International Journal of Engineering & Technology
CENTRE OF PROFESSIONAL RESEARCH PUBLICATIONS
ISSN 2049-3444

International Journal of Engineering and Technology Volume 2 No. 2, February, 2012

The Flushing Time of an Environmentally Sensitive, Yanbu Lagoon along the Eastern Red Sea Coast

Alaa M. A. Albarakati
King Abdulaziz University,
Faculty of Marine Sciences,
Department of Marine Physics,
P.O. Box 80207, Jeddah 21589,
Saudi Arabia

ABSTRACT

Yanbu Lagoon is located close to a huge industrial area. The lagoon is known as a rich marine environment habitat and is classified as an environmentally sensitive area by the Presidency of Meteorology and Environment (PME) of Saudi Arabia and the International Union for Conservation of Nature and Natural Resources (IUCN). The flushing time of Yanbu lagoon is about 2-3 days. The measurements also showed that the water exchange between the lagoon and the open sea is not only controlled by the tidal force but at times the effects of winds may be significant. This short flushing time may not cause intolerable stress to its ecology.

Keywords: *Red Sea, Yanbu, Flushing, Hydrography.*

1. LITERATURE REVIEW

Red Sea coast is bordered by shallow fringing reefs. Mostly the edges of the reefs shelve steep into deep water but in some areas, they slope gently into lagoons surrounded by offshore barrier reef (Morley 1975). Series of lagoons are found along the eastern coast of the Red Sea and most of them are still in their natural state.

Yanbu Lagoon is declared an environmentally sensitive area by Presidency of Meteorology and Environment (PME) of Saudi Arabia and the International Union for Conservation of Nature and Natural Resources (IUCN). It is located along the Saudi Red Sea coast (24° 10' N, 37° 55' E) and is about 350km north of Jeddah (Figure 1). The lagoon is shallow with an average depth of 5m. The estimated area is approximately $7.5 km^2$. The average depth at the entrance is about 17m with cross-sectional area of about $4.25x10^3 m^2$. Some physical and chemical aspects of the coastal lagoon/creeks of the Red Sea have been studied (Meshal 1987; El-sayed, 1987; Ahmad and Sultan, 1992). In this study the physical properties and the flushing time of Yanbu Lagoon are investigated.

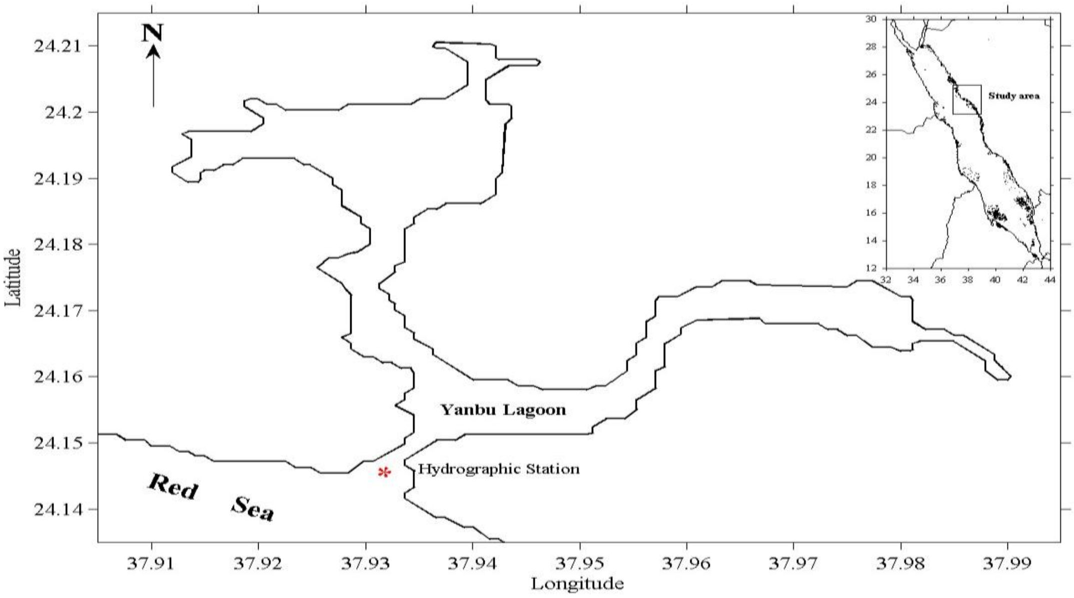

Figure 1. Yanbu Lagoon showing the location of the hydrographic station.

The Red Sea is bordered on both sides by high mountains and plateau that cause the air masses in the lower troposphere to flow approximately parallel to the axis of the Red Sea (Patzert, 1974). Because of this, the wind system over the Red Sea is relatively simple and mostly, the winds are along the direction of the main axis (Eshel et al., 1994).

In the northern region of the Red Sea (north of 19 °N) the winds are north-westerly all the year (Edwards and Head, 1987). In the southern part of the Red Sea (south of 19°N) the winds are influenced by the monsoon system of the Arabian Sea. During summer the winds are mainly north-westerly but in winter the wind direction changes to south-east (Quadfasel and Baudner, 1993).

The circulation is mainly controlled by wind and pressure gradient force. Neumann and McGill (1962) and Phillips (1966) showed that, the thermohaline forcing controls the water circulation at the upper layer. High evaporation in the north of the Red Sea cause the surface water temperature to decrease and its density increase and sinks to the lower and deep layers. This mechanism causes the sea surface to tilt northward. Therefore, the upper layer flows northward. In the southern region the currents are directed to the north in winter season due to the south-easterly winds. During summer the surface water is directed to the south flowing out of the Strait of Bab-El-Mandab under the influence of north-westerly winds which dominate the entire Red Sea (Patzert, 1974; Maillard and Soliman, 1986; Bethoux, 1988; Souvermezoglou, *et al.,* 1989; Shapiro and Meschanov, 1991; Albarakati *et. al.*, 2002).

Tides in the Red Sea are oscillatory and semi-diurnal. The time difference between the high water in the extreme north and south of the Red Sea is 6 hours. The nodal point is at about 19°N where the tidal height is at its lowest. (Morcos, 1970).

The effect of the tidal currents on the water circulation is only local. Near Yanbu Lagoon the tidal currents are expected to be weak because it is close to the nodal point. Due to the local topography the currents change their speed and directions.

2. COLLECTION OF HYDROGRAPHIC DATA

Temperature, salinity and current velocities were measured at the entrance of the lagoon. On each trip measurements lasted for 13 hours to cover semi-diurnal tidal cycle. Valeport CTD was used to measure water temperature and salinity. Nansen Bottles and reversing thermometers are used to test the accuracy of the CTD. Water speed and direction were measured by using, Japanese make, direct reading current meter (CM2). The measurements were collected at the mid depth which varies during the tidal cycle. Echo-sounder was used to measure the depth.

3. COMPUTATION OF THE FLUSHING TIME OF THE LAGOON

The lagoon was surveyed to determine the depths, area, and then the volume of water. Maximum depth of the lagoon is approximately 20m with an average of 5m. Estimated area is about $7.5\text{x}10^6\text{m}^2$ and volume of $37.5\text{x}10^6\text{m}^3$. The width of the entrance where the lagoon is connecting to the open sea is about 250m with an average depth of 17m

The flushing time of the lagoon was calculated depending on the recorded current speed and direction at the entrance.

$$\text{Flushing Time (Tidal cycle)} = \frac{\text{Total water volume of the lagoon}}{\text{In or out flow over a tidal cycle}}$$

$$\text{FT (Tidal cycles)} = \frac{\text{V}}{\alpha.\text{A}.\text{u}_{\text{in/out}}.\text{Half tidal cycle}}$$

V: Volume of the water in the lagoon.

u_{in}: Depth average in-flow velocity at the entrance.

u_{out}: Depth average out-flow velocity at the entrance.

A: Cross section area of the entrance.

α: Fraction of tidal prism exchange with sea or lagoon water over a tidal cycle.

4. RESULTS

The obtained field results during the project are presented. Results contain measurements of sea water temperature, salinity and current meter data along with the computed flushing time.

Variations of temperature with time at the mouth of the lagoon are shown in figures 2 and 3. These data were collected in June 2011 over spring-neap tidal cycle. The data show that the water temperature varies between 26.37°C and 28.66ºC.

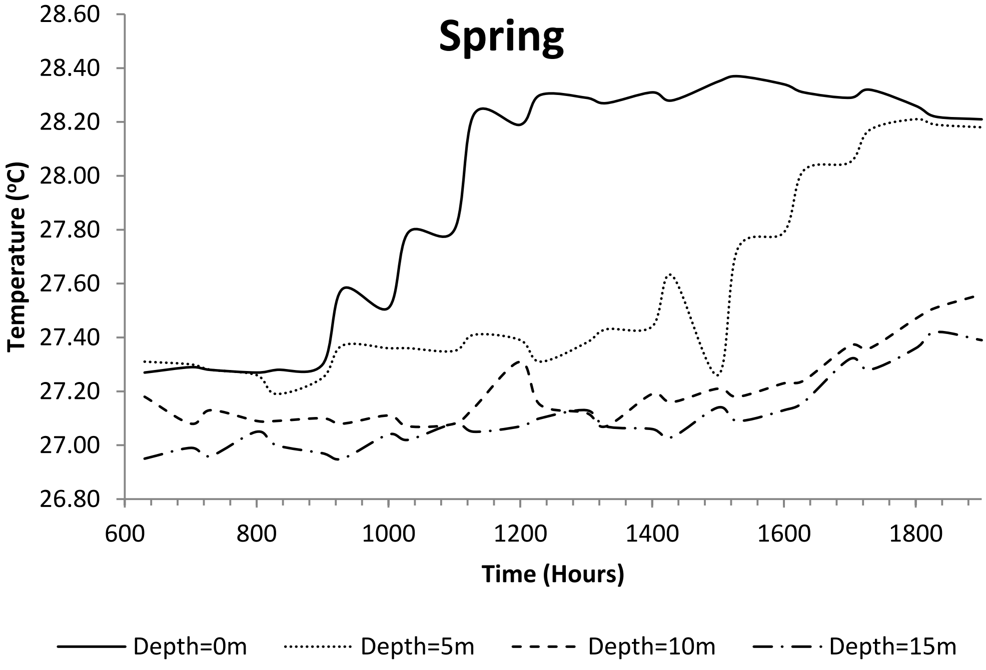

Figure 2. Temperature variation during spring tidal cycle.

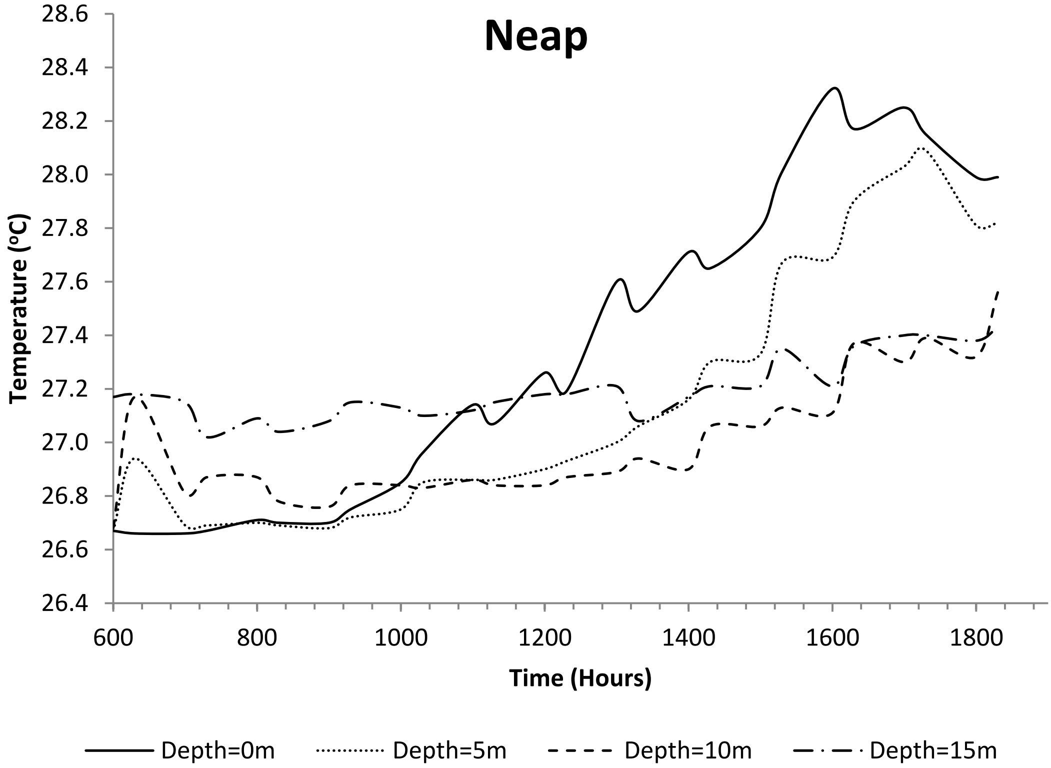

Figure 3. Temperature variation during neap tidal cycle.

Figures 4 and 5 show the variation of salinity with time at the lagoon mouth. These data were also collected during June over spring-neap tidal cycle. Water Salinity varies between 39.04‰ and 40.67‰.

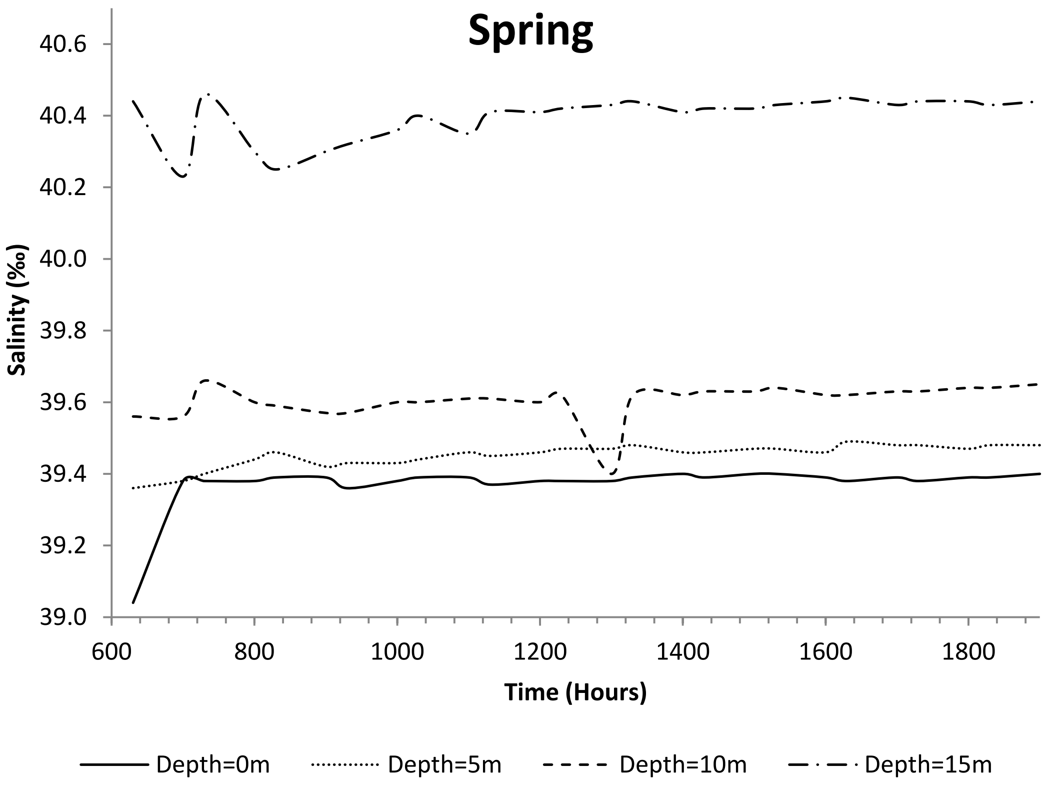

Figure 4. Salinity variation during spring tidal cycle.

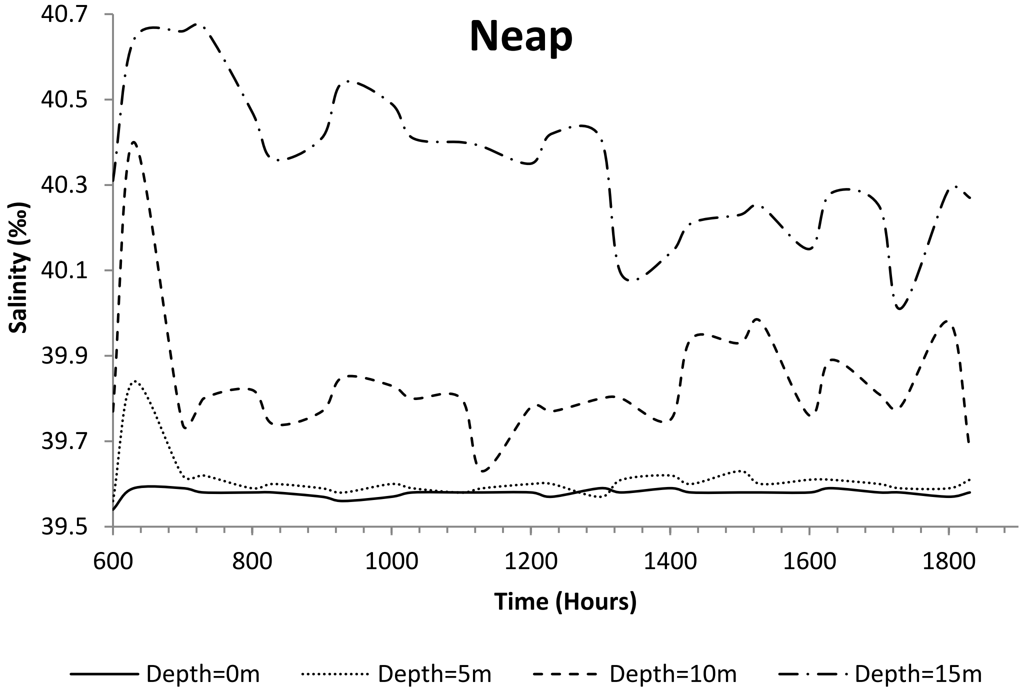

Figure 5. Salinity variation during neap tidal cycle.

The velocities at the lagoon entrance showed wide variability in direction. It may be that the water exchange between the lagoon and the open sea is not only due to the tidal exchange but the wind effect is significant. Depth averaged velocities were calculated by taking into account the direction of the flow (in or out). These averaged velocities are used to calculate the flushing time of Yanbu Lagoon.

Depth average in-flow velocity at the middle of the entrance is=0.42 $m.s^{-1}$ and depth average out-flow velocity at the middle of the entrance is =0.33 $m.s^{-1}$. Cross section area of the entrance is=$4.25x10^3 m^2$.

The velocities at the middle of the channel are about $\frac{1}{3}$ higher than the average for the whole width. Therefore, the flushing time is:

$$\mathrm{FT(Tidal\ cycles)} = \frac{\mathrm{V}}{\alpha.\mathrm{A}.\mathrm{u}_{\mathrm{in/out}}.\frac{3}{4}.\mathrm{Half\ tidal\ cycle}}$$

Combination of tidal range with broad open entrance yields tidal prisms that are large fractions (30 to 50%) of total volume (Hickey and Banas, 2003). Therefore, based on the tidal velocities at the entrance and lagoon hydrography, α is=0.3. The calculated flushing time is about 2-3 days.

The estimation of the non-tidal velocity variation U_{non} is calculated depending on the non-tidal sea level variation. If L is the length of the lagoon and h a measure of sea level variance and H is the depth of the lagoon then:

$$\mathrm{U}_{\mathrm{non}}.\mathrm{T} = \frac{\mathrm{L.h}}{\mathrm{H}}$$

T is the time scale of non-tidal velocity.

For Yanbu lagoon L=12km, H=5 m, h = 12cm/month (Morley 1975) which gives a very small seasonal variation in the non-tidal velocity. This shows that the seasonal mean sea level variations will not have a significant effect on the flushing time because the seasonal variation in the non-tidal velocity is very small.

5. DISCUSSION

In general the magnitude of tidal currents in the open Red Sea is less but in shallow areas the tidal currents may become very strong. These may be of tidal origin but the topographic influences and the effect of local or diurnal wind variation are the major factors influencing them. Accordingly, the currents speed at the entrance and inside the lagoon is high and consequently, the water column is homogenous in the lagoon.

Vertical profiles of the temperature and salinity variations show no changes with depth (homogenous). This could be related to the shallow depth of the water column. During high tide, a layer of relatively cold and low salinity water from the Red Sea enters the lagoon during. During low tide the higher temperature and higher salinity water from the lagoon flows into the Red Sea. Temperature variations in the area are controlled by meteorological conditions.

Measured velocities show that there is no systematic variation in the flow direction. Ahmad and Sultan (1992) showed similar measurements in Shuaiba Lagoon. Therefore, the effect of the flood and ebb tide are not playing major role in the flushing of Yanbu Lagoon. However, the averaged in and out flow velocities which were used to calculate the flushing time of the lagoon showed that the time scales are 2 to 3 days.

The non-tidal velocities are very small because of the small changes in the monthly variations of the sea level in the Red Sea, and may not be contributing to the flushing time.

6. CONCLUSIONS AND RECOMMENDATIONS

A fairly good hydrographic data were collected during this project. Trips were taken during spring neap tide and each trip covered one complete semi-diurnal tidal cycle (13 hours). Hydrographic data showed that the water column in Yanbu Lagoon is well-mixed with high temperature and salinity. Current velocities did not show a consistency in their direction within the water column nor during the semi-diurnal tidal cycle. Flushing time calculation showed that the time scale is about 2-3 days. In the arid zone lagoons, the marine environment is under stress due to high temperature and salinity but the calculated flushing time for Yanbu Lagoon may not cause intolerable stress to its ecology. Nevertheless, comprehensive environmental studies are needed to avoid any damage to the environment because few recreation constructions will start in the near future.

REFERENCES

[1] Ahmad, F., Sultan, S.A.R. and Moammar, M. O. (1989) 'Monthly variations of the net heat flux at the Air-Sea interface in coastal waters near Jeddah, Red Sea'. Atmosphere-Ocean, **27**, No. 2, pp. 406-413.

[2] Ahmad, F. and Sultan, S.A.R. (1992) ' The effect of the meteorological forcing on the flushing of Shuaiba Lagoon on the eastern coast of the Red Sea'. Journal of King Abdulaziz University, Marine Sciences, **3**, pp. 3-9.

[3] Al-Barakati, A.M.A., James, A.E. and Karakas, G. M., (2002) " A three-dimensional hydrodynamic model to predict the distribution of temperature, salinity and water circulation of the Red Sea ". Journal of Faculty of Marine Sciences, Jeddah, vol. 13, pp. 3-17.

[4] Bethoux, J. P. (1988) 'Rea-Sea geochemical budgets and exchanges with the Indian-Ocean'. Marine Chemistry, **24**, No. 1, pp. 83-92.

[5] Edwards, A. J. and Head, S. M. (1987) 'Red Sea'. Pergmon Press, pp. 42-78.

[6] El-Sayed, M.Kh. (1987) 'Chemistry of modern sediments in hypersaline lagoon, North of Jeddah'. Estuarine, Coastal and Shelf Science, **25**, pp. 467-480.

[7] Eshel, G., Cane, M. A. and Blumenthal, M. B. (1994) 'Modes of subsurface, intermediate and deep-water renewal in the Red-Sea'. Journal of Geophysical Research-Oceans, **99**, No. C8, pp. 15941-15952.

[8] Hickey, B. M. and Banas, N. S. (2003). 'Oceanography of the U.S. Pacific northwest coastal

ocean and estuaries with application to coastal ecology'. Estuarine, **26**, pp.1010-1031

[9] Meshal, A.H. (1987). 'Hydrography of a hypersaline coastal lagoon in the Red-Sea'. Estuarine Coastal and Shelf Science, **24**, pp. 167-175.

[10] Maillard, C. and Soliman, G. (1986) 'Hydrography of the Red Sea and exchanges with the Indian Ocean in summer', Oceanologica ACTA, **9**, No. 3, pp. 249-269.

[11] Morcos, S.A. (1970) 'Physical and chemical oceanography of the Red Sea', Oceanography and Marine Biology Review, **8**, pp. 73-202.

[12] Morley, N.J.F. (1975) 'The coastal waters of the Red Sea'. Bulletin of Marine Research Centre, Saudi Arabia, No. 5. pp. 8-19.

[13] Neumann, A. C. and McGill, D. A. (1962) 'Circulation of Red Sea in Early Summer'. Deep-Sea Research, **8**, pp. 223-235.

[14] Patzert, W. C. (1974) 'Wind-induced reversal in the Red Sea circulation'. Deep-Sea Research, **21**, pp. 109-121.

[15] Quadfasel, D. and Baudner, H. (1993) 'Gyre-scale circulation cells in the Red Sea'. Oceanologica ACTA, **16**, No. 3, pp. 221-229.

[16] Shapiro, G. I. and Meschanov S. L. (1991) 'Distribution and spreading of Red Sea water and salt lens formation in the northwest Indian Ocean'. Deep-Sea Research, **38**, No. 1, pp. 21-34.

[17] Souvermezoglou, E., Metzl, N. and Poisson, A. (1989) 'Red-Sea budgets of salinity, nutrients and carbon calculated in the Strait of Bab-El-Mandab during the summer and winter seasons'. Journal of Marine Research, **47**, No. 2, pp. 441-456.

