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EFFECT OF BITTER LAKES ON FLOW IN THE SUEZ CANAL
تأثير البحيرات المرة على السريان فى قناة السويس

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خلاصة:

تقسم البحيرات المرة قناة السويس إلى جزنين مستقلين عن بعضهما (هيدروليكيا): الجزء الشمالى والجزء الجنوبى. وقد استخدم فى هذا البحث نموذج رياضى لدراسة تأثير البحيرات المرة على السريان فى القناة. النموذج يستخدم طريقة الأجزاء المنتهية فى حل المعادلات الهيدروديناميكية ثنائية الأبعاد. وتم الخلوص إلى أن وجود البحيرات المرة يحسن ظروف الملاحة فى القناة. وقد أوصت الدراسة بتكوين مجموعة من البحيرات الضحلة الواسعة حول القناة الملاحية فى الجزء الجنوبى من القناة.

ABSTRACT:

The Suez Canal consists of two reaches, which are almost independent. The Bitter Lakes is a barrier between the two reaches. A finite-element two-dimensional hydrodynamic model is used to investigate the effect of the Bitter Lakes on the flow characteristics in the canal. The basic finding of this study is that the existence of the Bitter Lakes improves navigational conditions in the canal. It is recommended that similar shallow, wide water bodies be constructed along the south reach of the canal.

1. INTRODUCTION:

Although the Suez Canal is classified as one of narrow channels connecting two open seas, it has its own characteristics, which are not shared by similar channels. The existence of the Bitter Lakes creates a barrier between north and south reaches of the canal (Eid, et al, 1997). Hence flow in each of the reaches is almost independent of flow in the other reach.

The aim of the current research is to investigate advantages and disadvantages of the Suez Canal flow separation by the Bitter Lakes. The research depends on numerical modeling of the flow in the canal. The numerical domain has two configurations; the first consists of the Suez Canal with the Bitter Lakes while the Bitter Lakes are removed from the second domain. In section two, a full description of the numerical model will be provided. In section three, the effect of the Bitter Lakes will be investigated by comparing flow characteristics in both numerical domains. Study will be concluded in section four.

2. NUMERICAL MODEL:

Governing Equations: The governing equations of shallow water flow are (Kashiyama et al, 1995):

$$\frac{\partial U_i}{\partial t} + U_j U_{i,j} + g\zeta_{,i} + \frac{\tau_i^b}{\rho(h+\zeta)} - A_l\left(U_{i,j} + U_{j,i}\right)_{,j} + f_i = 0 \tag{1}$$

$$\frac{\partial \zeta}{\partial t} + \left[(h+\zeta)U_j\right]_{,j} = 0 \tag{2}$$

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where U is the mean horizontal velocity, ζ is the water elevation, h is the mean water depth, g is the gravitational acceleration, A_l is the eddy viscosity, and f is Coriolis force. The bottom friction, τ is determined as (Kashiyama et al, 1995):

$$\tau_i^b = \frac{n^2 g}{h^{1/3}} U_i (U_k U_k)^{1/2} \tag{3}$$

where n is the Manning Coefficient.

Here, the standard index notation and the summation convention with repeated indices are employed. The governing equations mentioned above are based on the following assumptions:

1. Navier-Stokes equations are integrated over the depth assuming hydrostatic pressure distribution.
2. The Reynolds stresses together with the viscosity term are modeled by a constant eddy-viscosity term.

Finite Element Formulation: The finite element scheme developed by Kashiyama et al (1995, 1997) is applied in the present study. The scheme has the following characteristics:

1. The mesh consists of linear triangular elements.
2. The bottom friction term is linearized.
3. For discretization in time, the three-step explicit time integration scheme is used.
4. The so-called "*selective lumping scheme*" was applied to combine the advantages of both the consistent formulation and the lumped formulation.

Boundary Conditions: For the solid boundaries, the zero-normal-velocity condition was applied. For the open boundaries, the Sommerfeld Radiation Condition stated by Chapman (1985) as:

$$\frac{\partial \phi}{\partial t} + C \frac{\partial \phi}{\partial n} = 0 \tag{4}$$

was applied, where φ is the variable to be defined at the open boundary (either U or ζ) and C is the phase speed (or advection velocity). The Someerfeld Open Boundary Condition (OBC) is suitable for problems dominated by advection and/or wave motion because it allows propagating waves, which are generated within the computational domain to pass through with minimum reflection. Blumberg and Kanta (1985) applied Sommerfeld radiation OBC in finite difference method taking C equal to the local, flat-bottom, shallow-water, surface, gravity wave speed:

$$C = \sqrt{gh} \tag{5}$$

and adding an "*ad-hoc*" friction-like term $(\frac{-\phi}{T_f})$ on the right hand side of Equation 4, where T_f is a friction time scale. Elzeir and Hibino (1999) applied the Sommerfeld radiation OBC as formulated by Blumberg and Kanta (1985) in finite element method. Elzeir et al (2000) refined that application. In the current study, the final formulation of Elzeir et al (2000) was applied.

3. SIMULATION RESULTS:

Two domains were used. The first domain (Fig. 1.a) represented the current geometry of the canal, which included the Bitter Lakes. It was discretized into 5169 nodes and 8574 elements. The second domain (Fig. 1.b) represented a theoretical geometry of the Suez Canal where the Bitter Lakes were replaced by only a 300-meter navigation channel. It was discretized into 5156 nodes and 8538 elements. The following parameters were fixed for both simulations: A_l = 0.0 m2/s, e = lumping parameter = 0.0 for both continuity and momentum equations, n = 0.04, and T_f = 5.6 for water level and 5.8 for velocity at south Open Boundary (OB) and 5.0 for water level and 5.9 for velocity at north OB. Time step was chosen as 4 seconds. The forcing applied at the open boundaries was a 12-hour sinusoidal tide with 1.5-m range. Three runs were conducted. First, tide was applied only at Red Sea while the Mediterranean Sea OB was controlled by the Sommerfeld OBC. Second, tide was applied at the Mediterranean Sea while the Red Sea OB was controlled by the Sommerfeld OBC. Third, tide was applied at both open boundaries where the tide at the Mediterranean Sea lagged behind that at the Red Sea by $\frac{\pi}{4}$ (i.e. 3 hours). Simulation results revealed the following facts:

1) The Bitter Lakes prevent waves in one reach of the canal from propagating into the other reach. When the Bitter Lakes were replaced by only navigation channel waves propagate further into the canal (Fig. 2).
2) In the canal, water level field lags velocity field. The lag increases from the open sea towards inside the canal (Fig. 3-a). The lag increased when the Bitter Lakes were replaced by only navigation channel (Fig. 3-b).
3) Most important observation was that when the Bitter Lakes were replaced by navigation channel, water level range was reduced and velocity field range considerably increased (Fig. 4).

When a uniform bathymetry of 20 m was assumed for the whole canal domain, it was noticed that there was almost no effect on flow characteristics. A similar observation was noticed when the Bitter Lakes width was increased by one kilometer.

From the above results, it could be seen that existence of the Bitter Lakes reduces flow problems in the south reach of the canal where velocity field is reduced. Increase in water level range is not significant because tidal variation in water level is slow (gradual) and mean tidal ranges in the Red Sea (1.5 m measured at Port Tawfiq) and the Mediterranean Sea (0.8 m measured at Port Said) are relatively small compared to other international ports.

It is clear that surrounding the deep navigation channel by a shallow, wide water body improves navigational conditions in the canal. It was recommended that a set of shallow pools in the south reach of the canal be constructed around the navigation channel to reduce current velocity in that reach of the canal.

4. CONCLUSIONS:

The Bitter Lakes separate the Suez Canal into two independent reaches; the south and north reaches. The south reach is characterized by fast currents. In this study, a numerical model was used to investigate the effect of the Bitter Lakes on flow characteristics in the canal with special attention to the fast current in the south reach It was concluded that there is a time lag between velocity field and water level field with velocity leading water level. The lag increases as the wave propagates into the canal. Also, the lag increases when the Bitter Lakes are replaced by only navigation channel. The existence of the Bitter Lakes reduces the range of the velocity field and increases the range of the water level field. In other words, when the shallow, wide water body of the Bitter Lakes intercepts the navigation channel of the Suez Canal, navigational conditions improve. However, the effect of increasing the Lakes' width or depth is not significant Therefore, it was recommended to create a set of shallow pools intercepting the navigation channel in the south reach of the canal.

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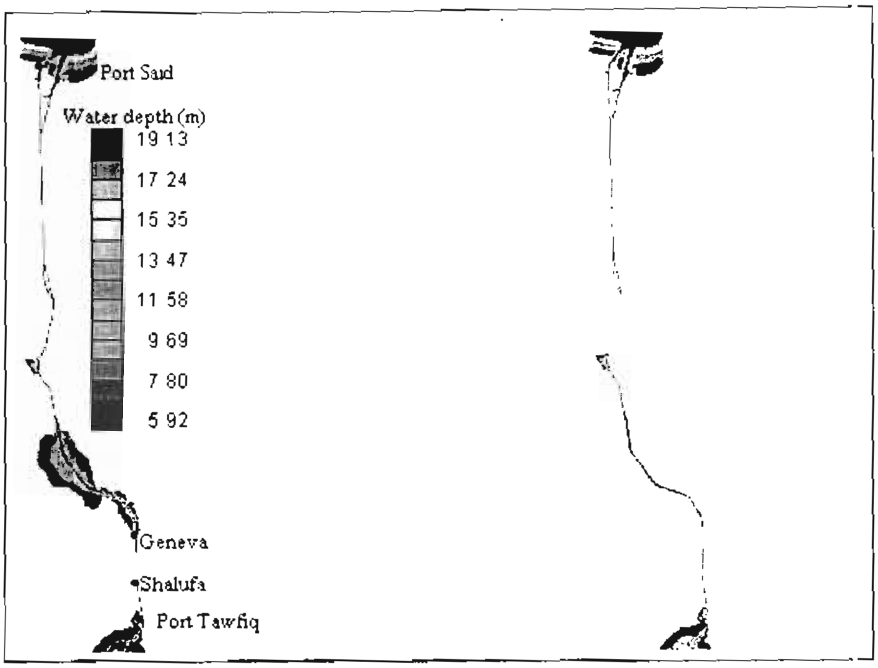
NOTATION:

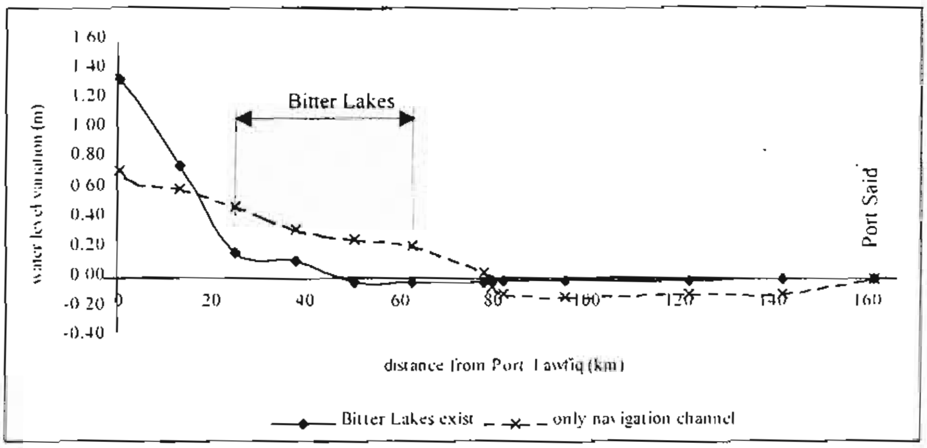
The following symbols are used in this paper:

A_l:	eddy viscosity
C:	phase speed (advection velocity)
e:	lumping parameter
f:	Coriolis force
g:	gravitational acceleration
h:	mean water depth
n:	Manning coefficient
OB:	Open Boundary
OBC:	Open Boundary Condition
T_f:	friction time scale
U:	mean horizontal velocity
φ:	variable to be defined at the open boundary
τ:	bottom friction
ζ:	water level variation around mean water level.

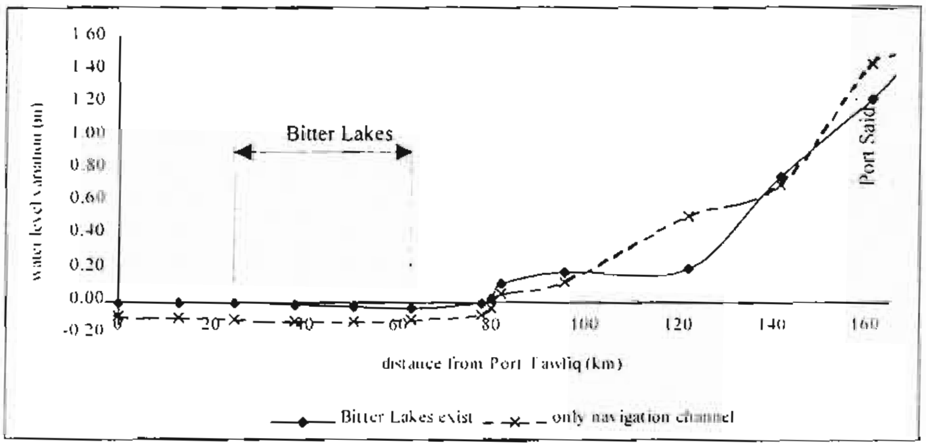


a) existing domain with Bitter Lakes b) theoretical domain with only navigation channel

Figure 1: Simulated domains of the Suez Canal

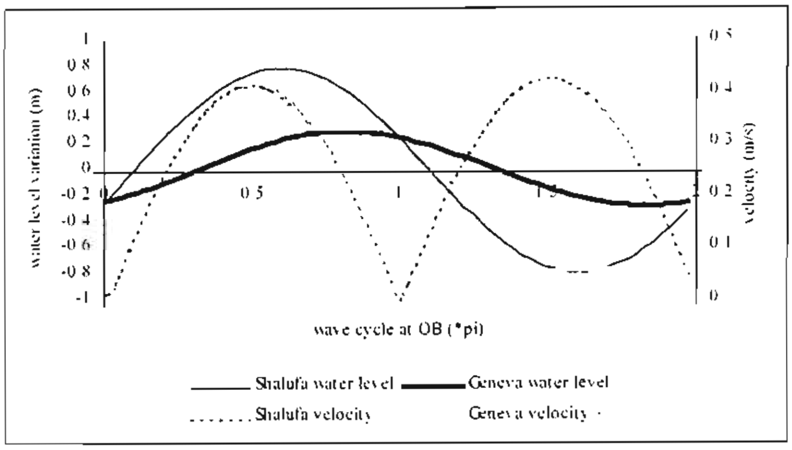


a) Tide is applied only at Red Sea

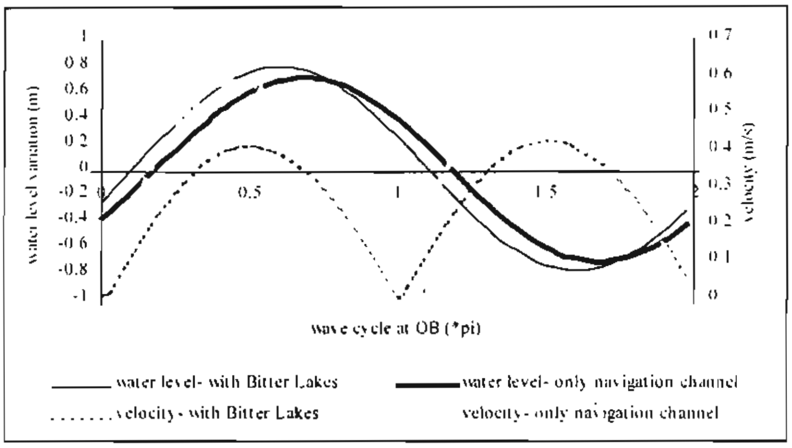


b) Tide is applied only at Mediterranean Sea

Figure 2: Water surface profile along the Suez Canal.

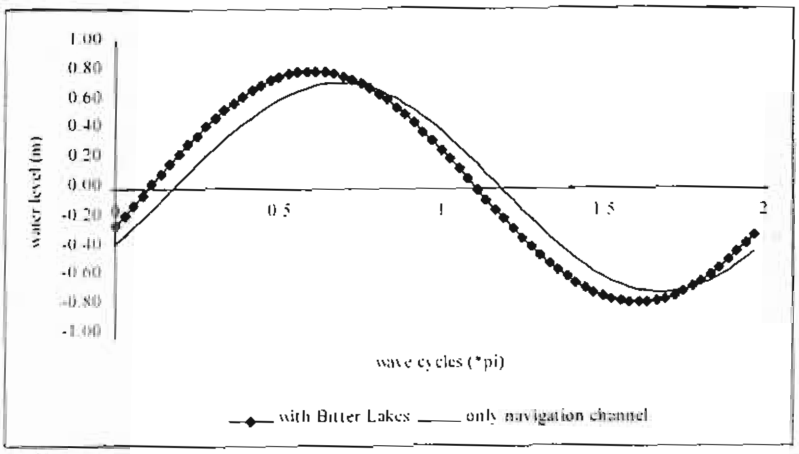


a) at two different locations along the canal

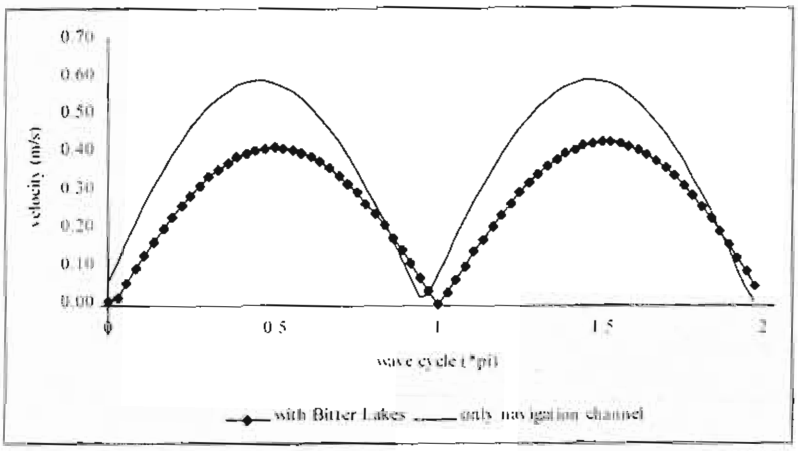


b) at the same location (Shalufa) for two different geometries

Figure 3: Lag between velocity field and water field in the Suez Canal.



a) Water level field



b) Velocity field

Figure 4: Effect of the Bitter Lakes on velocity and water level fields at Shalufa.