Research Article

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A two-dimensional finite element channel/lake flood model; case study of EDKO drain/lake, Egypt

Abstract

Floods have very devastating effects on human's lives and civil infrastructures such as houses, buildings, roads, bridges…etc. In order to safe guard against floods its necessary to have a tool to predict their extent and devastating effects. Numerical hydraulic models have the capabilities of being such tools. They provide ways of signaling areas which will be severely affected by floods in addition to investigating proposed solutions to flooding problems. The case of modeling of flooding at Edko lake/drain system in Egypt is a good example of successful prediction of flood effects in addition to finding the best solution to solve flooding problems.

A Finite Element numerical model called WAVES 2-D (WAter Velocity Elevation Simulation) is developed to simulate the current flow conditions in lake and channel systems such as Edko Lake and Drain system in Egypt and to find a solution to severe flooding problems that occurred. The model is two-dimensional (horizontal resolution) with a finite element mesh. A diffusive type approximation is used along with the finite element method for solving the non-linear parabolic flow governing differential equation.

After the model was successfully calibrated and verified, the worst-case scenario was run to highlight the nature of the flooding problem. In the worst-case scenario, the conditions that produce the highest possible water levels along Edko Drain and Lake were implemented. These conditions comprised of maximum tidal sea level and maximum pump station drainage flows to Edko drain. Then, different solution scenarios were tried for solving the flooding problems and these scenarios were compared and evaluated. Salinity levels of each solution scenario are assessed in order to assure sustainability of existing fish farms requirements.

Keywords: flood modeling, lake edko, flooding, salinity, environmental system, two dimensional numerical modeling, the finite element method

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Introduction

Floods have very devastating effects on human's lives and civil infrastructures such as houses, buildings, roads, bridges…etc. In order to safe guard against floods its necessary to have a tool to predict their extent and devastating effects. Numerical hydraulic models have the capabilities of being such tools. They provide ways of signaling areas which will be severely affected by floods in addition to investigating proposed solutions to flooding problems. The case of modeling of flooding at Edko lake/drain system in Egypt is a good example of successful prediction of flood effects in addition to finding the best solution to solve flooding problems.

The objective of this study is to develop a numerical hydraulic model that is capable of simulating flood effects and investigation mitigation solution and apply this model in investigating the causes of and solutions to the flooding problems at Edko lake and drain system in Egypt, Figure 1.[1] A constraint set forth by the drainage and fish authorities, is that any desired solution should not change the current salinity status to keep the existing fish species. For drainage of about 240,000 Feddans (one Feddan=1.038 acres) in the western delta area, the Edko drain was constructed some 50 years ago Kantoush et al.[2] to collect the drainage water from several drain collectors who, due to their low water levels, discharge their drainage water to Edko drain through pump stations at the confluences with Edko drain. Edko drain then discharges its water into lake Edko then to the Mediterranean Sea via a small channel called Maadia Bougaz thus comprising a unique aquatic environmental system. The drain has a length of 48.8Km starting south from Shubrakeet (km48.8) and ending north at the mouth of Maadia Bougaz (Km0.0) to the sea. The drain was designed to have a nearly trapezoidal cross section from km48.8 to 14Km. The design bed width ranges from 10m to 50.0 and side slope of about 2:1. The design bed level ranges from -1.0m to -5.0m negative means below sea levels). The banks are nearly stable except the reach from Km 14.0 to 17.5Km where random vents opened by the fishermen to allow more water from the drain into the lake. Significant sedimentation occurred in the drain causing significant rise in bed levels and consequent bank flooding, especially the lower left bank side. The reach from Km 14.0 to 8.0Km is called Magror-Edko; a submerged channel in the lake with only well defined right banks. The Magror's designed bed width is about 50.0m and designed bed level is about -5.0m. Sedimentation of Magror Edko has also occurred. The reach from Km8.0 to 1.2Km is Lake Edko that is a natural lake with average water depth between 0.8m to 1.2m and average bed level of -0.5m. The reach from Km1.2 to 0.0Km is Maadia Bougaz which is a channel of about 50.0m width with bed levels as deep as -6.32m. Tidal flow from the sea is significant in this part when the sea tidal-level is higher than the lake Edko level. Lake Edko Chloride (salinity) levels are low around, 1000gm/m^3, representing fresh water conditions with most fishes as trout species.

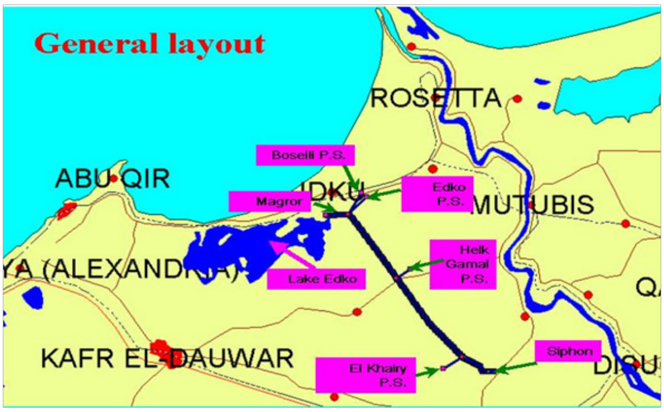

Figure 1 Layout of Edko Area; Edko Drain and lake (from HRI Report No. 115/2003).

Edko drain has six pumping stations that collect the drainage water and discharge it into the drain which then flows by gravity to the Magror submerged channel and lake Edko. In addition, there is a pumping station that takes water off the drain for irrigation called Edko irrigation pumping station which is located near the upstream part of Edko drain. On the southern boundary of lake Edko, there is Zarkoon pumping station that discharges its water directly to the lake. Table 1 shows the maximum flows from the six pump stations on Edko drain along with the permissible maximum water level at each station. If the water level in Edko drain is higher than this permissible water level the efficiency of the pumping station is greatly reduced to the point of forcing shutting down the pumping station.

During the winter season the seawater tidal levels are high and unfortunately this coincides with the period of maximum flows from the pump stations to Edko drain. The rise in the downstream boundary sea level reduces the flow from the lake to the sea with the consequent backwater effect along the lake up to the drain. Thus a significant rise occurs in water levels in Edko lake and drain. The rise in water levels in Edko-drain causes flow overtopping of the banks that inundates the surrounding agricultural lands. The rise also forces many pump stations to stop their flow causing further flooding problems to the areas served by these stations. It is required to find a solution to this flooding problem which does not affect the salinity of the lake.

A numerical model called WAVES 2-D (WAter Velocity Elevation Simulation) is constructed to simulate the current flow conditions in Edko lake and drain system. The model is two-dimensional (horizontal resolution) with a finite element mesh or grid. Due to the tidal variation in the water level at the sea boundary, water can flow from the sea to the lake or vice versa. Flow from the lake to the sea, or from the sea to the lake, is completely described by the model. In this way the sea-lake-channel interaction is fully considered. A diffusive type approximation is used along with the finite element method for the solving the system of governing differential equations which is reduced to one non-linear parabolic equation. After the model is calibrated and verified, the worst-case scenario is run to highlight the nature of the flooding problem. Then, different scenarios for solving the flooding problem are tried upon and the results are reported. In a previous study Kantoush et al.[2] Edko drain and lake system were modeled using a one-dimensional numerical-modeling approach which is difficult to describe this complex system. Costabbile et al.,[3] in the context of the closely related problem of 2D unsteady flows of surface runoff problems, indicate that the use of complete shallow water equations (full dynamic) introduces problems of instabilities and convergence due to the highly non-linear nature of the governing equations. Numerical problems exist due to small water depths over high slope, adverse slope and irregular topography which often associated with overland flows. The convective terms, after reducing the governing differential equation to system of algebraic equations at the nodes, induce unsymmetrical non-linear system of equations whose stability is less than symmetrical systems. For these reasons, the less complex, more stable and more economical diffusive models are widely used for flood modeling as in Leandro et al.[4] & Arico et al.[5]

Leandro et al.[4] presented a parallelized two-dimensional diffusive wave model (P-D Wave) with adaptive time step. The parallelization was achieved in the Matlab environment with the use of the parfor loop, and using computational vectorization whenever possible, while in Fortran it was achieved using OpenMP API. The model was validated in seven tests against known analytical solutions, and diffusive and dynamic models results. The model converged regardless of the spatial resolution as long as the selected minimum step was not too limiting (this limit is found to be case study dependent), and showed sensitivity to the changes of Manning's roughness in a sloped planar beach. Symmetry was kept in the test case of a horizontal plane, and the model was proven robust even in the presence of strong irregular geometries. The process devised to represent Wet-Dry fronts was effective in keeping a sharp front, while the variable time step kept the solution stable and oscillations-free in all tests.

Arico et al.[5] used novel coupling 1D-2D strategy which has been proposed in the shallow water models' framework. Governing equations are written in diffusive form and solved in the water level unknown. The procedure deals with both lateral and frontal 1D-2D domain connection. They claimed that previously proposed coupling approaches, developed from previous existing 1D and 2D models, require specific operations, depending on how each model perceives the coupling with the other one. These operations can lead to severe restriction of numerical stability and result accuracy. Their proposed approach does not require the solution of boundary equations nor an additional variable at 1D-2D interfaces. Computational cells in the 2D domain are the Voronoi polygons around each node, while standard 1D computational cells are the quadrilateral elements surrounding each section. Mixed cells include 1D computational cells and the Voronoi polygons of the 2D nodes located on the trace of the corresponding river section. In both the prediction and the correction steps, the same procedures are applied to solve computational cells, regardless if they are standard 2D, standard 1D or mixed cells.

The proposed approach presented in the next section treats the domain of the study in fully two dimensional fashion even the channel sections and thus does not require 1D-2D coupling. Moreover, the computations can be performed using usual desk top computers existing in the market without the need for computer processors parallelization.

Structure of the 2-D numerical model (WAVES 2-D)

The proposed WAVES 2-D numerical model is based on applying the conservation of mass and momentum concepts in two-dimensions. It describes sufficiently the movement of water in lakes and channels on a horizontal grid or mesh. This finite element computer model is developed by the author and written in FORTRAN 90 programming language. The finite element method is chosen for its high capabilities in handling complex geometries and ease in handling boundary

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conditions. The conservation of mass in two dimensions takes the following form

$$\frac{\partial h}{\partial t}+\frac{\partial(uh)}{\partial x}+\frac{\partial(vh)}{\partial y}=R-I-E=q \tag{1}$$

in which h is the local water depth, t is time, u and v are the depth-average velocities in the x and y coordinate directions respectively, R is the rainfall intensity, I is the infiltration rate and E is the evaporation rate and q is the net distributed input.

Assuming that the acceleration terms in the momentum equations can be neglected (or in other words that only gravitational, pressure and frictional forces are the dominant forces) the momentum equations can be reduced Di Giammarco et al.[6] to

$$S_{fx}=S_{ox}-\frac{\partial h}{\partial x}=-\frac{\partial H}{\partial x} \tag{2}$$

$$S_{fy}=S_{oy}-\frac{\partial h}{\partial y}=-\frac{\partial H}{\partial y} \tag{3}$$

where S_{fx} and S_{fy} are the frictional slopes in the x and y directions, respectively, S_{ox} and S_{oy} are the bed slopes in the x and y directions, respectively and H is the water surface elevation.

The u and v velocity components appearing in the continuity equation can be related to the corresponding water surface slope in the momentum equations by utilizing the two dimensional form of the Manning's equation[7] as

$$u=-\frac{\partial H}{\partial x}\frac{h^{2/3}}{n_x^2}\frac{1}{\sqrt[4]{\left(\frac{\partial H}{\partial x}\right)^2\frac{1}{n_x^4}+\left(\frac{\partial H}{\partial y}\right)^2\frac{1}{n_y^4}}} \tag{4}$$

$$v=-\frac{\partial H}{\partial y}\frac{h^{2/3}}{n_y^2}\frac{1}{\sqrt[4]{\left(\frac{\partial H}{\partial x}\right)^2\frac{1}{n_x^4}+\left(\frac{\partial H}{\partial y}\right)^2\frac{1}{n_y^4}}} \tag{5}$$

where n_x and n_y are the Manning's roughness coefficients in x and y directions, respectively.

Equations 4 and 5 are substituted in the continuity equation, Equation 1, yielding

$$\frac{\partial}{\partial x}\left[k_x\frac{\partial H}{\partial x}\right]+\frac{\partial}{\partial y}\left[k_y\frac{\partial H}{\partial y}\right]+q=\frac{\partial H}{\partial t} \tag{6}$$

And

$$k_x=\frac{1}{n_x^2}\frac{1}{\gamma(\nabla H)}h^{5/3}\ \&\ k_y=\frac{1}{n_y^2}\frac{1}{\gamma(\nabla H)}h^{5/3}\quad,\gamma(\nabla H)=\left[\left(\frac{\partial H}{\partial x}\right)^2\frac{1}{n_x^4}+\left(\frac{\partial H}{\partial y}\right)^2\frac{1}{n_y^4}\right]^{1/4} \tag{7}$$

Equation 6 has a parabolic type in which the water elevation,H, is the unknown function. It is non-linear as the coefficients K_x and K_y contain the unknown water elevation, H. The differential operator in Eq. 6 is symmetric which reduces its algebraic form to a symmetric system of algebraic equations. The resulting symmetry structure reduces significantly the computational running time and enhances the convergence characteristics of the equations in contrast to the full dynamic equations.

The Manning's roughness coefficients are also unknown, but their values are determined in the calibration process. The model initial condition is a prescribed water surface elevation along the lake and the drain. The model boundary conditions are a prescribed tidal sea water level specified along the sea boundary side nodes, prescribed flows from the pumping stations which are specified on portions of the boundaries at which there are pumping stations and a no-flow boundary condition applied to the rest of the boundaries (solid wall conditions).

Mesh construction

The mesh that represents Edko lake and drain is composed of quadrilateral four sided finite elements as shown in (Figure 2-4). Coordinates of the mesh loops were extracted from image photos and given in UTM coordinate system. The number of elements is 9,585 and the number of nodes is 10,755 nodes. The covered area of the lakes is 7250 Feddans while the drain area is about 250 Feddans giving a total study area of about 7500 Feddans (32,100,000m²). The lake's surface area is reported to reach between 5,000 and 11,000 Feddans but most of which are blocked by weeds and contribute very little to the storage capacity of the lake. Therefore, only the active storage area of about 7,250 Feddans is considered in this study, but adding additional area to the active area of the lake is considered in one of the solution scenarios as will be seen later. In this particular scenario the area of the lake reached 10,400 Feddans. The part of Edko drain that is included in the model starts from the Siphon at the intersection of Edko drain with El Mahmodia canal (38.8Km).

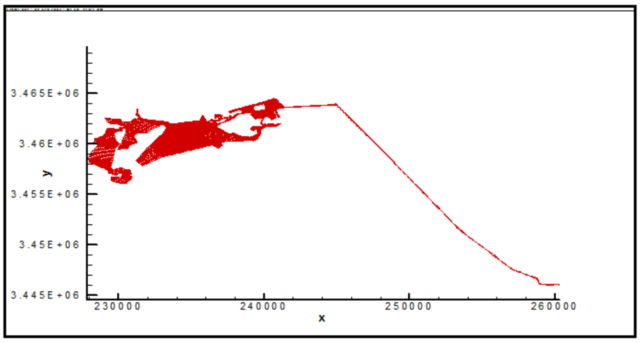

Figure 2 Finite Element mesh for Edko Lake and Drain.

Input data to waves numerical model

In May 17, 2003, data were collected by Hydraulics Research Institute (HRI), Coastal Research Institute (CRI) and Drainage Research Institute (DRI) for the flow and bed topography of the Edko lake-drain-Bougaz system.[1] Negative flow indicates flow is from the sea to the lake and positive flow indicates flow from the lake to the sea. Figure 5 shows the tidal water level in May 17, 2003 at Bougaz Maadia where the maximum water level reached 0.56m while the minimum water level reached 0.2m with a corresponding tidal range of 0.36m. It is noted in the figure that the tidal period is about 12 hrs.

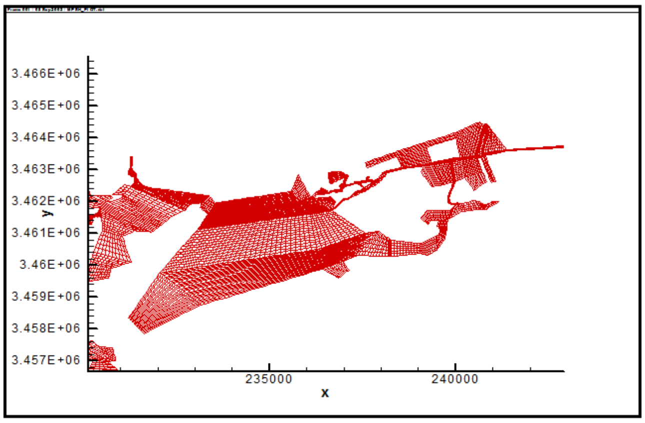

Figure 3 Finite Element Mesh for Lake Edko.

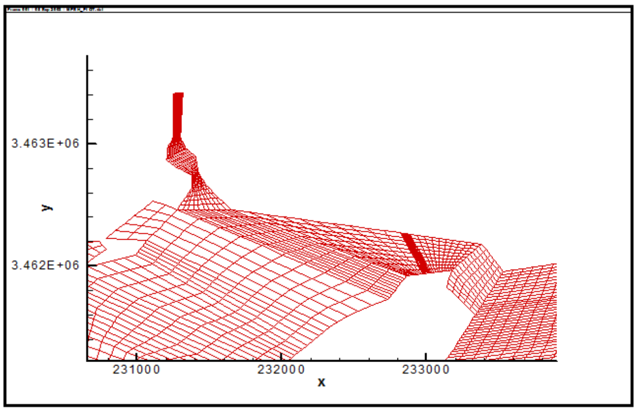

Figure 4 The Finite Element Mesh for the Sea Channel (Bougaz) and Lake Edko.

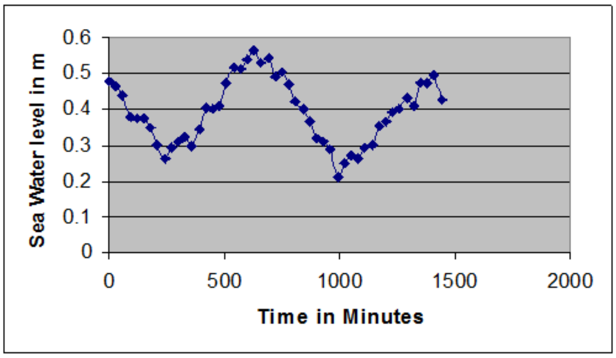

Figure 5 Sea Water level in May 17 2003 at Bougaz Maadia.

Figure 6 shows the net flow to Edko drain from all the pumping stations on the drain with exclusion of Barseek pumping station which discharges its water directly to Lake Edko. Figure 6 shows the maximum net flow in May 17, 2003 was about 50m^3/s while the minimum reached 30m^3/s.

The unsteady nature of the flows is clear in Figure 6 for the net flow in Edko Drain on May 17/2003. The data for the bed levels interpolated by the model from the existing measurements is displayed in Figure 7. The left bank levels along Edko drain and Magror are lower than the right bank levels. For example the left and right bank levels at Edko pumping station are 0.85m and 1.5m, respectively. Evaporation was taken as 5mm/day and seepage was neglected according to recommendations made by Drainage Institute's engineers.

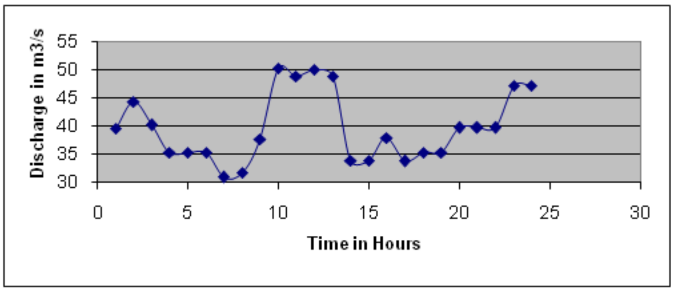

Figure 6 Sum of Pump Station Flows at Edko Drain, May 17 2003.

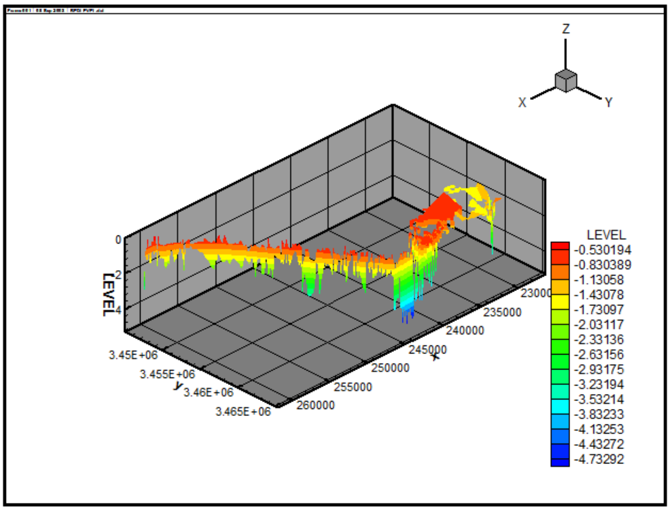

Figure 7 Model Interpolated Bed Levels for Edko Lake and Drain.

Calibration and validation of waves 2-d numerical model

Estimation of roughness is the major step in the calibration of hydrodynamic models. In the calibration of the Manning's roughness coefficients in the model, usually a known (from measurements) water surface profile corresponding to a known flow is given and the roughness coefficients are assumed until the model calculated water levels match reasonably well the measured ones. Unfortunately, data for water levels along Edko drain, lake and Bougaz were not collected on May 17 2003 the day for which the calibration run was implemented. However, use was made of the measured out/inflow at the Bougaz mouth where the model out/inflow predictions are compared with the measured ones. As seen from Table 2, the flow at time 11 hrs. (11 am) was directed from the sea to the lake reaching -45m^3/s while at time 16 hrs. (4 pm) the flow reached +67.5m^3/s from the lake to the sea. The sea flow transports sand which causes blockage of the Bougaz channel. In the nearby area of Rasheed Bougaz excessive sedimentation has been observed. This means that the Manning's roughness coefficient for the inflow in the Bougaz should be different from that for the outflow. Therefore, according to the calibration run, the roughness along the Bougaz channel was found to be 0.035 when the flow was from the

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lake to the sea while it was found to be 0.045 when the flow was from the sea to the lake. The latter value is associated with the assumption of existence of significant sand or sediment transport with dune bed forms (high roughness) when flow is from the sea to the lake. The Manning's roughness was found to be 0.02 for the lake area while it was found to be 0.03 for Edko drain. Due to lack of data, in all the model runs in this study the Manning's roughness coefficients were taken equal in both the x and y directions (i.e. $n_x = n_y$ =n). The lake initial water level was taken as 0.3m in accordance with data from Berseek pumping station. The sea levels were taken from the recorded data seen in Figure 5 and the inflows to Edko drain from the pumping stations data as from Figure 6. The model time step was 60 minutes (1 hour) and when using smaller time step of 10 minutes the results were nearly the same. The iterations needed due to the non-linear nature of the governing equation were stopped when the difference in water levels between two consecutive iterations reached 0.1mm.

Figure 8 and Table 2 show the model predictions and measured data for the flow at Edko Bougaz, the model outlet boundary. It is at this location that the model computed results are expected to be at maximum. It can be seen that the model predictions match very well the recorded data indicating the success in model calibration and in the simulation of the flow reversal from that at hour 11 to that at hour 16. The successful prediction of the flow reversal could be considered as the model validation step.

Table 1 Flows and Maximum Water Levels for the Pumping Stations on Edko Drain

Pump station	No. of working pumping units	Flow per unit(m^3/s)	Total flow(m^3/s)	Maximum allowable water level (m)	Area served(Feddan)
Shubrakeet	3	6.0	18.0	1.80	25,000
Zarkoon	3	5.0	15.0	1.60	41,000
El Khairy	3	6.0	18.0	1.50	75,000
Halk El Gamal	4	5.0	20.0	1.10	56,100
Edko Drainage	2	3.5	7.0	0.80	18,000
Boseili	2	7.5	15.0	1.45	25,000
Total			93.0		240,000

Table 2 Computed and Measured flows at the Outlet Boundary, Edko Bougaz, in May 17 2003

Time in hours	Run mode	Measured flows(m^3/s)	Model computed predictions(m^3/s)
11 (11 a.m.)	Calibration	-45.0	-46.8
16 (4 p.m.)	Validation	+67.5	+66.4

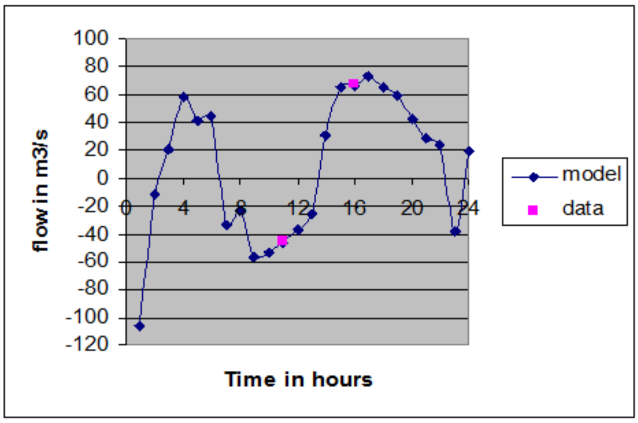

Figure 8 Model Flow Predictions at Edko Bougaz in May 17 2003.

Figures 9 & 10 confirm the success of the developed model in predicting the velocity field across the width of the Bougaz end section in both cases of inflow to and outflow from Lake Edko. The flow discharges in Table 2 were obtained through integrating the velocities in Figure 9 & 10 across the Bougaz channel width.

In order to gain insight into the water quality or environmental aspects in Lake Edko, a quality balance model was applied to the lake. Chloride was selected as the indicative parameter representing the salinity status of the lake. Chloride concentrations were measured by the Drainage Research Institute at the pumping stations and Bougaz sea side during April 1 2003. However, these concentrations were assumed as those to the May 17 2003 run. Figure 11 shows the Chloride concentration averaged over the lake reaching about 1000gm/m^3. The Central Laboratory for Environmental Quality Monitoring performed quality measurements in Lake Edko on May 5 2003. These measurements show Chloride concentration ranges between 500gm/m^3 to 1040gm/m^3. In the Bougaz the measured Chloride concentration reached 7799gm/m^3 while that near the sea had a concentration of 11,911gm/m^3. In light of insufficient data for running and calibrating the model, the results of Figure 11 can be considered acceptable. A two-dimensional quality modeling to yield 2D quality concentrations might not be needed and only a comparative analysis of the average concentrations between the different scenarios seems to be sufficient.

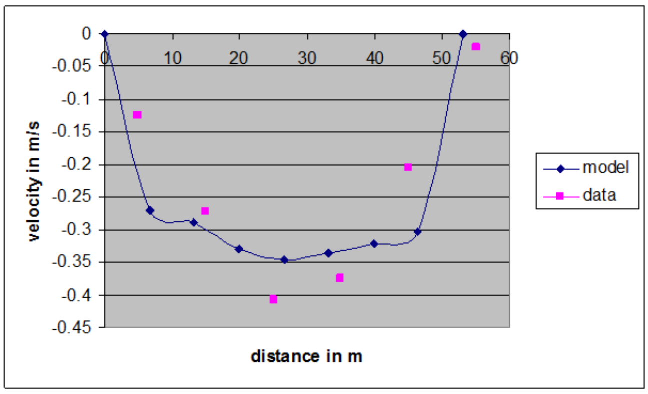

Figure 9 Velocities across the Width of the Bougaz Section at 11.0 a.m. 5/17/2003.

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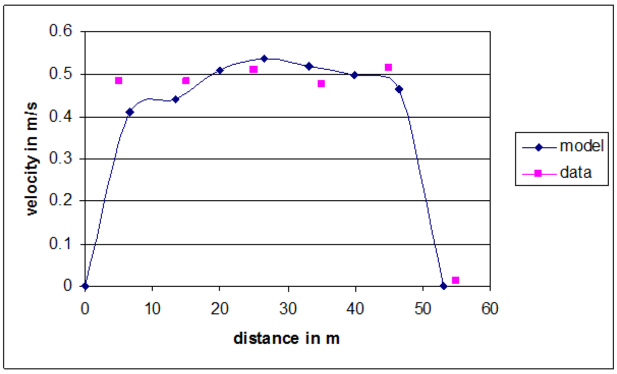

Figure 10 Velocities across the Width of the Bougaz Section at 4 p.m. 5/17/2003.

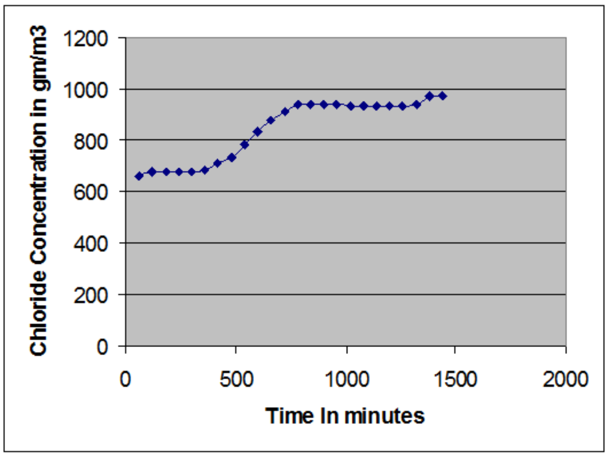

Figure 11 Chloride Concentration in Lake Edko, May 17 2003.

Flooding problems in edko drain (critical case, run cc):

In the foregoing section it was stated that the pumping stations flows to Edko drain in May 17 2003 amounted to a maximum of 50.0m^3/s. As seen from Table 1, the May 17th flows are below the maximum winter flows (93m^3/s) expected by the pump stations. Therefore, the flows from Table 1 will be taken as the critical flows for which severe flooding conditions are expected. This is in accordance with the field observation that flooding of Edko drain occurs when the pump stations flows reach the values in Table 1. In addition, it is expected that flooding conditions in Edko drain are likely to occur when the lake's water level is relatively high which reduces the water surface slope or the energy gradient between the Edko drain and Lake Edko. Therefore, to produce severe flooding conditions Lake Edko initial water level is taken as 0.55m. In addition, the highest possible sea water levels reduce the energy gradient that drives the drainage water from Lake Edko and drain to the seaside through the Bougaz.

The highest sea water level recorded between May 2002 and May 2003 is 0.668m. The shape of the sea tidal levels in a typical day is similar to that in May 17 2003. The sea level profile in May 17 is raised by an amount of 0.3m that results in maximum sea level of 0.86m. Therefore a maximum sea level of 0.86m seems sufficient. Figure 12 shows the resulting water levels at selected stations where the model is run in the first day using the same data of May 17 2003 except of an initial lake water level of 0.55m, then in the second day the sea water levels were raised by 0.3m and the pumping station flows were taken as maximum as in Table 1.

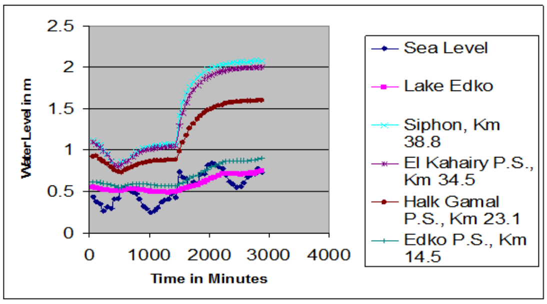

Figure 12 Water Levels for the Critical Flooding Conditions at Edko Drain and Lake, Run CC.

Figure 12 shows that starting from the second day (at time=1440min) the rise in sea water levels and pumping stations flows causes Lake Edko water level to jump from 0.5m to a near steady value of 0.75m. Unfortunately, there is no existing data about the shoreline levels of Lake Edko to check against this rise in water level. With an average bed level in Lake Edko of -0.5m, the water depth corresponding to lake's water level of 0.75m amounts to 1.25m. The increase in water levels for the rest of the selected stations in Figure 12 is due to the rise in the lake's level and the Edko drain inability to pass the increased pumping stations flows. It is clear that according to Table 4 and Figure 12 that all the levels are violated at the pumping stations locations and therefore a solution is needed to lower the water levels in Edko drain and Edko lake. Figure 13 shows that the left bank will be overtopped especially in the upstream sections (nearly the first half of the drain).

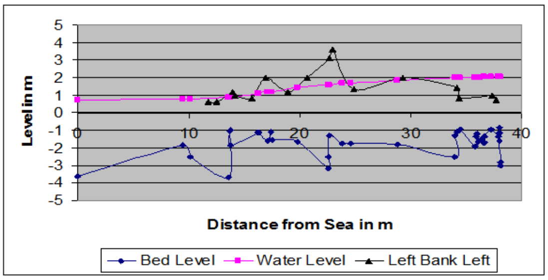

Figure 13 Water Surface Profile along Edko Drain and Edko Magror, Run CC.

The Chloride concentration shown in Figure 14 indicates that little changes (about 200gm/m^3) occurred in the lake's average Cl concentration as compared to that in May 17 2003 and still away from being affected by the sea salinity (Chloride) level.

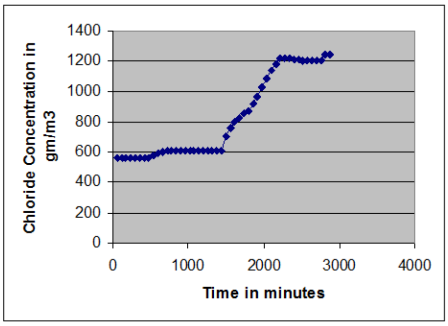

Figure 14 Chloride Concentrations for Run CC.

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Thus, the model succeeded in simulating the existed flooding problems at Edko Lake/Drain due to the management practices of this complex water resource system. This establishes the floor for using the model as a valuable tool to test planning solution scenarios as in the following.

7- Solution scenarios to flooding of edko lake and drain and salinity levels

The problem of flooding of Edko Lake and drain is solved herein using mainly two methods which are dredging and flow withdrawal via adding new pump stations. Dredging of Edko Magror and/or drain helps in lowering the bed levels and increasing the water depth; thus increases the drain carrying capacity and its hydraulic transporting efficiency. Adding new pump stations on the drain, Magror or the lake helps in lowering the water levels and increasing the outflow carrying capacity and thus reducing the retention time of water in the lake, i.e. speeding the drainage of the lake. A combination of the two methods might be the best solution and there seems that a number of possible combinations should be considered. These combinations or scenarios are shown in this section with the objective is that the best one is the one which reduces the water levels to the required ones, being least expensive and causing minimal environmental negative effects in terms of least change in Chloride (salinity) levels.

In all of the scenarios, WAVES numerical model will be run for three days. In the first day, normal conditions existing with Lake Edko initial level of 0.55m, typical pump flows as the data of May 17 2003 and with the existing bed levels of the Bougaz, Lake, Magror and drain. This is done to give the model enough time to run in unsteady mode. The water levels are expected to be at normal conditions. In the second day, the model is run for the critical case conditions outlined in Sec. 6 where the sea water levels are raised by 0.3m and pump station flows on Edko drain are increased to 93m3/s in addition to Barseek pump station being as that of May 17 2003 and no withdrawal from Edko irrigation pump station. These conditions produce maximum inflows to the lake from the pump stations. The water levels are expected to jump to the critical water levels causing flooding of Edko drain and lake. In the third day, the suggested or planned solution as defined by the scenario is implemented in the form of either dredging works or adding extra pump station or the combination of the two. The water levels are expected to be lowered than the critical case and might reach the desired conditions depending on the efficiency of the scenario.

Table 3 shows that the Chloride concentration will be changed from one scenario to another and almost doubling the Cl concentration occurred in Scenario 3. However, the lake's average concentration will be far from that at the Seaside indicating fresh water lake condition. Table 4 shows the results of implementing seven scenarios using WAVES numerical model where more details are found in.[1] It is seen from Table 4 that scenarios 5.1 and 7 are the most successful in terms of producing the least water levels in Edko drain below the maximum permissible water levels for pump operation.

Table 3 Average Chloride Concentrations in Lake Edko

Run type	Chloride concentration (gm/m^3)
Calibration Run	974
Critical Case, Run CC	1240
Scenarios 1 & 7	1297
Scenario 2	1611
Scenario 3	1706
Scenario 4	1191
Scenario 5.1	1321
Scenario 5.2	1333
Scenarios 6	1258

Table 4 Summary of the Resulting Water Levels (W.L.) after implementing the Solution Scenarios

Station	W.L. before scenarios, Run CC (m)	W.L. after scenario 1 (m)	W.L. after scenario 2 (m)	W.L. after scenario 3 (m)	W.L. after scenario 4 (m)	W.L. after scenario 5.1 (m)	W.L. after scenario 5.2 (m)	W.L. after scenario 6 (m)	W.L. after scenario 7 (m)	Allowable water level (m)
At Siphon	2.074	1.348	2.072	2.03	2.068	1.30	1.87	1.298	1.30	No Data
At El Khairy	1.997	1.246	1.994	1.95	1.99	1.19	1.67	1.188	1.19	1.50
At Halk ElGamal	1.599	1.005	1.590	1.52	1.59	0.94	1.14	0.932	0.934	1.10
At Edko P.S.	0.897	0.870	0.851	0.63	0.87	0.80	0.824	0.813	0.792	0.80
Lake Edko	0.752	0.805	0.691	0.67	0.72	0.77	0.77	0.803	0.719	No Data

W.L. is the water level.

Scenario 1, Dredging of Edko Magror and Drain (start level of -4.0m at Km 10).

Scenario 2, Installing Pumping Station Near Maadia Bougaz (100m^3/s).

Scenario 3, Installing Pumping Station at El Boseili (100m^3/s).

Scenario 4, Adding an Additional Area of 3000 Feddans to Lake Edko.

Scenario 5.1, Dredging Edko Magror and Drain (-4.0m start level at Km 10) and adding P.S. at El Boseili (25m^3/s).

Scenario 5.2, Dredging Edko Magror and Drain (-3.0m start level at Km 10) and adding P.S. at El Boseili (25m^3/s).

Scenario 6, Dredging of Edko Magror and Drain (start level of –4.0m at Km 10) and adding P.S. at Zamzam (50m^3/s).

Scenario 7, Dredging Edko Magror and Drain (-4.0m start level at Km 10) and dredging Bougaz with start level of -2.0 m and slope 0.002.

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Conclusion and recommendations

The developed two-dimensional hydrodynamic finite element numerical-model WAVES (WAter Velocity Elevation Simulation) proved to be a successful tool for flood modeling and investigation of solution/mitigation methods. It succeeded in simulating the hydrodynamics of Edko drain, Magror, lake and Bougaz system. In particular, flow from the sea to Edko Lake and vice versa were successfully predicted. The finite element mesh was able to capture the high irregular shape of the lake and channel systems in two dimensions.

Table 4 shows summary of the water levels resulting from implementing the different scenarios. From the Table, it is apparent that Scenarios 5.1 and 7 are the best scenarios that meet the allowable water level criteria for pump stations operation. Both scenarios include dredging the drain channel to improve its transport capacity and adding emergency pumping stations to divert excess flows to non-populated areas. No significant change in salinity levels occurred due to any of the solution scenarios and thus the lake quality and fish types are not likely to change.

It is recommended to investigate which scenario gives the best overall satisfaction as to the prevention of flooding, assuring operating of all the pump stations all the time, giving enough water depth in lake Edko for fishing and navigation and being most economical and efficient. Scenario 5.1 consists of implementing dredging works in the drain channel in addition to adding a pump station with capacity of $25m^3/s$ on the eastern side. The water withdrawn by this pump station with discharge of $25m^3/s$ could be diverted directly to the sea via a drainage channel or used in irrigating new farm lands in the area. It is recommended also to do left bank protection works in Edko drain and Magror and cleaning the weeds in Lake Edko. Dredging and cleaning of the Bougaz channel as in Scenario 7 is also helping in improving the drainage characteristics of the system.

Urgent need arises to improve the existing data collection program for Lake Edko and Edko drain. For example, surveying of Lake Edko bed levels, establishing water level gauges along Edko Drain and Magror, Bougaz and lake Edko, establishing flow measurement stations along Edko drain, Magror and Bougaz, measuring sediment transport along Edko drain and Bougaz El Maadia and more water quality data collection are required. After getting the necessary data in point (2) above, it will be possible to investigate in more depth pollution and water quality in lake Edko system and sediment deposition in the lake and drain system. The WAVES model is useful for studying other lakes, open channels and rivers in two-dimensional investigations.

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Conflict of interest

The author declares no conflict of interest.

References

1. Hafez YI. *Solving Flooding and Drainage Problems in Edko Drain and Lake System*. Egypt: The Hydraulics Research Institute Internal Report; 2003. 108 p.
2. Kantoush SA, Nagy HM, Watanabe K. *Evaluation of the Drainage Management by Hydraulic Modeling in the Coastal Area of Egypt*. Proceedings, XXX IAHR Congress, Thessaloniki, Greece; 2003.
3. Costabile P, Macchione F, Mercogliano P. Two-Dimensional model for overland flow simulations: A case study. *European Water*. 2012;38:12–23.
4. Leandro J, Chen AS, Schumann A. A 2D Parallel Diffusive Wave Model for floodplain inundation with variable time step (P-DWave). *Journal of Hydrology*. 2014;517:250–259.
5. Arico C, Filianoti P, Sinagra M, et al. The Flo Diffusive 1D-2D Model for Simulation of River Flooding. *Water*. 2016;8(5):200.
6. Di Giammarco P, Todini E, Consuegra D, et al. *Combining a 2-D flood plain model with GIS for flood delineation and damage assessment*. Proc of the Specialty Conf ENEL-DSR-CRIS, In: Molinaro P, Natale L, editors. USA: ASCE; 1994. p. 171–185.
7. Todini E, Zamboni L. A Control Volume Finite Element approach to flood plain inundation modeling. *Hard Copy from Personal Communication*. 2002;40:13.