez Canal, in 1976, for navigation an important resolution has been declared to enlarge and deepen the pass-way between the Mediterranean and the Red Sea, particularly after closing the canal for more than eight years. Such works have required a long time to be completed. The cross-section of the channels has been doubled in few sectors and increased in width and depth in some others. The Great Bitter Lake has been modified to receive super tankers and huge fleets. Accordingly, a new bathymetric map for the lake was basically needed. The survey has been conducted as a joint work between Suez Canal Authority, Suez Canal University and National Institute of Oceanography and Fisheries. A more advanced technique was applied in doing the survey using a recent Echo sounder system and a precise positioning instrument (Magellan PRO 1000 GPS). Fig. 3 presents the new topographic feature of the lake, where the contours are given in meters.

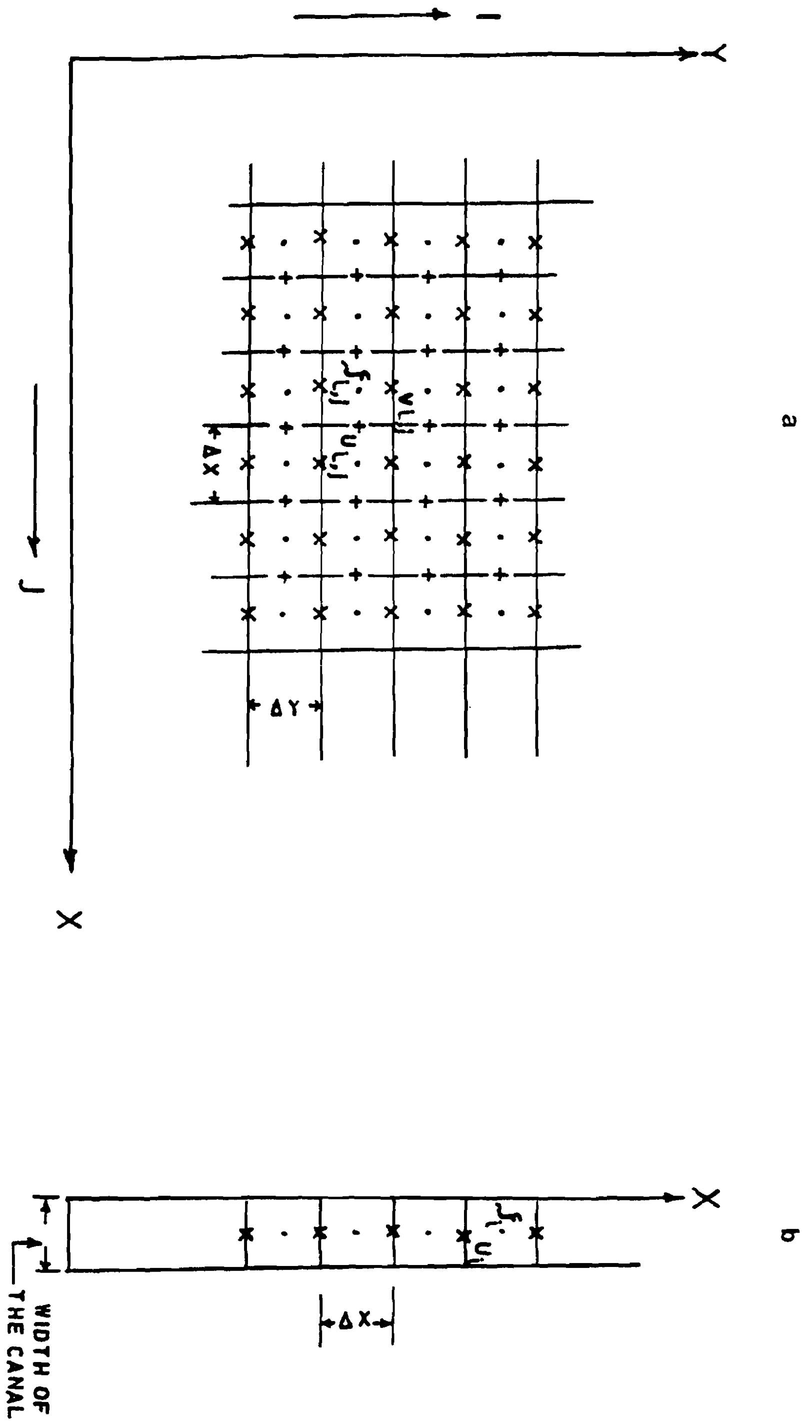


Fig.2. The grid system for channels and lakes.

Due to the great variety in the dimensions of the canal and its lakes, the whole area of the canal between the two entrances at Port-Said (P.S.) and Port-Tawfik (P.T.) was divided into six connected segments as follows:

1- The northern part of the canal is of about 76 km long (from km 0.0 at P.S. to km 76) and comprises 128 grid points.

2- Lake Timsah of about 4 km long (from km 76 to Km 80) and comprises 7*46 = 322 grid points (old depths of 1967); or comprises 7*48 = 336 grid points (recent survey of 1994).

3- The central part of the canal of about 17.5 Km long (from Km 80 to Km 97.5) and comprises 27 grid points (old depths) or 23 grid points (recent survey).

4- Great Bitter Lake of about 20 km long (from Deversoir km 97.5 to Kabret km 120), and comprises 33*178 = 5874 grid points (old depths), or 37*166 = 6142 grid points (recent survey).

5- Little Bitter Lake of about 14 Km long (from Kabret Km 120 to Genifa Km 134), and comprises 20*64 = 1280 grid points (old depths), or 20*68 = 1360 grid points (recent survey).

6- The southern part of the canal of about 28 km long (from Genifa to P.T Km 162), and comprises 44 grid points.

RESULTS AND DISCUSSIONS

In the first trial, the depth distributions of the canal and its lakes were obtained from the Admiralty Chart No. 2431 of 1967 (old depths). The dimensions of the suggested grid points were taken as : $\Delta x = 20''$ Lat. = 610 m, $\Delta y = 4''$ Long.= 108 m. The depth of the canal was 11.7 m at that time.

Sine the Suez Canal is opened at both ends, the boundary conditions at the opening were imposed to represent the semi-diurnal constituent observed at P.S.

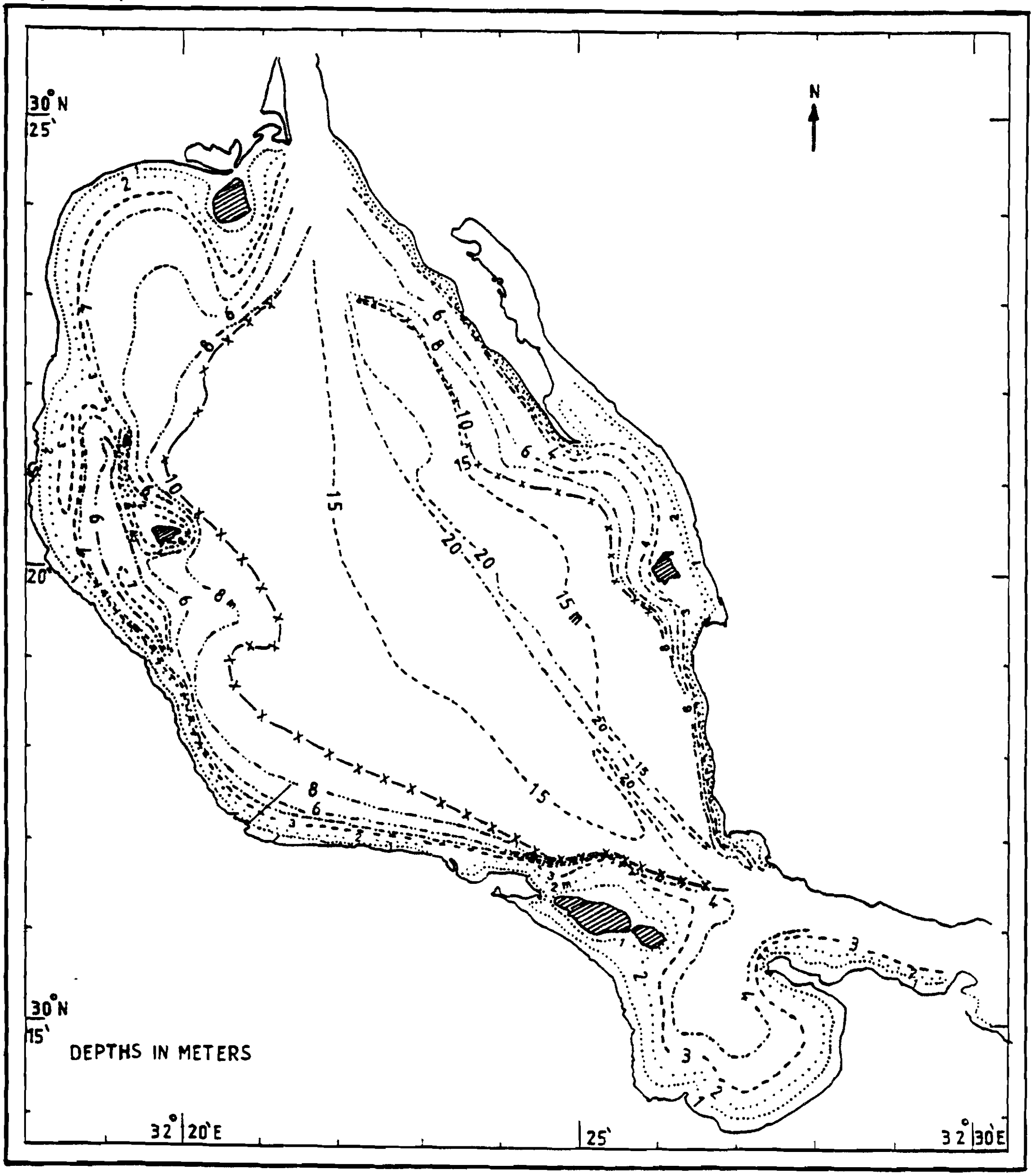


Fig.3. The new bathymetric map for the G.B.L.

in the north (with amplitude A=11.7 cm) and at P.T. in the south (with amplitude A= 56.1 cm).

At P.S., tidal flood occurs when the water flows from the Mediterranean into the northern part of the canal; and the reverse motion is taking place during ebb. On the other hand, at P.T. flood occurs when the water flows from the Gulf of Suez into the southern part of the canal, while water flows out towards the south into the Gulf during ebb. Moreover, the phase difference between the occurrence of high tide at the both ends is about 25° .

Taking into consideration all these features, the model was executed with the suggested grid point dimensions and the true depths distribution as obtained from the old chart of 1967 (old depths).

The model was then applied again using the new depths as obtained from the recent survey of 1994 (recent survey) and the new grid dimensions of : Δx= 20" Lat.= 610.0 m, Δy = 118 m. The depth of the present canal was taken as 19.5 m.

The model has been tested many times, before starting the executions, to reach the optimum condition for stability.

Table 1. gives the amplitudes and phases of M2-tide at different locations along the canal for the two depths distributions as well as the observed values {after, Shukry (1968) and Eid *et al.* (in press)}. Table 2. shows the computed tidal currents at the same locations as well as the maximal total currents (tidal and non - tidal currents) as mentioned by Shukry (1968), Morcos (1960).

Fig. 4. is an example of the observed water level elevations during the period (21-22 Sept.86) at different locations along the canal. Fig. 5. shows the computed water level values and the accompanied currents of the M2-constituent at the same locations. The figures showed the time lag in the occurrence of the high tide at the different locations and the type of propagation both in the northern, southern parts of the canal and in the lakes.

I would like to emphasize that without the substantial capability of the numerical methods to execute instantaneously the horizontal and the vertical motions, it could be too difficult to construct such patterns. The co-ranges (in

Table 1. Observed and computed values of M2-tide for depths of 1967 and new one.

STATION	LOCATION			OBSEVATION		OBSERVATIONS		COMPUTED VALUES		COMPUTED VALUES	
	Kilometers from P.S.	Long. E	Lat. N	After SHUKRY & DOODSON				DEPTH OF 1967		DEPTH OF 1995	
				Amplitude cm	Phase in deg.	Amplitude cm	Phase in deg	Amplitude cm	Phase in deg.	Amplitude cm	Phase in deg.
SUEZ (P.T.)	161.5	32 33' 47	29 56' 14	57 2	343**	51.1	339	56.1	277.4	56.1	277.4
				58.2	340*						
SHALLOUFA	146.1	32 34' 12"	30 03' 34"	'27.3**		21.8	258	29.4	282	34.7	284.2
GINEFA	134	32 34' 00"	30 10' 13"	'7.1**		10.2	45	7	283.8	16.5	298
				7.3	4*						
KABRET	134	32 34' 00"	30 10' 13"			13.7	131	1.6	9	3.3	21.8
DEVERSOIR	97.5	32 21' 22"	30 24' 48"			11.9	179	1.5	37.5	3.1	38.6
LAKE-TIMSAH (south)	80.5	32 18' 04"	30 33' 30"			5	131	1.3	15.8	2	24.7
LAKE-TIMSAH (north)	76.3	32 19' 02"	30 46' 18"					1.3	12.2	1.8	24.7
EL-BALLAH	54.6	32 18' 52"	30 51' 26"					3.5	291.4	3.3	276.5
KANTARA	45	32 18' 32"	31 02' 34"			4 6	39	5	280.9	4.4	263.7
EL-TINA	24.8	32 18' 21"	31 08' 14"			7	143	8			
RAS EL-ESH	14.3	32 18' 51"	31 15' 54"			8.3	303	9.5	255.8	9.5	249.3
PORT-SAID (P.S.)	0			11.7	304**	10.6	304	11.7	243.4	11.7	243.4

* Shukry, 1968

** Doodson, 1921

Table 2. Observed maximal total current and computed M2-tidal currents at some locations along the Canal.

STATION	LOCATION			OBSERVATION		COMPUTED VALUES		COMPUTED VALUES	
						DEPTH OF 1967		DEPTH OF 1995	
	Kilometers from P.S.	Long. E	Lat N	Amplitude cm/sec	Phase in deg.	Amplitude	Phase in deg.	Amplitude cm/sec.	Phase in deg.
SUEZ (P.T.)	161.5	32 33' 47	29 56' 14			36.3	282.4	45.4	287.3
				92.05 N					
SHALLOUFA	146.1	32 34' 12"	30 03' 34"	98.19 S	Summer	37	292.8	46.3	292.8
				100 40 N					
				60 00 S	Winter				
				86.40 N					
GINEFA	134	32 34' 00"	30 10' 13"	90.60 S	Summer	37.4	298.9	45.6	298.4
				94.63 N					
				57.66 S					
				20.97 N					
KABRET	120	32 30' 03"	30 15' 40"	17.00 S	Summer	5	357	6.3	358
				15.54 N					
				12.09 S					
DEVERSOIR	97.5	32 21' 22"	30 24' 48"			0.5	(123.6) 303.6	2.5	85.4
LAKE-TIMSAH (south)	80.5	32 18' 04"	30 33' 30"			0.9	(124.8) 304.8	4	83.9
LAKE-TIMSAH (north)	76.3	32 19' 02"	30 46' 19"			2.5	(108.6) 288.6	4.5	94.2
EL-BALLAH	54.6	32 18' 52"	30 51' 26"			3	(98.6) 278.6	4.8	90.1
KANTARA	45	32 18' 32"	31 02' 34"			3.1	(88.5) 268.5	5.2	88.4
EL-TINA	24.8	32 18' 21"	31 08' 14"			3.5	(62.6) 242.6	4.9	75.7
RAS EL-ESH	14.3	32 18' 51"	31 15' 54"			3.9	(47 8) 227.8	5	69.9
PORT-SAID (P.S.)	0					4.8	(29.4) 209.4	5	56.3

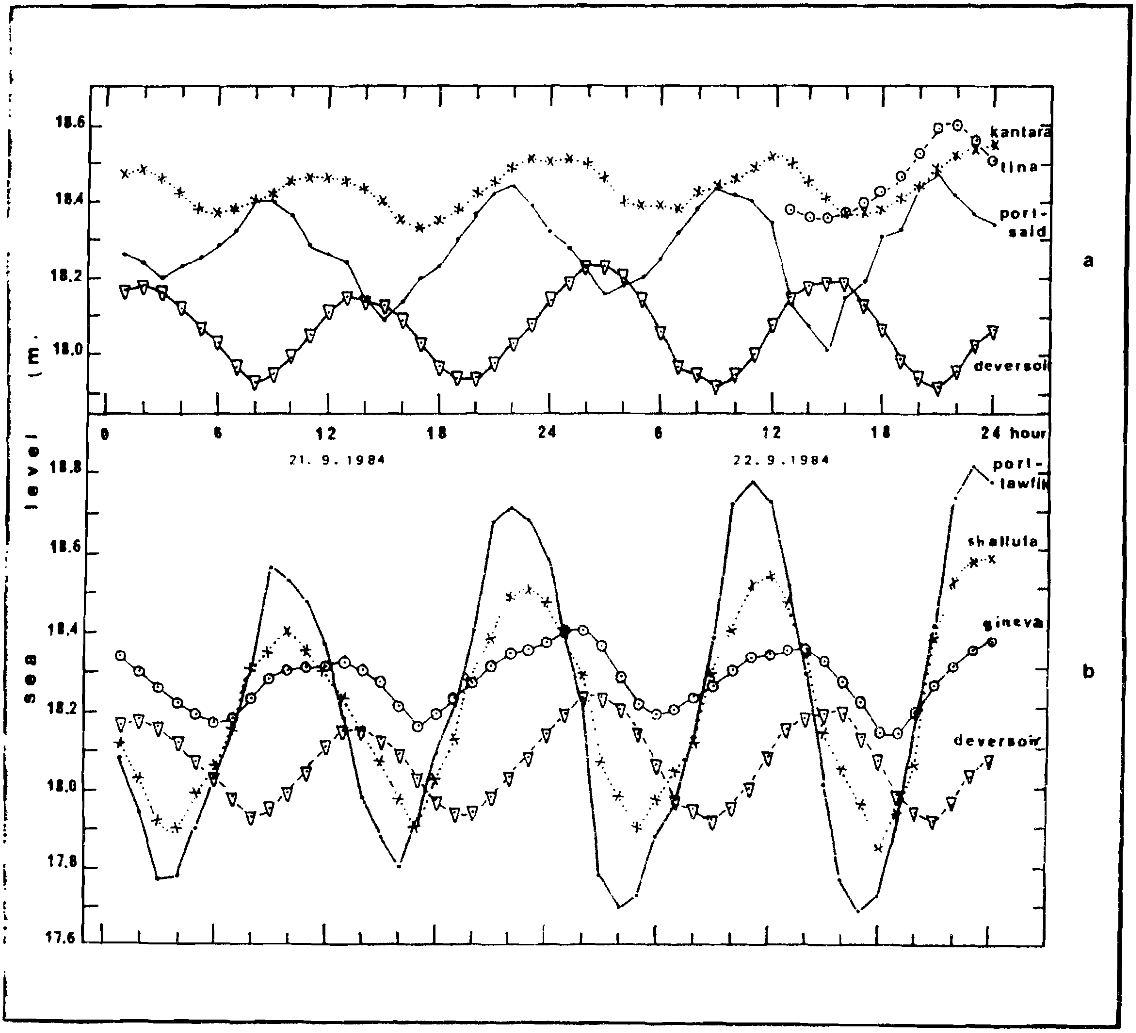


Fig.4. Observed water elevation during the period 21-22 September 1986 at different locations along the canal.

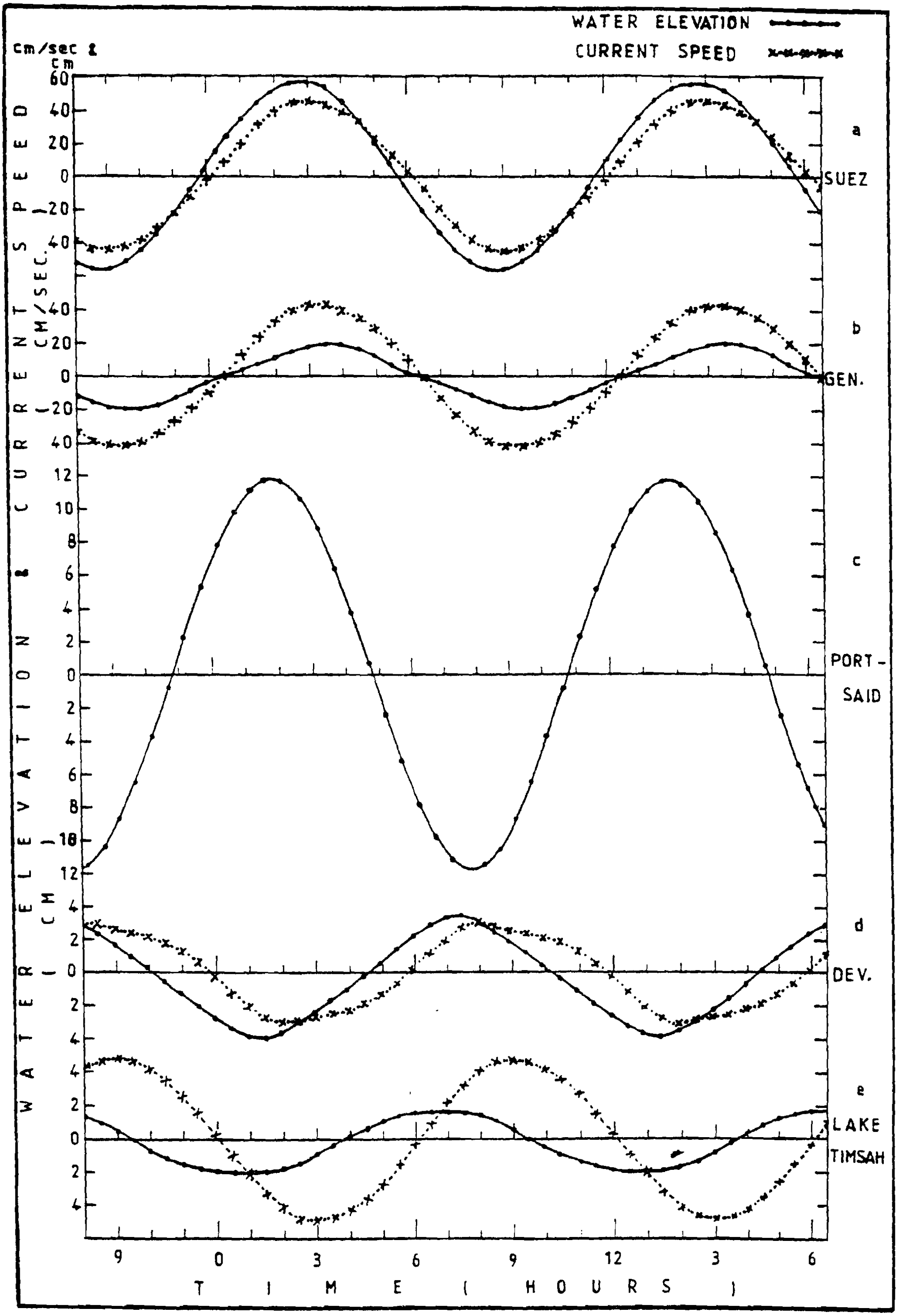


Fig.5. Computed water level and accompanied currents at the observed locations

cm) and the co-tidal-lines (in hours) for the second case of depth distribution (recent survey) are given in Figs (6-8).

The obtained patterns indicate the followings:

A- <u>Water Elevation:</u>

1- There is a phase difference in the occurrence of high tide of about:

- 38.0^o ($\simeq$ 1.6h) between the two ends of the canal (.i.e., between P.S. and P.T.).
- 15.0^o ($\simeq$ 0.5h) between P.T. and Genifa.
- 93.0^o ($\simeq$ 3.0h) between P.T. and Kabret.
- 30.0^o ($\simeq$ 1.0h) the apparent phase difference between Kabret and Deversoir.
- 132.0^o ($\simeq$ 4.5h) between P.S. and Lake Timsah.
- 157.0^o ($\simeq$ 5.2h) between P.S. and Deversoir.

2- The results obtained with the old depths distribution showed very good agreement with observations (Table 1).

3- As mentioned in previous works (Soliman *et al.*, 1993 ; Soliman and Maiyza, 1994), friction does not essentially influence the amplitude but also the phase distribution.

4- The influence of widening and deepening of the canal:
After the last widening and deepening of the canal and the lakes, the ranges and phase angles showed relatively increase in the southern part of the canal and Little Bitter Lake (L.B.L.) and relatively small decrease in the northern part of the canal.

B- <u>Tidal Currents:</u>
In general, there is little information about published tidal current of the constituents in the Suez Canal. The total current measurements taken at certain spots along the canal were reported by Lemasson (1908), Morcos (1960) and

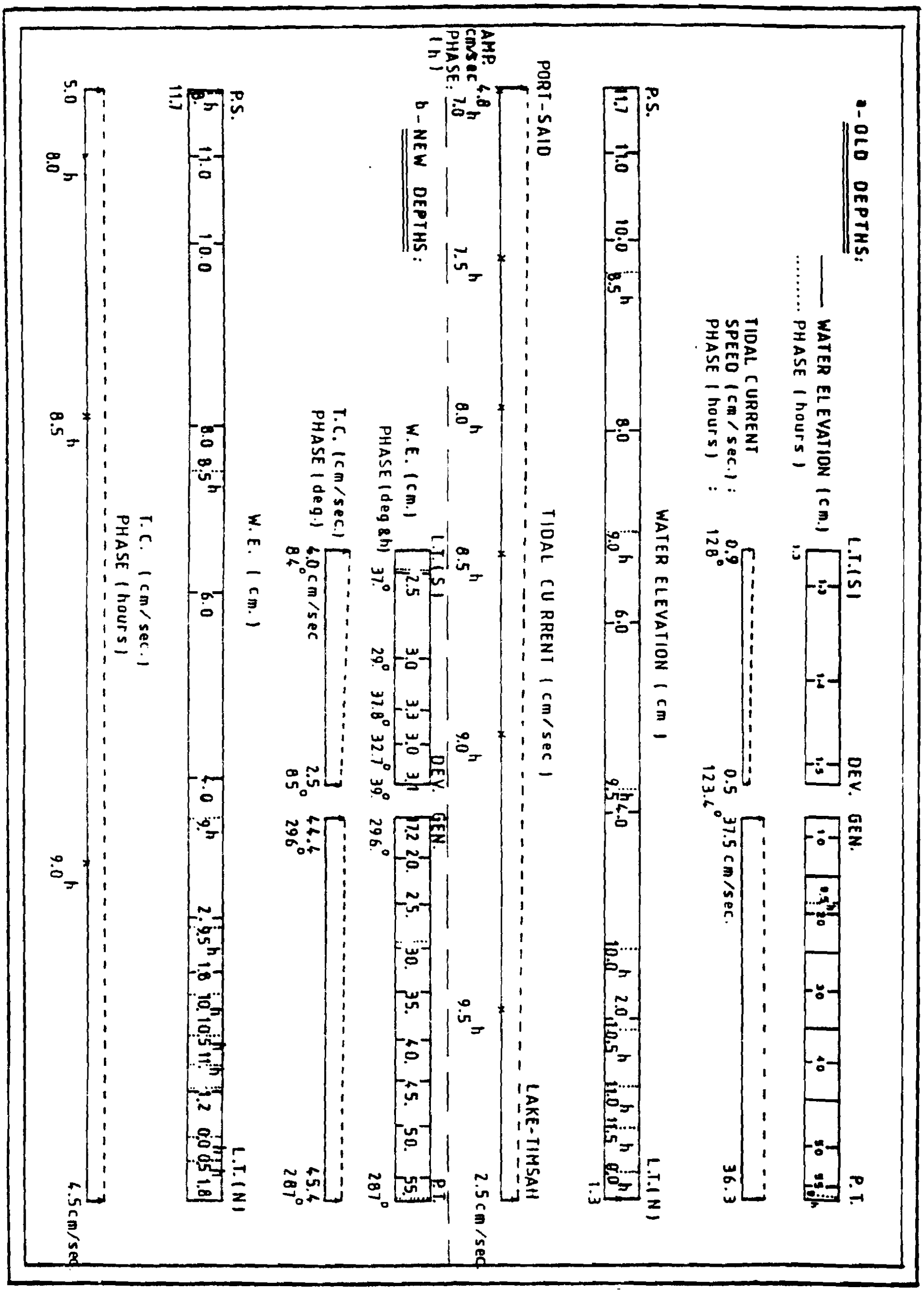


Fig.6. M2-co-oscillating tide in the northern, central and southern parts of the canal. Co-ranges are in cm., and the co-tidal lines correspond to lunar hours of high tide after lunar transit at Greenwhich.

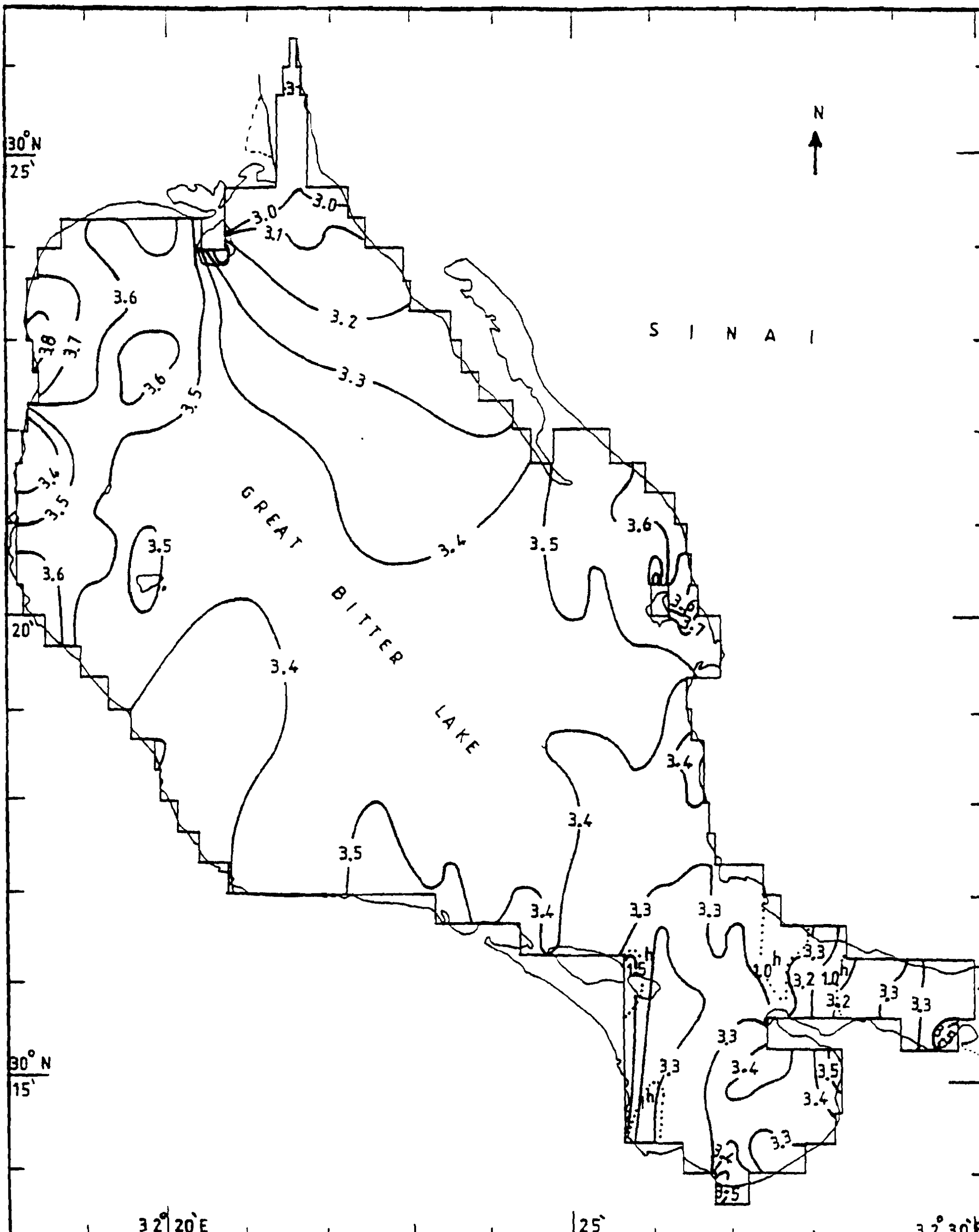


Fig.7. M2-co-oscillating tide in the G.B.L. with its new depths.

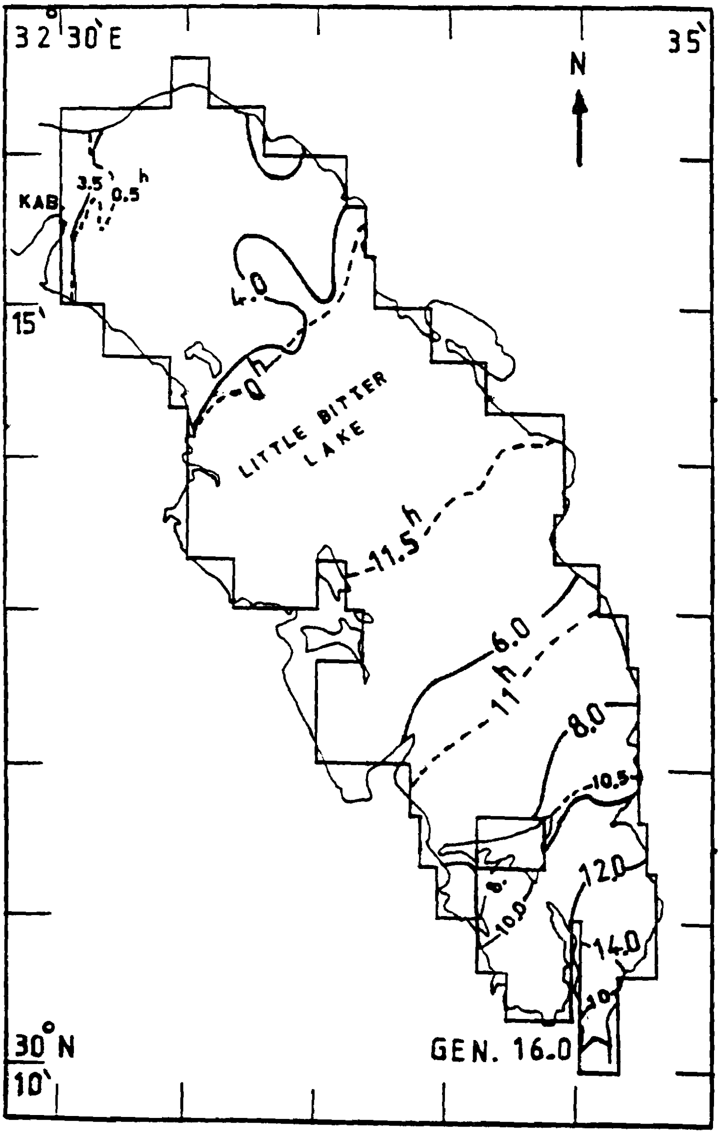


Fig.8. M2-co-oscillating tide in the L.B.L

Shukry (1968). It seems from these previous works that the investigators were more interested in the current regime caused by the residual currents, rather than the tidal current itself, and the factors that producing these non-tidal currents. Morcos (1960) noted that the northward tidal current after leaving the southern part of the canal vanishes in the L.B.L., being imperceptible five kilometers north of Genifa as reported by Fox (1926). Accordingly, he believed that the water level at Kabret is much affected by the water budget of the Bitter Lakes and other hydrographical and meteorological factors.

The application of the mathematical model in studying the tides(M2-Tide) of the Suez Canal and its lakes offers a great help in understanding the temporal and spatial variability of their tides and tidal currents (Figs. 9 & 10). The tidal currents as obtained from the model with the recent depths distribution at different times of the tidal cycle were given in Figs. (11-13) The current speed, which represents the depth mean value at each grid point, if multiplied by 1.25 it will give the water flow in the central part of the canal which is in a good agreement with observations.

The deepening of the canal to depths more than 19.0 m has increased the M2. tidal current in the southern part of the canal from 37.0 cm/sec to more than 45.0 cm/sec. Hence the tidal current alone (for the most important constituents together) may reach values more than 100.0 cm/sec. When the other factors are introduced (that causing non-tidal currents), the total current during spring tide in the central part of the cross-section may exceed 150.0 cm/sec. Such values are considered too strong and hence influence greatly the navigation in the canal.

Moreover, the width of the canal itself is too small to enhance standing waves as Kelvin waves. Accordingly, from the time series presentation of the water elevation and currents (Fig. 5), it is concluded that the waves in the northern and southern parts of the canal is of progressive type, while the penetrating waves from these two parts particularly the southern one showed continuous dampening in the amplitude of both water elevation and currents before reaching the openings of the Great Bitter Lake (G.B.L). These damped waves at Deversoir in the north and Kabret in the south have the same frequency and differs slightly in phase. Since they are advancing in opposite directions, then it could be easily concluded that they form a standing wave with a developed amplitude at Kabret. This pattern is also appeared in the observations at Kabret.

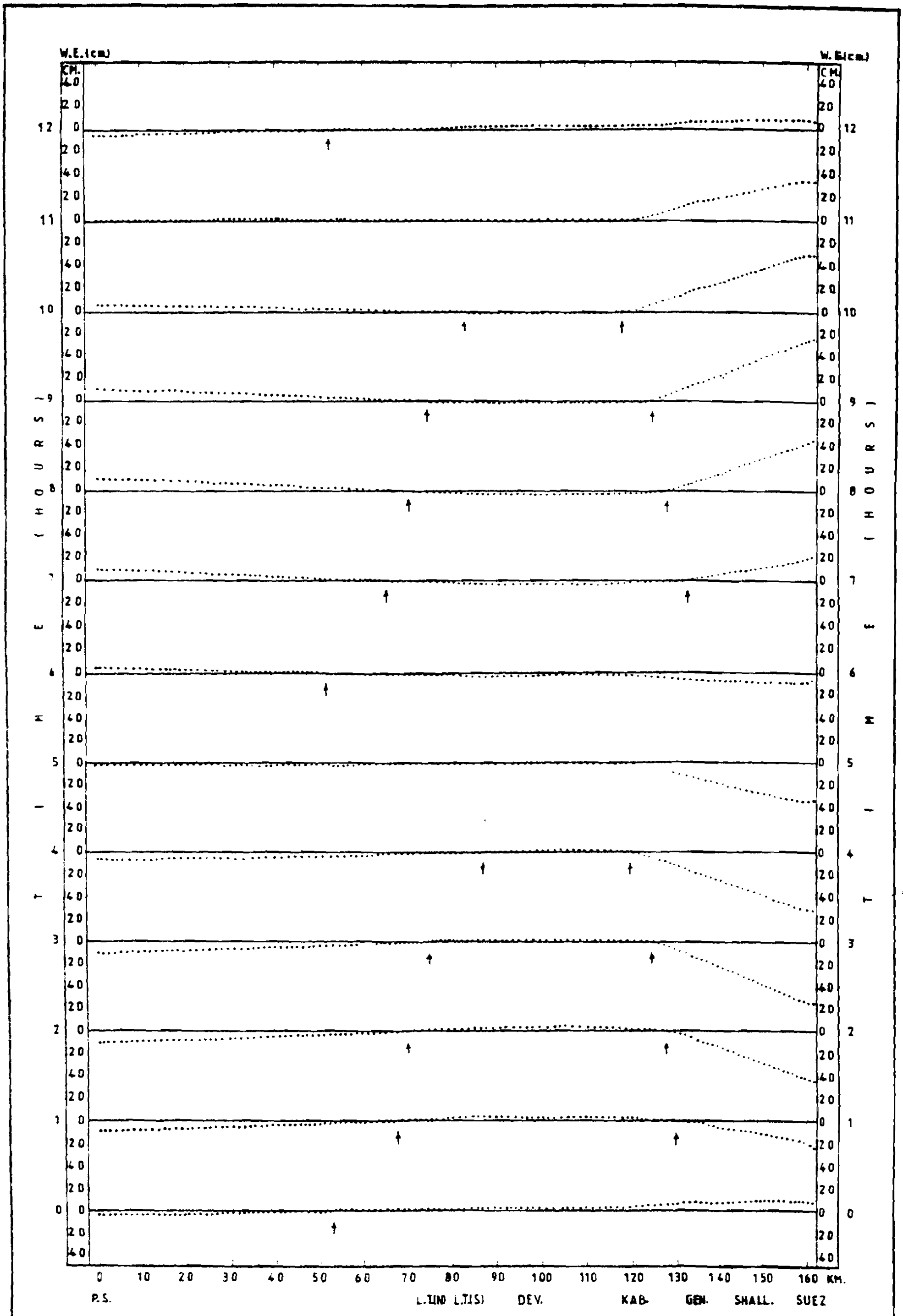


Fig.9. The temporal and spatial M2-tide along the canal with its new depths.

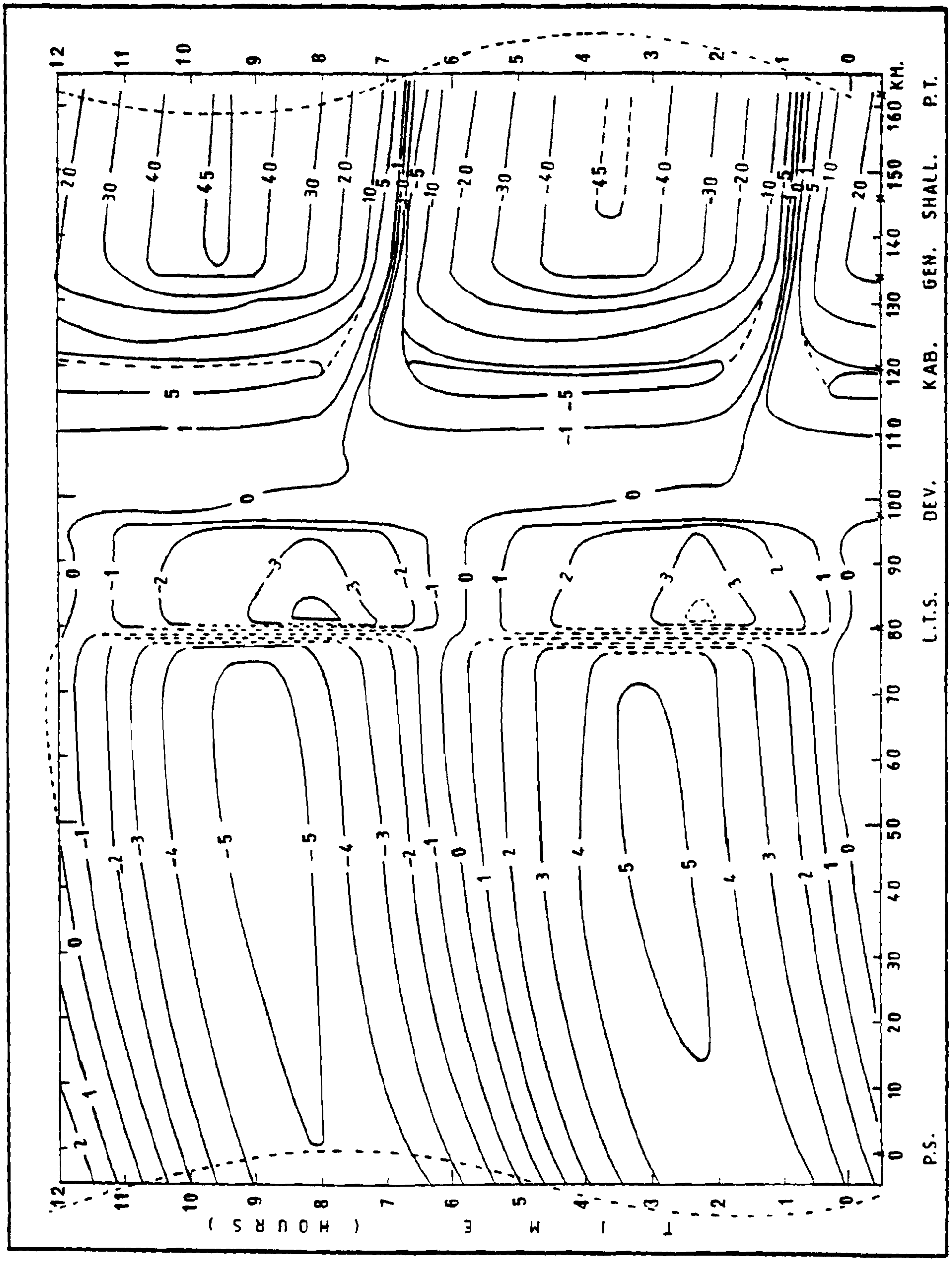


Fig.10. The temporal and spatial M2-tidal current along the canal with its new depths.

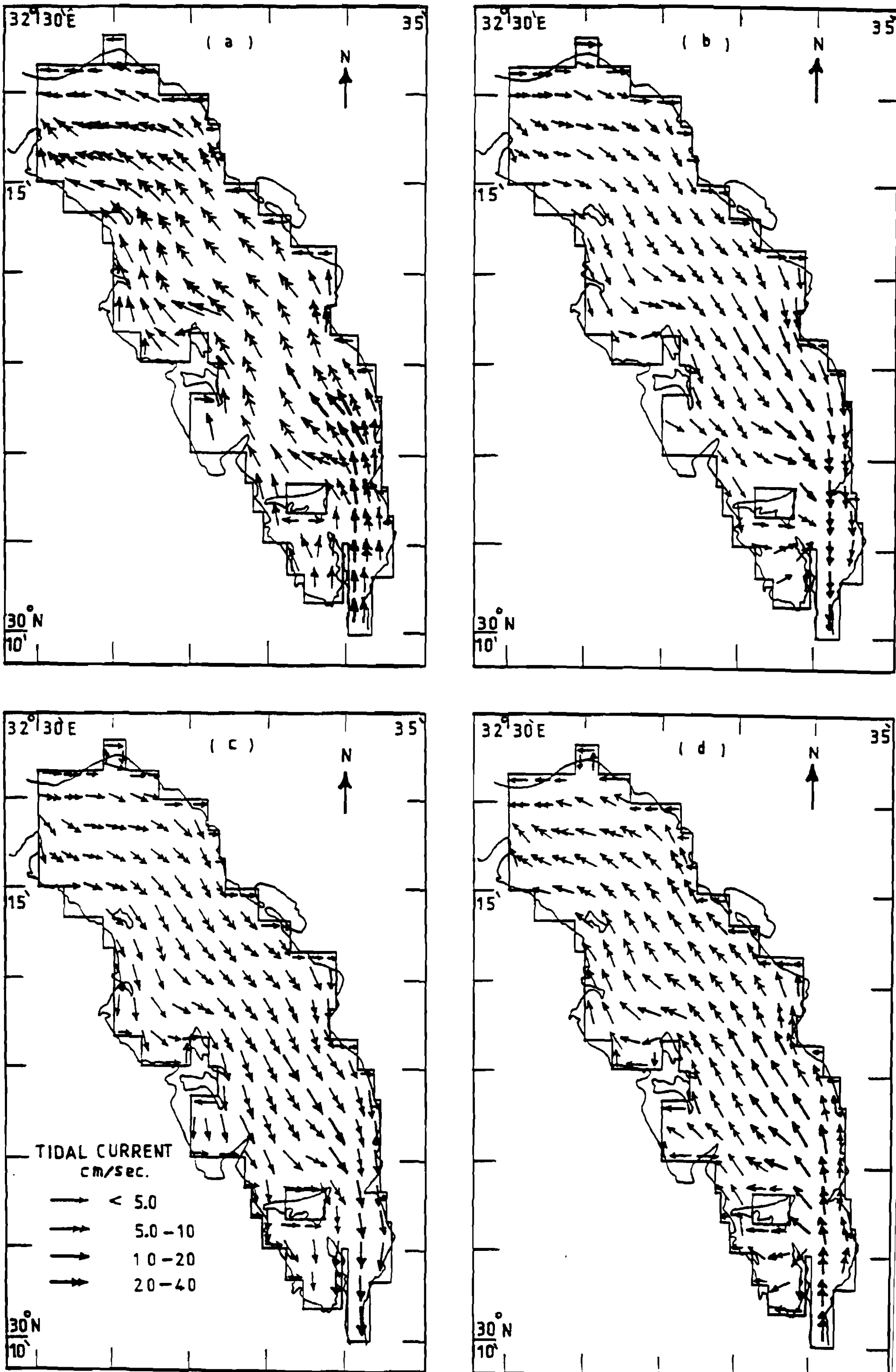


Fig.11a-d. The tidal currents at different times in the Little Bitter Lake

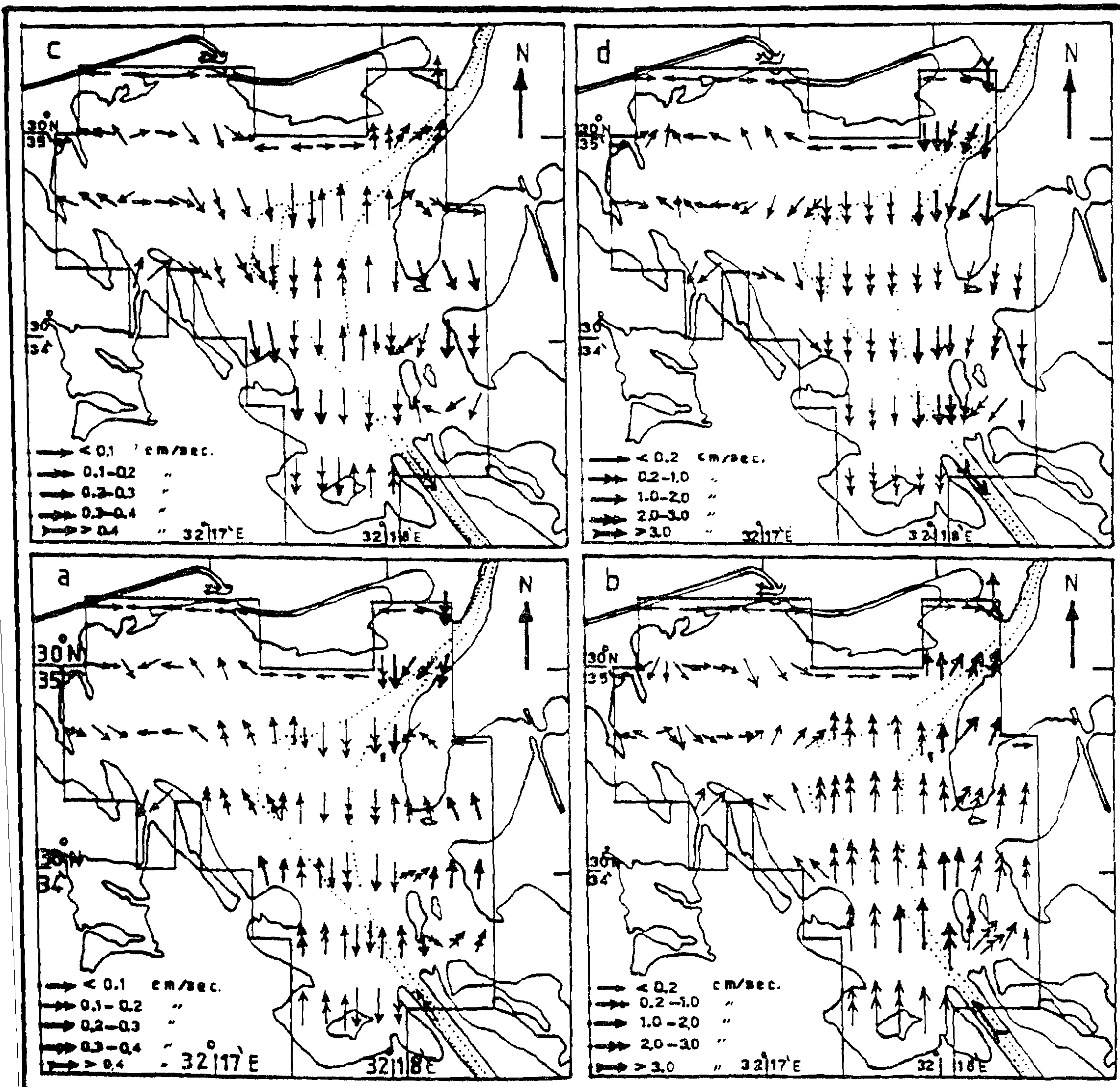


Fig.12a-d. The tidal currents at different times in Lake Timsah.

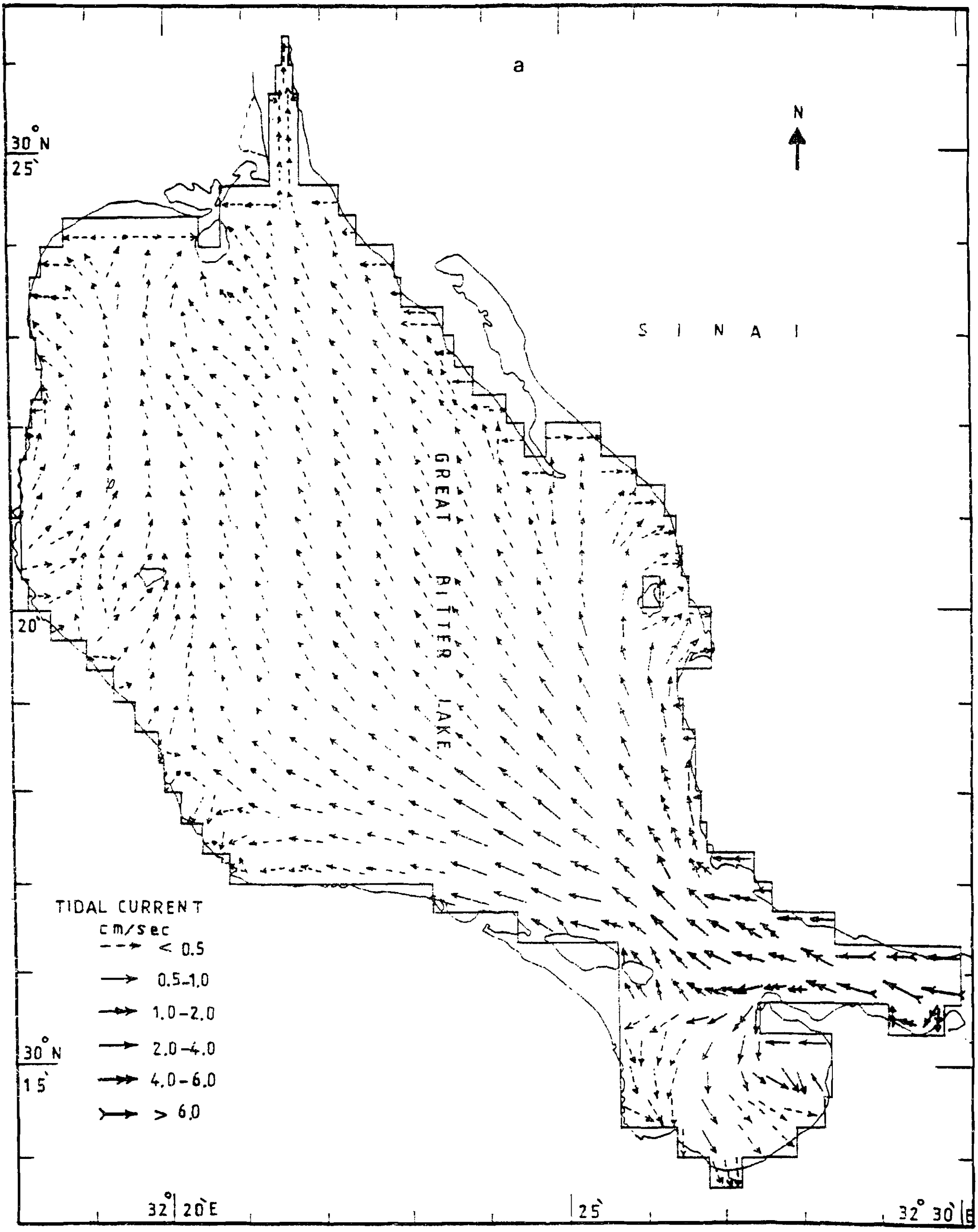
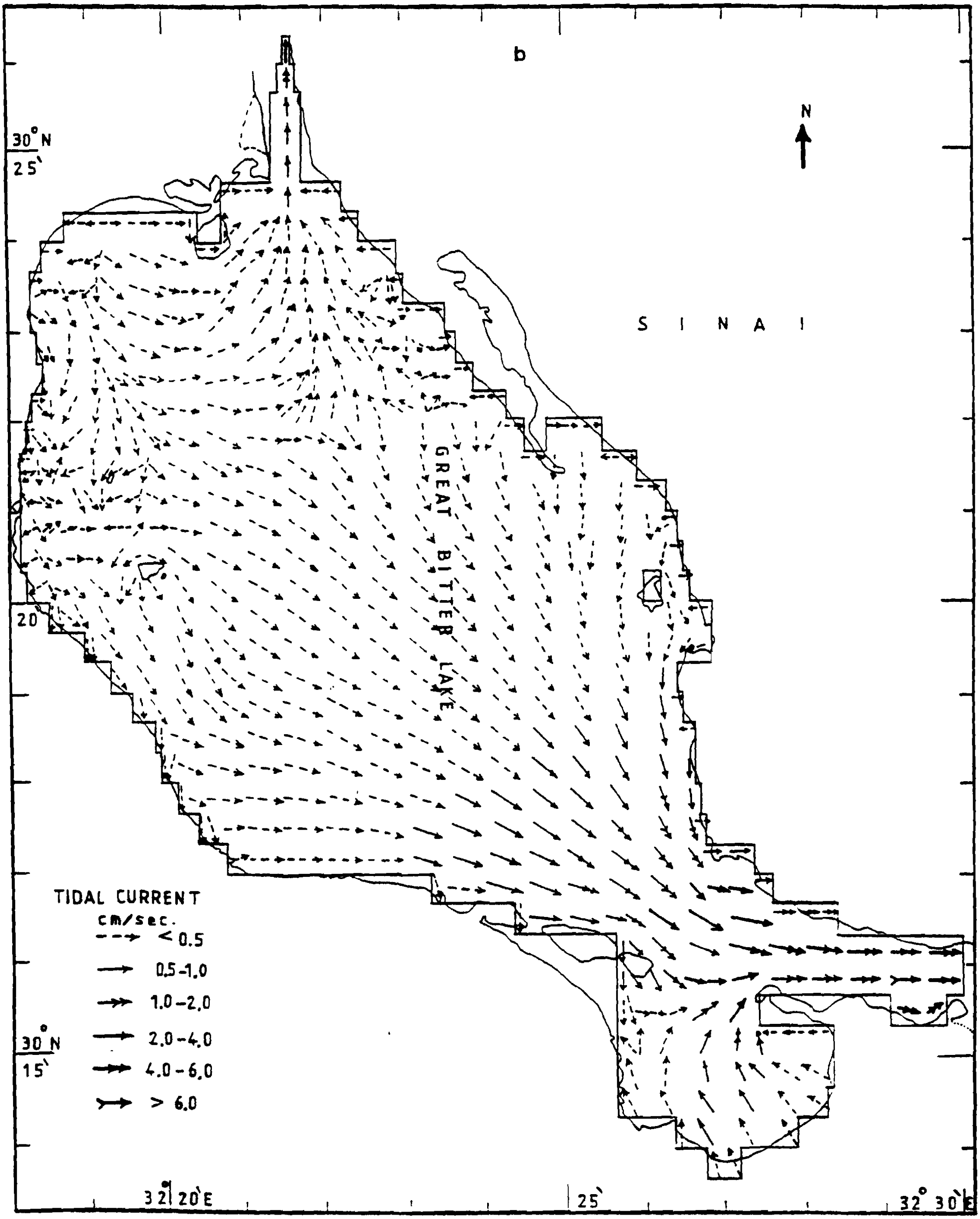
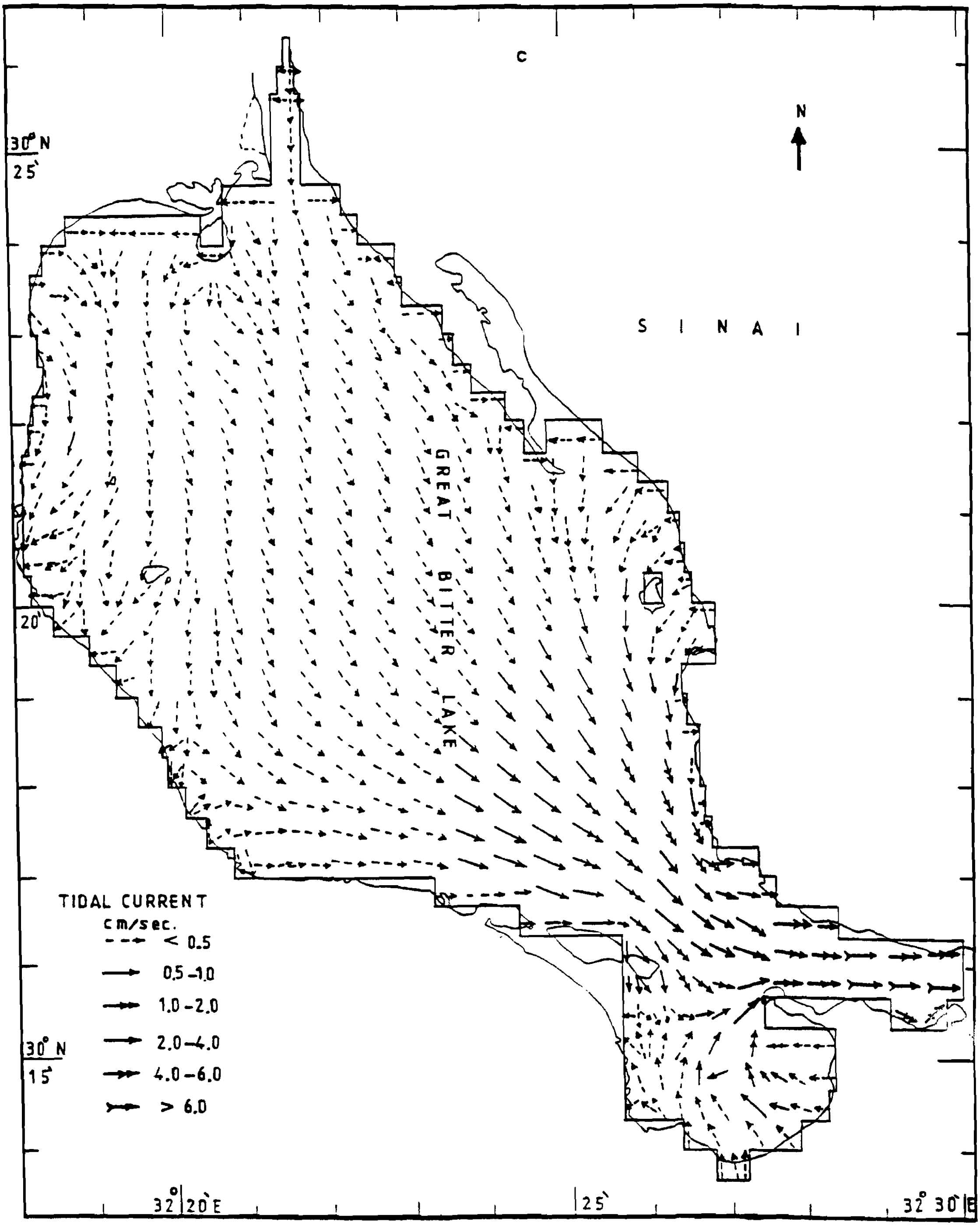
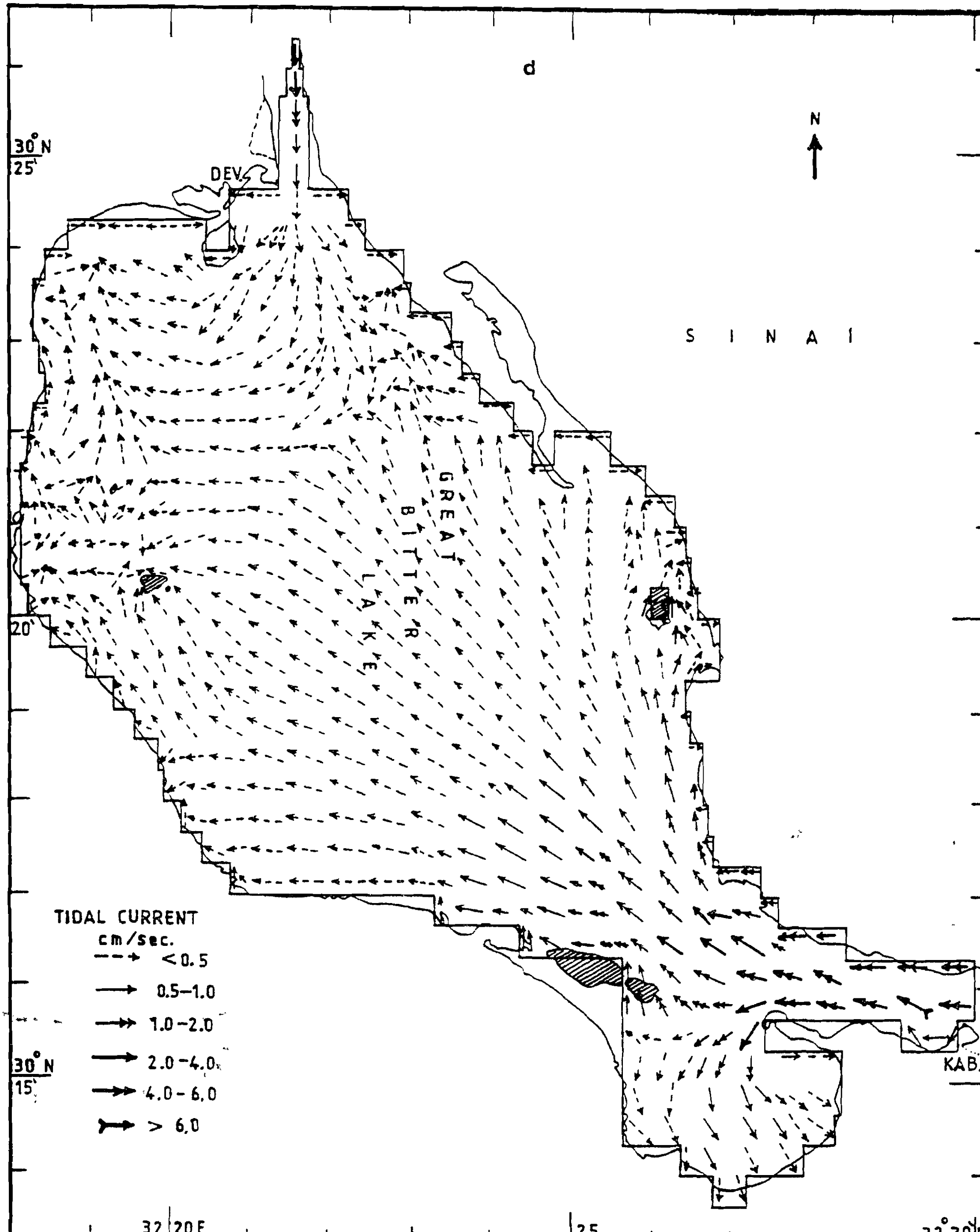


Fig.13a-d. The tidal currents at different times in the Great Bitter Lake.


b
N
30° N
25'
S I N A I
GREAT BITTER LAKE
20
TIDAL CURRENT
cm/sec.
< 0.5
0.5-1.0
1.0-2.0
2.0-4.0
4.0-6.0
> 6.0
30° N
15'
32 20 E
25'
32° 30' E


C
N
30° N
25'
SINAI
GREAT BITTER LAKE
20'
TIDAL CURRENT
cm/sec.
< 0.5
0.5 - 1.0
1.0 - 2.0
2.0 - 4.0
4.0 - 6.0
> 6.0
30° N
15'
32° 20' E
25'
32° 30' E


d
N
SINAI
GREAT BITTER LAKE
DEV.
KAB.
30° N 25'
20'
30° N 15'
32 20 E
25
32° 30 E
TIDAL CURRENT
cm/sec.
< 0.5
0.5–1.0
1.0 –2.0
2.0 –4.0
4.0 – 6.0
> 6.0

CONCLUSIONS

1- A combination of one-and two-dimensional numerical models has been developed to study the water movements in the Suez Canal and its lakes. A linear friction term with friction coefficient of $6*10^{-1}$ sec^{-1} has been used in the one-dimensional model, while a quadratic friction term with friction coefficient of $2.5*10^{-2}$ was considered in the two-dimensional model.

2- The results obtained for the amplitudes and phase angles of M2-tide at different locations with the depths distribution processed from the Admiralty chart No. of 1967 are in good agreement with observations.

3- While the tidal range decreases linearly between P.T. and Genifa (from 56.1 cm to about 7.0 cm in the first case and from 56.1 cm to about 16.5 cm in the second case) as well as between P.S. and Lake Timsah (from 11.7 cm to about 1.5 cm in both cases), the amplitudes of the tidal currents remain almost unchangeable in the southern part of the canal (about 37.0 cm/sec in the first case and about 46.0 cm/sec in the second case). Slight changes were found in the northern part of the canal (about 3.0-5.0 cm/sec in the two cases). There is a phase difference of about 11^{o} ($\simeq 0.35h$) at the two locations in the south and about 81^{o} ($\simeq 2.7h$) at the two locations in the north.

4- The strongest M2-tidal current was traced in the southern part of the canal between P.T. and Genifa in the vicinity of Shalloufa. This can be attributed to the fact that the tidal volume of the Bitter Lakes is very large compared with the tidal volume of the southern part of the canal.

5- The maximum velocity of the ebb and flood tidal currents occur about 50 minutes after low and high water at P.T. and P.S.

6- The tidal current in the northern part of the canal is almost 150^{o} ($\simeq 5.0$ h) out of phase with the tidal current in its southern part. This implies that flood currents of different strengths are nearly driven simultaneously towards the G.B.L. from both ends of the canal. The reverse processes were traced from the G.B.L. towards the two ends of the canal during ebb flows.

Only during very short interval of time in one half-tidal cycle, southward flow was observed to occupy the whole canal from P.S. to P.T. In the next-half-cycle, the reverse condition was followed where a northward flow was dominated along the whole canal.

7- The enlarging of the Suez Canal and its lakes has great influence on both the water elevation and the tidal currents particularly in the southern part of the canal. Such increase in the tidal currents may add some difficulties with navigation. These problems could be solved if the tankers and magnificent fleet are allowed to transit the southern part of the canal in the same direction of the strong dominant tidal currents.

ACKNOWLEDGEMENT

The author wishes to express his gratitude to Prof. A. M. Abd-El-Wahab, Vice-President of Suez Canal University; Prof. M.A. Gerges, OCA/PAC UNEP; Prof. A.I. Beltagy, Director of Nat. Inst. Oceanogr., Alex., Branch; Dr. Eng. M. El-Ghamry, Suez Canal Authority; Dr. A.M. Rifaat, Mr. M. El-Mamouny, Mr. S. El-Shazly, N.I.O.F., for their great support and help to carry out the marine survey of the Bitter Lakes to produce a new bathymetric map for the lakes. Thanks to Prof. S.H. Sharaf El-Din and Prof. A.I. Beltagy for revising the text.

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