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Hydrography and Water Budget of Obhur Creek, Red Sea

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Abstract. Obhur creek is located on the eastern side of the Red Sea, 35 km north of Jeddah. The hydrographic characteristics of the mean water circulation pattern and the possibility of flushing of the creek into the Red Sea are investigated based on the collected data during the year 1990.

The hydrographic structure showed evidence of three water masses at the entrance of the creek: a surface water mass characterized by high temperature and salinity; intermediate water mass distinguished by minimum salinity with core at 10-20 m depth and a bottom water mass that reaches maximum salinity. This structure yields a two-layer flow at the entrance; inflow of low salinity water at both surface and intermediate depths and outflow of salter water at the bottom.

Based on the water budget, the flushing time of the creek varied between one and four days during the period of investigation.

The creek waters were found to be near saturation with dissolved oxygen and almost transparent, reflecting its oligotrophication.

Introduction

Jeddah, during the last two decades, has experienced rapid growth in both population and size. This growing has an adverse effect on two of its marine inlets namely Arbaeen and Reayat Al-Shahab lagoons due to discharging the waste effluent into them. Study of their hydrographical properties (El-Rayis, 1992) reveals that the pollution problem are also due to restriction of the water exchange between them and the Red Sea waters. The size of Jeddah City has expanded northward towards another marine inlet (summer resort) namely Sharm Obhur which is the area under investigation.

Sharm Obhur (Fig. 1) is a creek located on the east coast of the Red Sea, 35 km north of Jeddah, between latitudes 21°42′11″ & 21°45′24″N and longitudes 39°05′12″ & 39°08′48″E. It is narrow (maximum width 1.5 km), elongated 9.5 km and connected with the Red Sea through an outlet of 350 m width and about 40 m deep. The surface area of the creek is about 7.79 km^2. The creek is not connected directly or indirectly with any river or stream (Behairy *et al.*, 1983). The transverse section at any part of the creek, generally, has V-shape and the sides are covered by fringing reefs that continue into its outer part. The water depth decreases gradually along its axial line, and sharply towards the head (Fig. 2). Most of the creek sediments are from an indigenous carbonate mixed with clastic materials in different proportions. According to Behairy (1980), the present work represents a part of an old fluvial valley flooded by seawater.

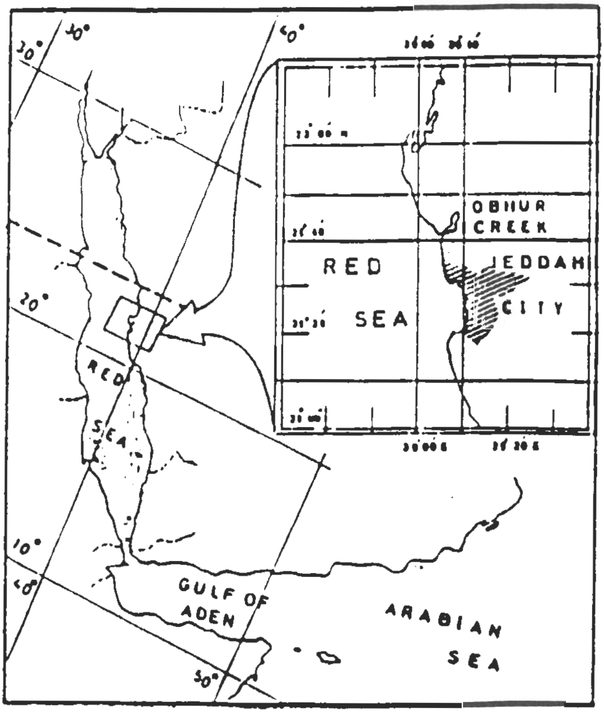

FIG. 1. Map of the Red Sea and location of Obhur creek, north of Jeddah.

The aim of the present work is to shed some light on the hydrography of the Obhur creek including the distribution of temperature, salinity, dissolved oxygen and transparency depth during different months. The water budget of the creek is also investigated.

Material and Methods

Water samples were collected from nine stations lying along the longitudinal axis of the creek and extending out about 2 km seawards from the creek entrance (Fig. 2). Samples are acquired during 5 cruises in 1990 during the following months: February

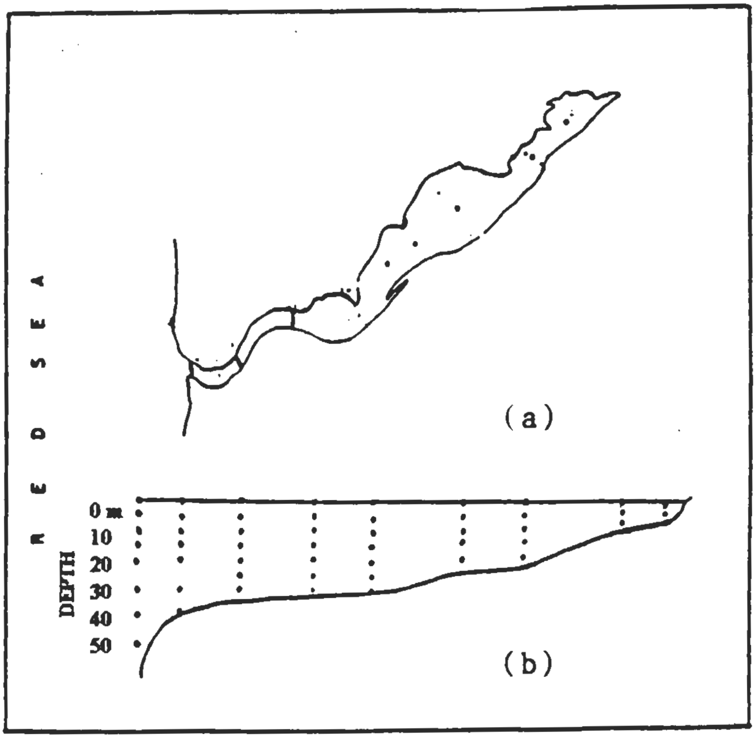

FIG. 2. Obhur creek: (a) stations positions and (b) sampling depths of nine water columns extending along the longitudinal axis of the creek, Jeddah.

(winter), May (spring), October (late summer) and November and December (autumn). Water samples were taken from the surface layer (0.5 m) and from subsurface levels at 5 m depth intervals until reaching near bottom and to a maximum depth of 50 m at stations outside the creek. The water samples for the determinations of dissolved oxygen (DO) and salinity were collected by the use of Nansen bottles, four at each hydrocast, provided with reversing thermometers for temperature measurement. Transparency is measured with the conventional Secchi disc. Salinity is measured by a salinometer (Beckman bench-type) and the DO is determined using the titrimetric method following the procedure of Grasshoff *et al.* (1983).

The climatological data (air temperature, atmospheric pressure, relative humidity, wind speed and direction, precipitation) measured at Jeddah meteorological station compiled from 30 years (1961 to 1990) (Meteorology & Environmental Protection Administration, MEPA, Personnal communication) are shown in Table (1) in addition to the sea surface temperature for the calculation of the evaporation rate.

In calculating the water budget, the volume of the inflow and outflow water can be calculated by means of the following :

TABLE 1. Sea-surface temperature and meteorological data at Jeddah (1961-1990, after MEPA).

Month	T_W (°C)	T_d (°C)	AP (mb)	Re %	W (knot)	P mm
Feb.	24.2	23.5	1012.6	61.0	10.0	5.6
May	27.5	29.6	1006.7	60.0	8.0	1.5
Oct.	30.2	29.1	1009.6	67.0	6.0	2.4
Nov.	30.1	27.0	1011.9	64.0	5.0	11.9
Dec.	29.6	24.7	1013.5	59.0	5.0	11.9

T_W = Sea-surface temperature; T_d = Air temperature;
AP = Atmospheric pressure at sea level; Re = Relative humidity;
W = Wind speed; P = Precipitation.

Under stationary conditions, the total amount of water (T_i) at a given time that flows into a region must equal the sum of the outflow (T_o) and the difference (D) between precipitation (P), run-off (R) and evaporation (E) during the same period, *i.e.*

$$T_i = T_o + D \tag{1}$$

Simultaneously, the amounts of salt carried by the in- and out-flowing currents are assumed equal, *i.e.*

$$T_i \; S_i \; f_i = T_o \; S_o \; f_o$$

where :

S_i and S_o are the average salinity of the inflowing and outflowing water respectively, and f_i and f_o are the respective densities. For a constant water density the above equation reduced to :

$$T_i \; S_i = T_o \; S_o \tag{2}$$

From these two relations (1 & 2), one obtains Knudson's relationships :

$$T_i = D \; S_o \, / \, (S_o - S_i)$$

$$T_o = D \; S_i \, / \, (S_o - S_i)$$

The evaporation rate (E) is calculated using the bulk formula :

$$E = f_d \, C(q_w - q_a) \; W$$

where :

q_w is saturated specific humidity at sea surface temperature,

q_a is specific humidity in the air,

f_d is density of the air,

W is wind speed, and

C is constant (2.1×10^{-3}, Bunker *et al.*, 1982).

The monthly precipitation (P) over the investigated area is shown in Table 1. No river discharged into the area, *i.e.,* $R = 0$.

If the mean volume of the water of the creek (V) is divided by (T_o), an estimate of the time required for the creek to exchange its water is obtained. This is the flushing time (t), *i.e.*

$$t = V / T_o = V (S_o - S_i) / D S_i \quad (3)$$

Results and Discussion

1) Hydrography of the Creek

Vertical distributions of both temperature and salinity during the five cruises along the longitudinal axis of the creek and extending out to the Red Sea are presented in (Fig. 3). Range and mean values of these hydrographic elements as well as those of dissolved oxygen (DO) and Secchi disc (transparency depth) inside and out of the creek are listed in Table 2.

a – Salinity

In winter (February) (Fig. 3-a1): salinity inside and outside the creek ranges between 39.27 and 39.53, with an average 39.35. Inside the creek, despite of the narrow range, there is an observable decrease in salinity with depth to reach minimum values < 39.30 at about 10 m depth. Then, in the deeper waters, salinity increases (to values > 39.30). On the horizontal scale, salinity increases towards the creek head. The increase is slightly from 39.27 near the creek entrance to 39.35 at an intermediate distance inside the creek. Then it increases rapidly to reach a value of 39.53 near the head. Fig. 3-a1, shows that the minimum salinity water spreads as an intermediate layer from the sea towards the creek head (its salinity is < 39.30). Its upper side is parallel to the sea surface, at 3 m depth, while its lower side inside the creek is nearly parallel to the bottom. Accordingly, its thickness is greater near the creek entrance with respect to that on going towards the creek head, suggesting that this layer is originated from the Red Sea waters.

In spring (May) (Fig. 3-a2): the salinity values, inside the creek range between 39.23 and 39.49, with an average 39.31. There is a slight decrease in both the range and average values of salinity with respect to their corresponding in the winter season, suggesting that there is a dilution or flush of the creek with more waters from the Red Sea.

The pattern of the vertical distribution of salinity during this season inside the creek does not show much difference from that in winter.

Late summer and autumn (October, November and December): In October, salinity of the creek ranges between 39.23 and 40.14, with an average 39.59. There is a noticeable expansion in the salinity range, to reach values as high as > 40.0 and the average value subsequently increases. These increases are referred to the effect of hot and dry weather that prevails the area during summer months. It indicates low rate of the water exchange with the Red Sea.

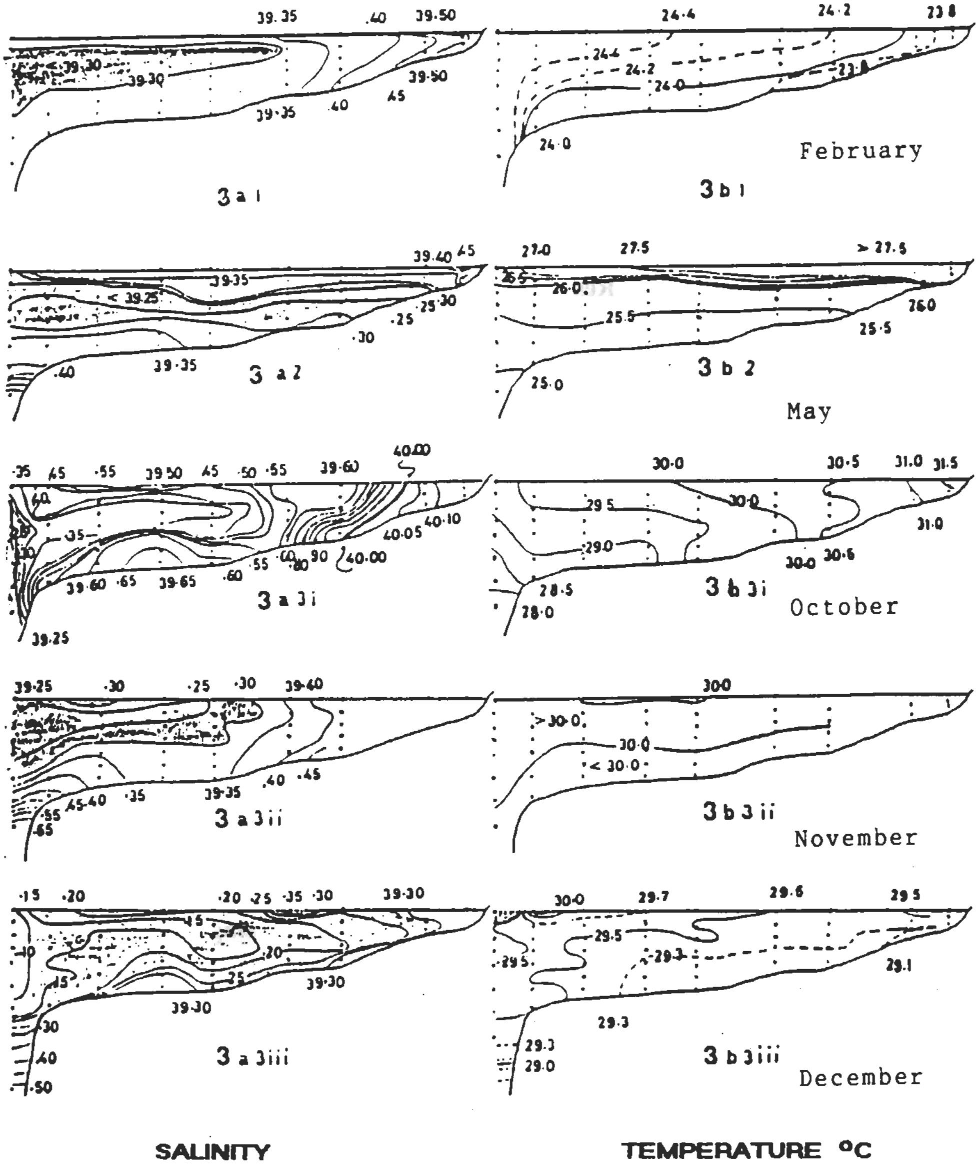

FIG. 3. Vertical distribution of (a) salinity and (b) temperature along the longitudinal axis of Obhur creek during the period of investigation.

Also, it is noticeable that the creek water in the inner part is convected and vertically mixed, as the water columns become more homo-haline.

Figure 3a3i, shows that the convected water as soon as it reaches the bottom, and because of its inclination seaward, it glides over it backward first towards the outer

TABLE 2. Range and mean values of the hydrochemical elements inside and outside Obhur Creek during 1990.

Element	Month	Inside the creek		Outside the creek entrance	
		Range	Mean	Range	Mean
Temp. (°C)	Feb.	23.45 – 24.48	23.76	24.40 – 24.49	24.43
	May	25.10 – 27.89	26.30	24.59 – 26.15	25.46
	Oct.	28.87 – 31.62	29.99	27.12 – 29.90	28.60
	Nov.	29.90 – 30.90	30.10	29.10 – 30.90	30.11
	Dec.	29.00 – 30.60	29.44	28.30 – 29.52	29.25
Sal. (ppt)	Feb.	39.27 – 39.53	39.35	39.28 – 39.32	39.31
	May	39.23 – 39.49	39.31	39.24 – 39.62	39.34
	Oct.	39.23 – 40.14	39.59	39.2 – 39.32	39.24
	Nov.	39.25 – 39.52	39.33	39.23 – 39.67	39.32
	Dec.	39.11 – 39.38	39.21	39.07 – 39.51	39.16
Oxygen (mg/l)	Feb.	6.03 – 7.93	6.82	6.66 – 7.56	7.13
	May	6.76 – 7.43	7.12	6.66 – 7.35	7.09
	Oct.	6.13 – 7.54	6.85	6.18 – 7.00	6.76
	Nov.	– –	–	– –	–
	Dec.	6.00 – 7.17	6.60	6.24 – 6.98	6.64
Seechi Disk (Transparency) depth, m)	Feb.	6[d] – 20[b]	10[c]	22[d]	22[d]
	May	4 – 17	8	20	20
	Oct.	6 – 20	10	21	21
	Nov.	6 – 21	11	24	24
	Dec.	6 – 21	13	22	22

a – The shallowest innermost station of depth 6 m.
b – The outermost station of depth 40 m.
c – The mean depth along the longitudinal axis is 20 m (Rashad, personal communication).
d – Depths greater than 75 m.

part of the creek as bottom layer and thence to the sea mostly as intermediate density current. As a result of this process and as a compensation for the outflowing saline water, a Red Sea water (of salinity < 39.30) that stands near the creek entrance starts to inflow into the creek as a surface layer. This is in a sequence described by many physical oceanographers, *e.g.* Pritchard (1952) and Nuns Vaz *et al.* (1990) as an inverse estuarine circulation. See the preceding of this process in the autumnal months November and December (Fig. 3a 3ii-iii).

b – Temperature

The vertical distributions of the temperature along the axial line of the creek and out to the sea during the five cruises are shown in Fig. 3b. The patterns of the temperature distribution confirm most of the above observations deduced through the discussion of salinity. For example, the intrusion of the proper Red Sea water to the creek in autumn and winter is clearly seen here from presence of a tongue of warm water (of about 20 m thick) that is extended as a surface layer inside the creek (see

Fig. 3-b1 and 3-b3 ii). The autumnal overturn of the waters in the inner part of the creek is easily seen in Fig. 3b 3i, where the water columns there become homo-thermal. In addition, two more observations are listed :

1 – The effect of land mass on the water temperature is seen quite well. For example in winter the landward shallow waters become quite colder than the seaward waters outside the creek and vice versa in the other seasons, as the land is usually of lower heat capacity with respect to that of the water (Defant, 1961).

2 – There is a seasonal change in the mean temperature inside the creek (Table 2). The minimum temperature was about 23.7°C in winter while a maximum of about 30.1°C was observed in late summer.

c – Dissolved Oxygen (DO)

Study of the DO usually gives an indication about trophic status of a water body (Vollenweider, 1976 and 1992, and Wetzel, 1983). Table 2, shows that the concentrations of the DO in the creek waters in winter, spring, late summer and autumn fluctuated between 6.03 – 7.93; 6.67 – 7.43; and 6.00 – 7.54 mg O_2/l, respectively. The respective average is 6.82, 7.12 and 6.73 mg O_2/l. These values are comparable to those in the Red Sea waters near the creek entrance. At the same time, they are near the saturation values of these waters with DO. This fact means that the creek waters are always near saturation with DO during the year, suggesting its oligotrophication (Wetzel, 1983). Its oligotrophication is also confirmed by the observed high transparency (Table 2) and low values of measured chlorophyll α biomass (unpublished data). These values, however, are comparable to those characterizing the oligotrophic systems (Vollenweider, 1976 and 1992).

d) Transparency depth

The transparency depth inside the Obhur creek (Table 2) varies between 4 and 21 m. The lower value is measured at the shallow water stations where the transparency depth reached to the bottom (maximum depth of 6 m). At the deeper water inside the creek (maximum depth of 40 m), the transparency depth changed between 17 and 21 m. While, outside the creek entrance (where the maximum depth greater than 75 m), it varied between 20 and 24 m (Table 2).

2) Temperature-salinity Analysis

Figures (4 and 5) show the vertical structure of temperature and salinity during the period of investigation outside the creek and at its entrance respectively. It is clear that, the temperature at these two stations decreases slowly with depth. While the salinity curves showed a high salinity at the surface then it decreases gradually with depth to reach a minimum value at depth between 10 and 15 m. Then it increases with depth to reach its maximum value at the bottom, except during October, in which the maximum salinity is observed at the surface.

Figures (6 and 7) show the T-S diagrams at the stations located outside and at the entrance of the creek respectively. It is seen that, there are three water masses at each month namely: 1. The surface water mass, which occupied the upper 5 m layer,

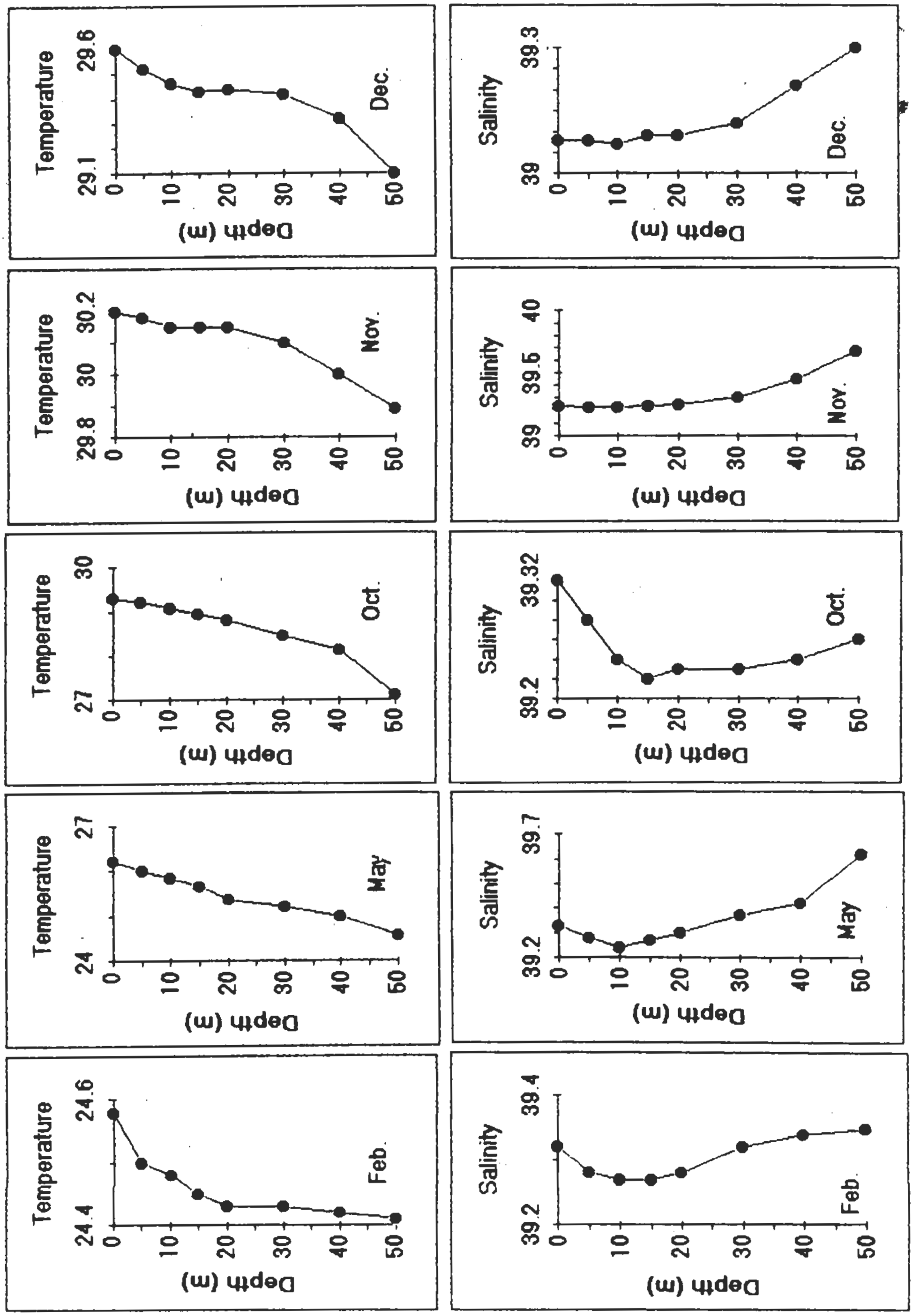

FIG. 4. Vertical structure of both temperature (°C) and salinity outside the creek during 1990.

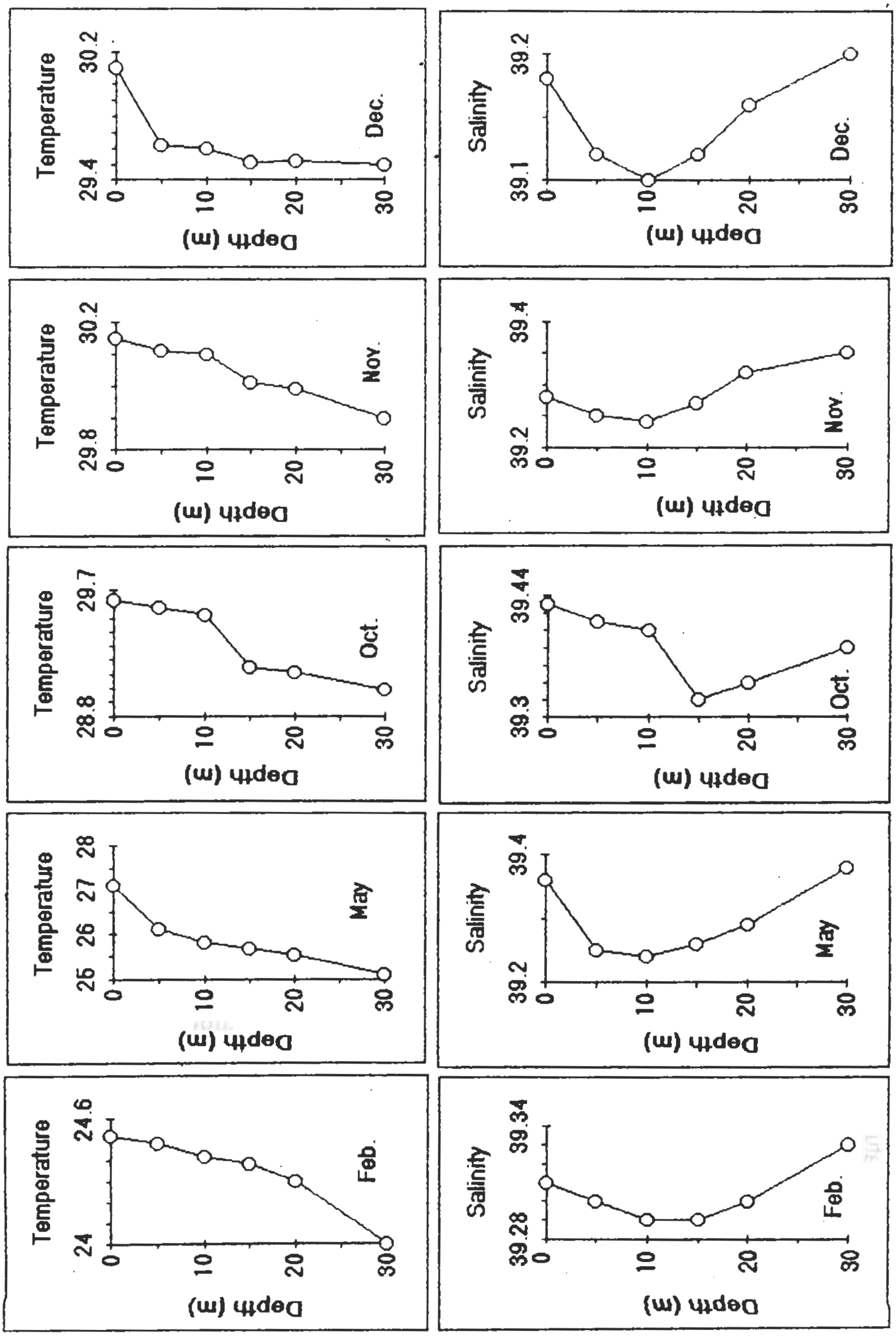

FIG. 5. Vertical structure of both temperature (°C) and salinity at the creek entrance during 1990.

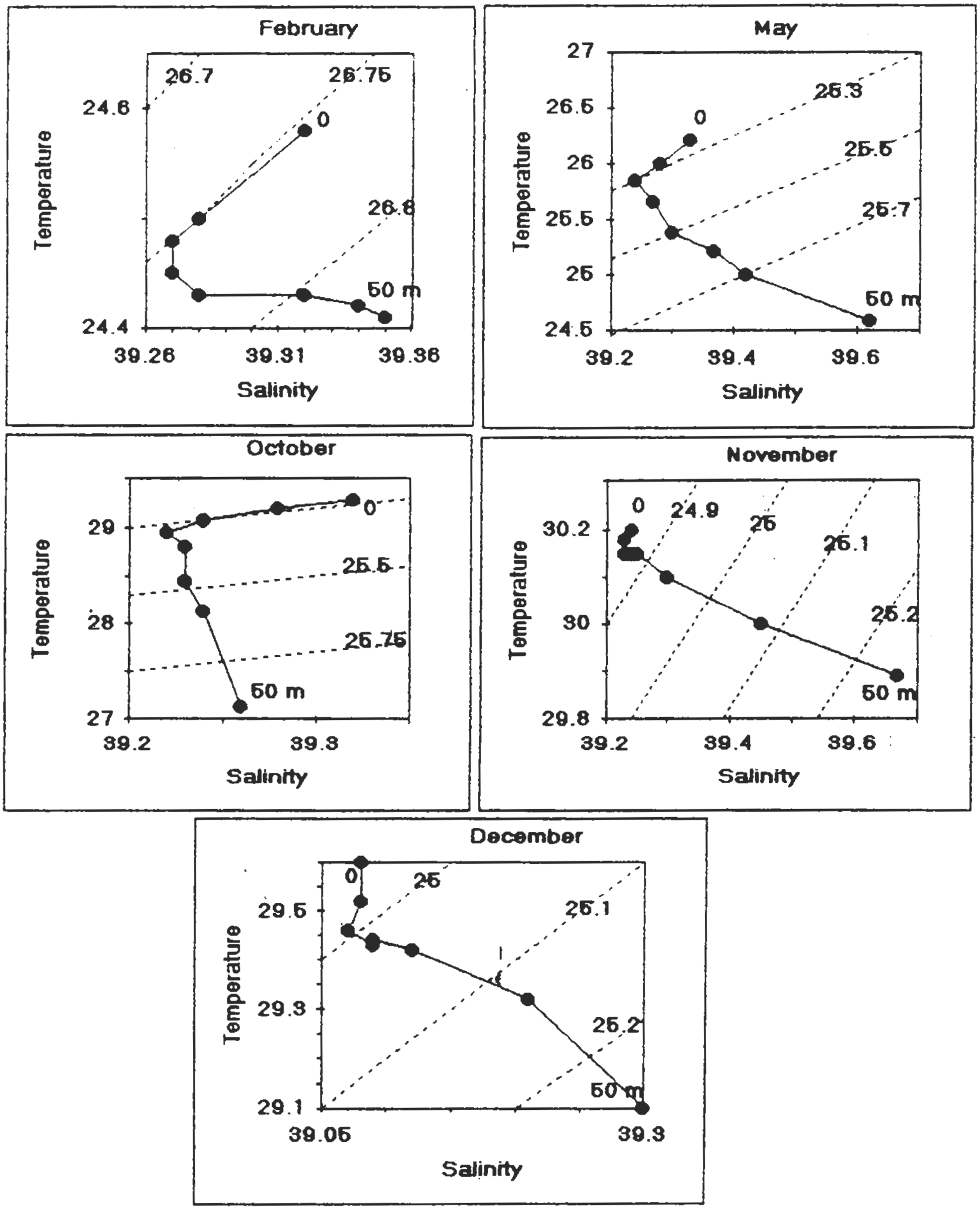

FIG. 6. Temperature versus salinity outside the creek during 1990 (dashed lines are isopycnal lines).

is characterized by high temperature and relatively high salinity. 2. The intermediate water mass, which occupied the intermediate layer between 10 and 20 m depth, is distinguished by a core of minimum salinity. 3. The bottom water mass, which extends from 20 m depth to the bottom, is characterized by lower temperature and maximum salinity, except during October where the maximum salinity occupied the surface water mass. The main characteristics of these water masses outside and at the entrance of the creek during the period of investigation are summarized and listed in Table 3.

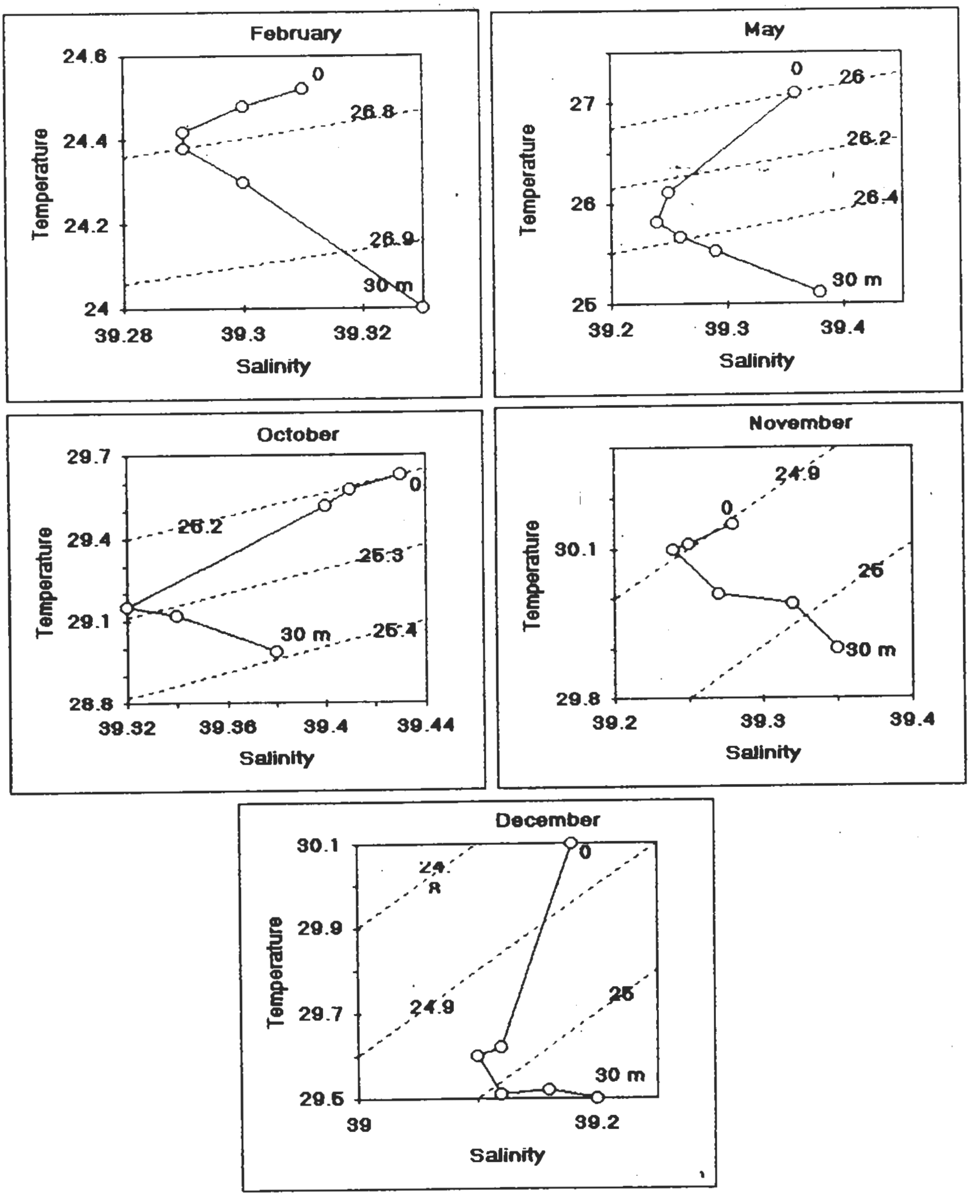

FIG. 7. Temperature versus salinity at the creek entrance during 1990 (dashed lines are isopycnal lines).

TABLE 3. The main characteristics of the different water masses outside and at the entrance of the creek.

Month	Surface water mass T	S	σ_t	Intermediate water mass T	S	σ_t	Bottom water mass T	S	σ_t
Outside the creek									
February	24.54	39.30	26.76	24.45	39.27	26.77	24.41	39.34	26.82
May	26.11	39.30	26.27	25.23	39.27	26.40	24.93	39.47	26.77
October	29.24	39.30	25.24	28.94	39.22	25.29	27.90	39.24	25.62
November	30.19	39.24	24.86	30.15	39.23	24.88	30.0	39.47	25.11
December	29.56	39.08	24.96	29.44	39.08	25.00	29.28	39.21	25.16
At the entrance of the creek									
February	24.50	39.31	26.78	24.40	39.29	26.80	24.15	39.32	26.89
May	27.10	39.36	26.00	25.79	39.26	26.34	25.11	39.38	26.64
October	29.58	39.41	25.20	29.14	39.33	25.30	28.99	39.38	25.38
November	30.15	39.28	24.91	30.07	39.25	24.92	29.95	39.34	25.03
December	30.10	39.18	24.85	29.58	39.11	24.95	29.51	39.18	25.06

T = Temperature, °C; S = Salinity, σ_t = Water density.

3) The Water Budget of the Creek

Sharm Obhur is a semi-isolated body of water located in an arid zone which is subjected to no stream supply and has negligible rainfall. Evaporation from its surface is relatively high. Thus the water budget of the creek is mainly determined by evaporation rate and by the water exchange with the open sea through its entrance.

The general pattern of the water exchange between the creek and the Red Sea, as deduced from the hydrographic sections, shows the evidence of two layers of water flowing through the entrance, surface inflow from the Red Sea into the creek and bottom outflow moving out the creek into the Red Sea.

The evaporation per unit area per day ($g/cm^2 \cdot day$) was calculated during the period of investigation as shown in Table 4. The rate of evaporation during the period of investigation shows maximum during February (0.815 cm/day) and minimum during May (0.599 cm/day).

TABLE 4. The evaporation (E) and precipitation (P) in cm/day calculated during 1990.

	Feb.	May	Oct.	Nov.	Dec.
E	0.815	0.599	0.606	0.638	0.752
P	0.020	0.005	0.008	0.040	0.038
E – P	0.795	0.594	0.598	0.598	0.714
E (Behairy *et al.*, 1981)	0.411	0.735	0.387	0.580	0.516
E (Ahmad & Sultan, 1987)	0.573	0.522	0.554	0.877	0.730

The excess evaporation over precipitation (E-P) in cm/day per unit area is shown in Table 4, in addition to two earlier estimates off Jeddah for the purpose of comparison. There is a slight difference between the above calculated rates of evaporation with that calculated by Behairy *et al.* (1981) and Ahmad & Sultan (1987).

From the hydrographic data at the entrance, the average salinity of the inflow and outflow waters are determined and listed in Table 5. Also, Table 5 shows the computed amount of inflow (T_i) and outflow (T_o) waters during the investigated months and the excess of evaporation over the precipitation (D). It is seen that, the greatest inflow of water takes place during December while the lowest one occurs during October. This pattern is in agreement with the monthly mean sea level variations of the Red Sea, where the rise in sea level starts from November to May with maximum height during December-January; and then drops from June to October with minimum height during August-September (Osman, 1985).

TABLE 5. The average salinity of inflow (S_i) and outflow (S_o) waters and the water budget components at the entrance of creek.

Month	S_i	S_o	T_i	T_o	D
	ppt		m^3/sec		
Feb.	39.26	39.33	402.85	402.13	0.72
May	39.25	39.38	162.37	161.83	0.54
Oct.	39.32	39.45	163.57	163.03	0.54
Nov.	39.26	39.40	151.69	151.15	0.54
Dec.	39.12	39.20	315.56	314.92	0.64
Average	39.25	39.35	239.21	238.61	0.60

T_i & T_o are the amounts of inflow & outflow waters, respectively.
$D = T_i - T_o$.

Moreover, the strong vertical mixing of the upper layer during December and February by the strong winds leads to decrease the difference in the salinity of inflowing and outflowing water. Consequently the amounts of T_i and T_o during these months are relatively large.

The total volume of the water within the creek was estimated as 50×10^6 m^3 (Rashad, personal communication). The flushing time of the creek (based on water budget) can be calculated according to equation (3) and the results are given in Table 6. On the average, the creek renews its water after one to four days with a weighted average of about three days.

TABLE 6. The estimated flushing time (t) of the creek.

Month	Feb.	May	Oct.	Nov.	Dec.	Average
t (days)	1.44	3.58	3.55	3.83	1.84	2.87

Conclusions

Based on five cruises in 1990, the hydrography and the water budget of the Obhur creek are studied. The result reveals that the vertical distribution of both temperature and salinity along the longitudinal section of Obhur creek showed two layers of water flowing through the entrance, a surface and intermediate inflow of low salinity water from the Red Sea into the creek and a deeper outflow of higher salinity water from the creek towards the Red Sea. The average densities of the inflow water varied between 1.02488 and 1.02680 g/cm^3 throughout the period of investigation, and that of outflow ones oscillated between 1.02505 and 1.02695 g/cm^3.

Three water masses are observed at the entrance of the creek: 1. Surface water mass which occupied the upper 5 m layer and characterized by a higher salinity; 2. Intermediate water mass which occupied the layer between 10 and 20 m depth and distinguished by a salinity minimum; and 3). Bottom water mass which extends from 20 m depth down to the bottom and identified by a maximum salinity.

The rate of evaporation during the period of investigation is maximum (0.815 cm/day) during February and minimum (0.599 cm/day) during May.

The maximum inflow and outflow waters (302.85 and 402.13 m^3/sec, respectively) takes place during February, while the lowest ones (151.69 and 151.15 m^3/sec) occurs during November. This pattern is in agreement with the monthly variations of sea level of the Red Sea.

The calculation of the flushing time of the creek showed that, the creek renews its water after three days on the weighted average.

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هيدروجرافية وميزانية المياه لخليج أبحر على البحر الأحمر

عثمان عبد المطلب الريس و فهمي محمد عيد
قسم علوم البحار ، كلية العلوم ، جامعة الأسكندرية
جمهورية مصر العربية

المستخلص . منطقة الدراسة هي شرم أبحر ، وهو خليج صغير يقع في المنطقة الحارة للبحر الأحمر ويبعد عن مدينة جدة بحوالي ٣٥ كيلو مترًا شمالاً . تمت دراسة هيدروجرافية المياه والميزانية المائية وزمن تجديد مياه هذا الخليج من خلال خمس رحلات بحرية تم القيام بها عام ١٩٩٠م . تم التوصل إلى الشكل العام لحركة المياه عند مدخل الخليج من التوزيعات الرأسية لدرجة حرارة المياه وملوحتها لمقطع رأسي ممتد على طول محور الخليج ، وقد اتضح أن حركة المياه تتكون من طبقتين : الطبقة السطحية وهي مياه أقل في نسبة ملوحتها تدخل الخليج من البحر الأحمر - والطبقة القاعية وهي مياه أكثر ملوحة وتخرج من الخليج إلى البحر الأحمر .

لحساب الميزانية المائية للخليج تم حساب كمية المياه المتبخرة من السطح خلال فترة الدراسة ، وكانت قيمتها على وحدة المساحة تتراوح مابين ٠,٥٢ سم/يوم خلال شهر أكتوبر و ٠,٨٩ سم/يوم خلال شهر ديسمبر . أما عن كميات المياه الداخلة للخليج والخارجة منه عند المدخل فكانت تتراوح مابين ١٤٢,٦٣ و ١٤٢,١٦ متر مكعب/ثانية خلال شهر أكتوبر ومابين ٣٩٢,٠٠ و ٣٩١,٢٠ متر مكعب/ثانية خلال شهر ديسمبر على الترتيب .

بمعلومية كمية المياه الخارجة من الخليج والحجم الكلي لمياه الخليج فقد تم حساب الزمن اللازم لتجديد مياه الخليج وكان يتراوح مابين ١,٥ و ٤,١ يوما .

أظهرت الدراسة أيضًا أن مياه الخليج كانت دائمًا قريبة من نسبة التشبع بالنسبة للأكسوجين الذائب وأيضًا كانت المياه شفافة غالبًا .