Proceedings of ICFDP9:
Ninth International Congress of Fluid Dynamics & Propulsion
December 18-21, 2008, Alexandria, Egypt

ICFDP9-EG-279

COMPUTATIONAL MODELS FOR ANALYZING SCOURING PROBLEMS AT NILE RIVER

Magid M. Elfiky
Professor of hydraulics, Water. & W. Str., Engineering Dept.,
Faculty of Eng., Zagazig University, Zagazig, Egypt
e-mail: m_elfiky1@yahoo.com

Abdelazim M. Negm
Professor of hydraulics, Water. & W. Str., Engineering Dept.,
Faculty of Eng., Zagazig University, Zagazig, Egypt
e-mail: amnegm85@yahoo.com

Talaat M. Owais
Professor of Hydraulics, Water. & W. Str., Engineering Dept.,
Faculty of Eng., Zagazig University, Zagazig, Egypt

Mohamed A. Nassar
Assistant Professor, Water. & W. Str., Engineering Dept.,
Faculty of Eng., Zagazig University, Zagazig, Egypt
e-mail: nasserzagazig@yahoo.com

ABSTRACT

A computational model was used to estimate and analyze scouring problems at the Nile River. A partial failure of the upper slab of the lock guide pier upstream of the new Esmaeilia canal intake was observed. Therefore, the reach upstream of the new Esmaelilia canal 920 m long on the Nile River in front of Esmaeilia canal intake is considered in this paper. The hydrodynamic process has been calculated using a 2-D hydrodynamic model (HYD-2), which simulates the flow behavior in rivers. The sediment transport in the reach was simulated using a 2-D sediment transport model which has the capability of predicting the locations of scouring and silting along the considered reach. The use of the models was illustrated through the use of two alternatives solution to the problem.

KEYWORDS:

Numerical model, scour, Nile River, Hydroinformatics.

INTRODUCTION

The sediment transport in rivers is an important issue especially in practical applications. Many numerical models were developed to solve the related problems. Guo et al., [7] developed a 1-D mathematical model to simulate long-term and long-distance sediment transport and channel bed variation for both ordinary and hyper-concentrated flows.

Wu et al., [9] established a 1D finite-volume model to simulate the non-equilibrium transport of non-uniform sediment with transient flows, such as dam-break flow and overtopping flow, over movable beds. The effects of sediment transport and bed change on the flow were considered in the flow continuity and momentum equations.

Ouillon et al., [7] described a mathematical model for simulation suspended sediment transport under equilibrium and non-equilibrium situations. The Schmidt number variability was studied for several particle types. Some 2D vertical test cases for equilibrium situations or non-equilibrium situations with net erosion or net deposition flux to the bed were presented, and the predicted development of the concentration profiles was compared with measurements.

Greimann1 et al., [1] used the vertical and horizontal momentum equations for sediment to obtain the concentration and velocity profiles of a dilute suspension of particles in a 2D uniform flow. No empirical coefficients in the model were tuned to match individual experiments, for which the experimental data cover a large range of particle sizes and densities. The models were shown to accurately predict two experimentally observed but theoretically unexplained phenomena: the increased diffusive flux of large particles, and the measurable velocity lag of particles.

Zeng et al., [2] discussed the validation and application of a model to solve for the flow, the sediment transport, and bed morphology changes in open channels. The non-hydrostatic model solved the three-dimensional (3D) incompressible, Reynolds-Averaged Navier-Stokes (RANS) equations in generalized curvilinear coordinates. The model used adaptive grids in the vertical direction needed to account for changes in the free surface elevation and bed levels due to erosion/deposition at the bed as the code converges toward steady state (equilibrium conditions). The model was used to predict flow and sediment transport through straight and curved open channels.

The construction of water storage, conservation and control works for stream flow and water level regulation was mostly unavoidable to satisfy the interests of land irrigation and drainage, hydropower development, inland navigation and other purposes. Such works, which were often referred to man-made works, eventually lead to environmental changes. Of these works, the High Aswan Dam was one that played, and probably still plays a major role for causing such environmental changes. Sedimentation and degradation, e.g., were considered the more dangerous phenomena resulted as side effects of constructing the High Aswan Dam.

The sediments transported by the Nile River were made up of bed and suspended loads. The investigations carried out in the pre-High Aswan Darn period had shown that the bed load transport was only 1.0 to 2.0 % of the total transport of the river, Shahin [6]. It accordingly became customary to consider the total sediment load equal to the suspended load. The Nile River brings about 98 % of the annual sediments during the flood season (August-November). The observed sediment concentration varies from 100 to 5800 ppm corresponding to discharges of 200 to 1000 mm^3/day. The average annual volume of sediments reaching Aswan amounts to about 60 Mm^3, weighting about 125 M metric tons, Shahin [6]. When the flood reaches Nasser Lake, the velocity of water drops from approximately 1.0 m/sec to about 0.02 m/sec. This leads to the deposition of about 98 % of the suspended matter in the lake. The average weight of sediments passing downstream of Aswan in the post-dam condition was about 2.5 M metric tons compared with 125 M metric tons in the pre-dam condition, Shahin [6]. Such sediment free flow had the ability to convey sediment from either the river bed and/or banks, causing as a result bed degradation and bank erosion. In general, when the equilibrium of a stable river system was disturbed, degradation and aggradation may occur in its branches.

DESCRIPTION OF THE PROBLEM

The old intake of Esmaeilia canal, located 10.80km D/S of Roda staff gauge. Investigating the bed topography from 1982 to 1991, it can be reported that the canal intake lays on the Right Bank 500m upstream a sharp curved river reach of an angle about 37o. The average riverbed level beside the Right Bank. (Outer side curve) is lowered from (10.00) on 1982 to less than (8.00) on 1991 while beside the left bank; it was (13.50) on 1982 raised to (14.25) on 1991. The submerged island created before 1982 with dimensions 450m x 100 m and level of (14.95) has risen on 1991 to level (16.50) and dimensions 975m x 155m, advancing towards upstream direction. The old intake of Esmaeilia canal consists of a regulator of 3 vents each of them 6.0m width with 2 piers each of 2.0m width and a 80m x 12m lock with a guide pier of 4.0m width. The area served by Esmaeilia canal has been increased due to the land reclamation processes followed in the sixty and seventy decades, therefore the old intake could not satisfy the required flow capacity. So, it has been decided to construct a new intake, which had been built beside the old one in the period from 1976 to 1981. The new intake consists of a regulator of 4 vents each of 8.0m width with 3 piers each of 2.5m width and a 1 16m x I 7m lock with a guide pier of 4.5m width. The old intake was completely closed and the new one was operated. The old and new intakes of the Esmaeilia canal were constructed directly on the Right Bank of the River Nile without a guide canal reach. Description of the site can be introduced as shown in Fig. (1). The bed topography of studied reach at 1991 and overall details of site have been introduced.

On the other side, On August 1992, it has been noticed a partial failure of the upper slab of the lock guide pier U/S of the new canal intake. The sand filling the sheet piling has been escaped. The bed topography survey U/S the canal intake indicated that the normal bed level was (8.25) but a deep local area, pyara, of level (3.50) has been formed just beside the guide pier while the sheet piling base level was (3.30). So, it has ordered to close the new intake and reuse the old one again. Studying the problem, it has found that the changes of the river morphology were behind the failure due to the magnification of the island size and its advancing in the upstream direction. In addition to increasing of the Esmaeilia canal discharge and lying its intake directly upstream a sharp curved reach on the outer side curve, the river flow was concentrated beside the river right bank creating dangerous eddies and extensive secondary currents upstream the canal intake. The present paper concerned with studying the problem. In addition, the best proposal will be selected from a set of alternative proposals. Each alternative is evaluated from both hydrodynamics and sediment transport points of view. Hydrological data were collected about maximum and minimum discharges through Nile River. The collected data are as follows in table (1).

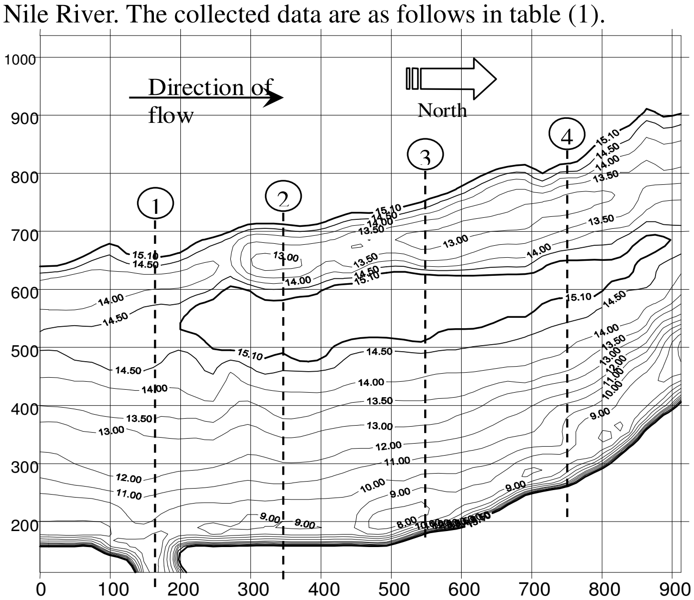

Figure 1: Bed topography at studied reach (1991)

Table 1: The hydrological collected data

The collected data	flood case	winter closure case
Total discharge	160 M m^3/day	65 M m^3/day
East branch discharge	120 M m^3/day	50 M m^3/day
West branch discharge	40 M m^3/day	15 M m^3/day
Water level + MSL	(16.92)	(15.12)
Water slope for Nile River in this reach is assumed to be equals about 4 cm/km		

APPLIED MODELS

The 2-D hydrodynamic model (HYD-2) developed by Elfiky et al. [3] was used for simulating the flow field, it was based on the solution of the Reynolds form of Navier-Stokes equations for turbulent flow. The governing equations of (HYD-2) used for simulating the flow field are the momentum equations in x and y directions in addition to the continuity equation, reading as:

$$\frac{\partial \bar{u}}{\partial t}+\bar{u}\frac{\partial \bar{u}}{\partial x}+\bar{v}\frac{\partial \bar{u}}{\partial y}+g\frac{\partial z_s}{\partial x}+\frac{\tau_{bx}}{\rho h}-\frac{\sum F_x}{\rho h}-\varepsilon_{fx}\nabla^2\bar{u}=0 \qquad (1)$$

$$\frac{\partial \bar{u}}{\partial t}+\bar{u}\frac{\partial \bar{u}}{\partial x}+\bar{v}\frac{\partial \bar{u}}{\partial y}+g\frac{\partial z_s}{\partial y}+\frac{\tau_{by}}{\rho h}-\frac{\sum F_y}{\rho h}-\varepsilon_{fy}\nabla^2\bar{v}=0 \qquad (2)$$

$$\frac{\partial h}{\partial t}+\frac{\partial h\bar{u}}{\partial x}+\frac{\partial h\bar{u}}{\partial y}=0 \qquad (3)$$

The sediment behavior has been simulated using the 2-D sediment transport model (SED-2) that was developed by Elfiky et al. [4,5], which simulates the sediment transport behavior in rivers. The movement of the suspended sediment in alluvial streams can be governed by the mass balance equation of sediment. Integrating the 3-D convection-diffusion equation of the suspended sediment in vertical direction, yielding

$$\frac{\partial h\bar{c}}{\partial t}+\frac{\partial h\overline{uc}}{\partial x}+\frac{\partial h\overline{vc}}{\partial y}-\varepsilon_{sx}\frac{\partial}{\partial x}h\frac{\partial \bar{c}}{\partial x}-\varepsilon_{sy}\frac{\partial}{\partial y}h\frac{\partial \bar{c}}{\partial y}+\alpha\, w_s\,(\bar{c}-c_*)=0 \qquad (4)$$

in which $\bar{u}$ and $\bar{v}$ are the depth-averaged velocity components in x and y directions, respectively, g is the gravitational acceleration, z_s is the elevation of water surface above reference plane, h is the flow depth, ρ is the water density, τ_b is the bottom shear stress, F is the external deriving force, ε_f is the horizontal fluid diffusion coefficient, c is the depth averaged sediment concentration, c_* is the sediment carrying capacity, ε_s is sediment horizontal diffusion coefficient, α is the ratio of sediment concentration near the bed to the averaged concentration.

PROPOSED SOLUTIONS

The optimal scientific solution for the problem has depended on the investigation of the problem reasons. In addition, it has investigated the problem effects on the Nile River morphology and the necessary steps for the problem elimination. Proper solutions may be suggested and easily studied for the present problem to define the optimum proposal.

FIRST PROPOSAL

The first proposal has suggested the island erasing up to level (13.50). In addition, the proposal has given a new developing of the western bank. It is necessary to keep the cross-section area of river in same limits. It should fill an area in studied reach at the western bank. The purpose of filling at the western bank is reducing the cross-section area of the reach by the value, which has been increased after the island removing.

SECOND PROPOSAL

The second proposal has suggested the island erasing up to level (13.50). Also, it is required a new smoothing to the western bank. It is similar to first proposal in the technique, which was discussed. But main differences between the first and the second proposals are listed as: The period, which has been required for the island reforming, Efficiency of each one to reduce the scour rate in front of Esmaeilia canal intake, Efficiency of discharge distribution of each one, and The maximization of benefits from developing Elwarake island waterfront.

INVESTIGATION FOR BASE CASE (1991)

The hydrographic survey was done for the studied reach, which is 920m long on the Nile River in front of the intake of Esmaeilia canal, as shown in Fig. (1). The considered river reach has been schematized in a uniform rectangular mesh with Δx = 12.5m and Δy =12.5m. The reach was investigated at first, using the 2-D hydrodynamic model (HYD-2) for two flow cases; case of minimum passing discharge and the flood case. The water slope was adjusted to be about 4.2 cm/km for the first case while it was 4.0 cm/km for the second one. Moreover, a variation in the bed levels, within 0.01m may be taken place, to simulate the velocities in the field. Velocities in lateral and longitudinal directions and discharge distribution were investigated. It was very important to satisfy the hydrodynamic model calibration before using its velocity computations in the developed model solving the convection-diffusion equation in two dimensions. Now, the studied reach should be investigated with the help of the developed model SED-2 in addition to the HYD-2 model outputs.

Figure (2) and Fig. (3) has showed the discharge distribution and the discharge distribution percentage in the studied reach, respectively. It is clear that, island divides the flow into two parts. The first part passes through the western branch. It is nearly about 7% of the total discharge, which passes through river. The second part passes through the eastern branch. It is nearly about 68% of the total discharge, but nearly 25% of the total discharge passes through Esmaeilia canal. Figure (4) has showed the distribution of the average longitudinal velocity in x-direction. It is clear; the average velocity of the flow near the eastern bank is about 0.4 m/sec. But, it is value near the western bank is about 0.2 m/sec.

Figure (5) has showed the scour and the silting zones in the studied reach. The positive values mean a silting process but the negative values mean a scour process. The locations of the silting are U/S the island only. Also, it can be noticed that, the scour zones areas should be increased in the eastern side of reach and also, it is concentrated U/S the canal intake.

The 2-D sediment transport model (SED-2) has generated new bed topography for the studied reach after a short period up to 30-days. The model depends upon the scour and the silting rates to predict the new bed topography map. The comparison between the initial bed levels and the predicted has been investigated as shown in Fig. (6). It can be noticed that, the bed levels have dropped by 1.0m at the problem site. It means that, the deep local area, pyara (scour hole) will be at continuous dropping.

FIELD INVESTIGATION FOR FIRST PROPOSAL

Figure (7) has presented the developed bed topography of the studied reach as suggested in this proposal. It is clear that, the island has been erased up to level (13.50). The western bank has been enlarged by 50.0 m toward the eastern bank along the studied reach. This reduction in cross-section area keeps the cross-section area in its limits after island removing. The modified reach should be restudied with the help of the SED-2 model in addition to the HYD-2 model outputs.

Figure (8) and Fig. (9) depict the discharge distribution and the discharge percentage in the modified reach, respectively. It is clear that, the distribution of the discharge has become more uniform than the initial case.

Figure (10) shows the distribution of the average longitudinal velocity in x-direction. It can be noticed that, the average velocity of the flow near the western bank has been increased from 0.2 m/sec to 0.3 m/sec. But, near the eastern bank, the average velocity has been decreased from 0.4 m/sec. to 0.3 m/sec. The average velocity in the middle part has been decreased from 0.3 m/sec. to 0.2 m/sec.

Moreover, Fig. (11) presents the scour and the silting zones in the modified reach. It can be noticed that, the reach still has been subjected to a scour rate U/S the intake of the Esmaeilia canal at the problem site. Figure (12) presents the comparison between the bed levels at Sec. (1) for initial case and after 30-days. During this period, The bed levels have risen in old location of island by 0.5 m from level (13.50) to level (14.00). But also, It has fallen by 0.9 m near the East bank at intake of the Esmaeilia canal from level (8.60) to level (7.70).

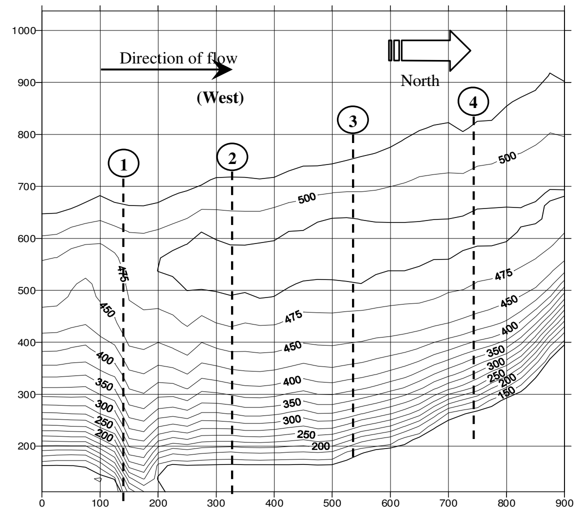

Figure 2: Discharge distribution at the studied reach

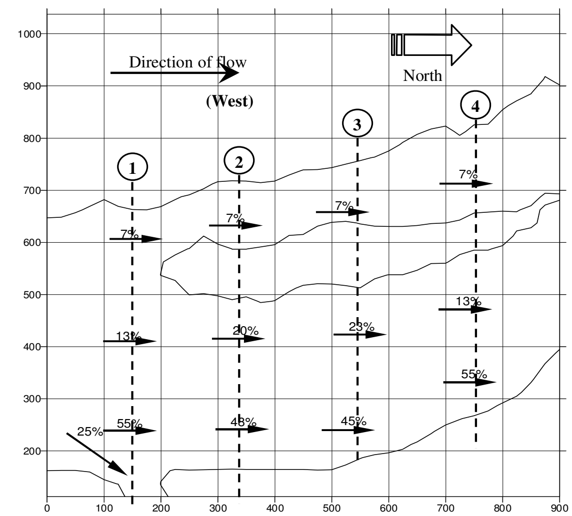

Figure 3: Discharge distribution %age at the studied reach:

Figure 4: Average longitudinal velocity distribution

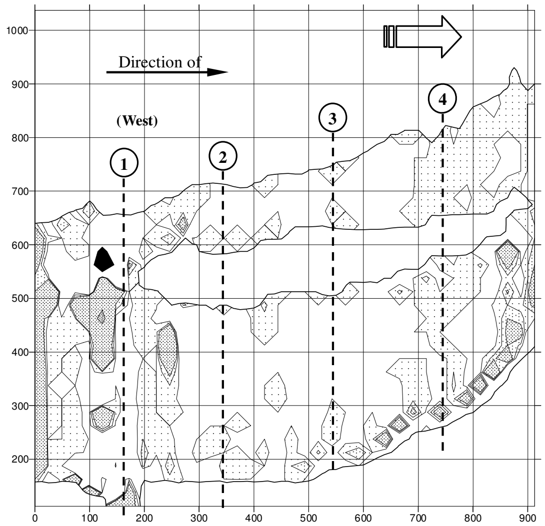

Figure 5: Scour and silting rates at studied reach

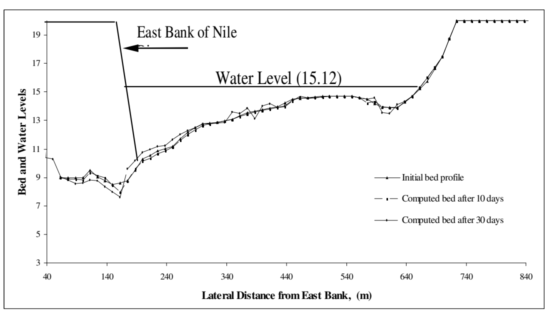

Figure 6: Between bed levels at Sec. (1) for initial bed, predicted one after 10 days and after 30-days.

FIELD INVESTIGATION FOR SECOND PROPOSAL

Figure (13) has presented the developed bed topography of the studied such as suggest in the second proposal. It is clear that, the island has been erased up to level (13.50). The western bank has been enlarged by 62.5 m toward the eastern bank. Main difference between the two proposals is at the smoothing method of the western bank. The western bank has been enlarged in the second proposal by about 12.5 m more than the first proposal. Figure (14) and Fig. (15) present the discharge distribution and the discharge percentage in the modified reach, respectively. It is clear that, the distribution of the discharge has become more uniform than the base case. Figure (16) shows the distribution of average longitudinal velocity in x-direction. It can be noticed that, the average velocity of the flow near the western bank has been increased from 0.2 m/sec. to 0.4 m/sec. But, near the eastern bank, velocity has been decreased from 0.4 m/sec. to 0.3 m/sec.

Moreover, Fig. (17) indicates the scour and the silting zones in the modified reach. Also, Fig. (18) provides the comparison between the bed levels at Sec. (1) for initial case and after 30-days. During this period, The bed levels have risen in old location of island by 0.5 m. but also, It has fallen by 0.7 m near the eastern bank at intake of the Esmaeilia canal.

COMPARISON AND DISCUSSION

The comparison between the two proposals has been investigated depending on many factors. Mainly, the comparison between them depends the their efficiency to reduce the scour rate at the deep local area, pyara (scour hole). The bed topography at deep local area, pyara, has been investigated under each proposal.

Figure (19) represents the comparison between the alternative proposals as the velocity vector for a section just upstream the intake of the Esmaeilia canal, the scour and silting rate for the same section. It gives also, a definition sketch for the site. It can be noticed that, all proposals have a great effect on scour hole, which was forming. But the second proposal is more effective in reducing the scour hole at deep local area, pyara. The comparison between alternative proposals depends also upon the efficiency of each proposal for the uniformly distribution of the discharge, the effect of each proposal on the bed topography during the prediction time, the cutting volume and also, the fill volume.

As shown, Fig. (20) proves that the second proposal is more effective for uniformly discharge distribution than the first proposal. Also, it can be noticed that, the second proposal has required a large quantity for each of the cut and the fill. As consequently, the cost of the second proposal is large with comparing the first proposal.

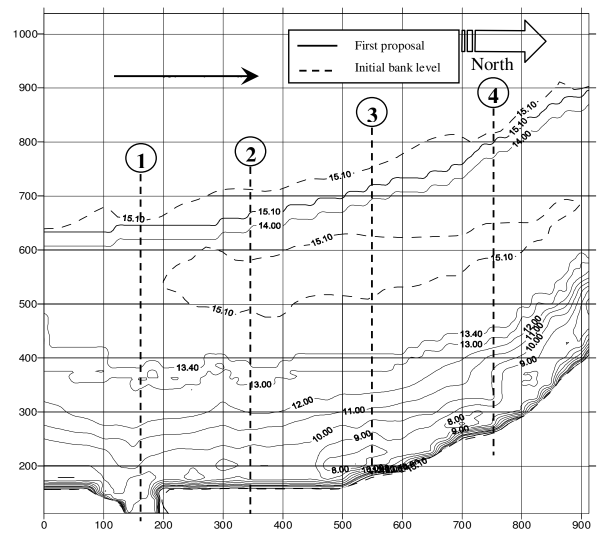

Figure 7: Bed topography at studied reach for the first proposal:

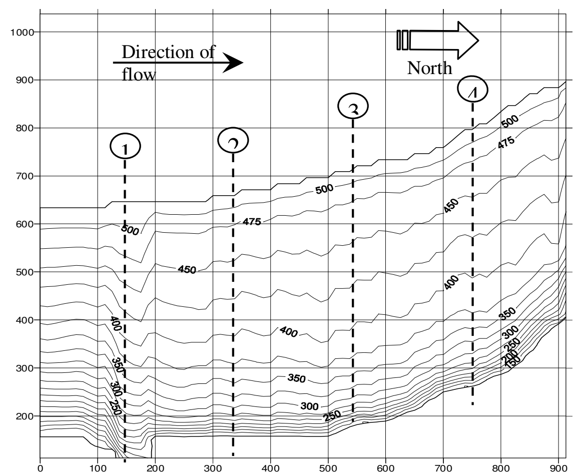

Figure 8: Discharge distribution for the first proposal

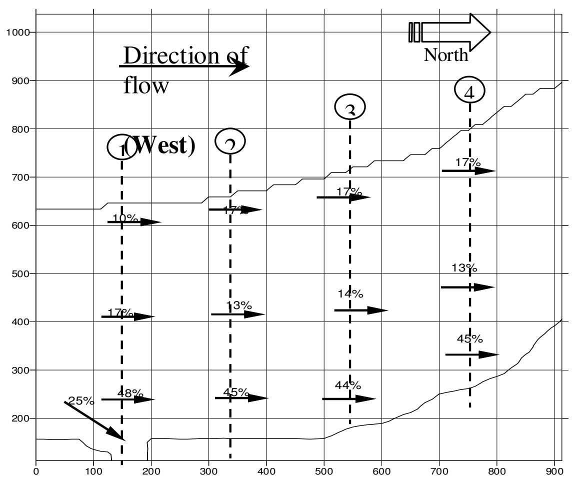

Figure 9: Discharge distribution %age for the 1st proposal

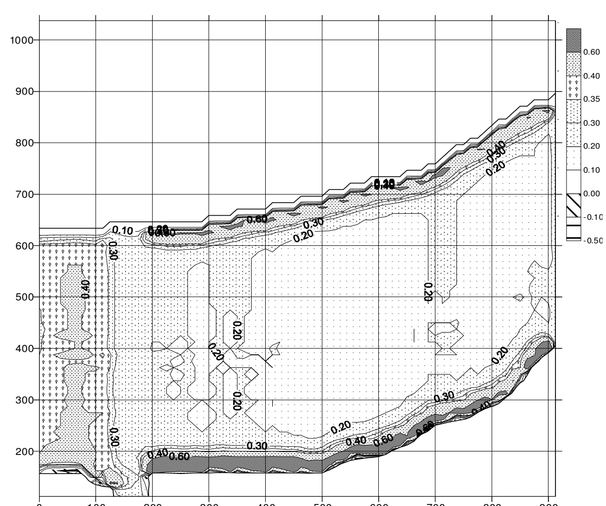
Figure 10: Average longitudinal velocity distribution

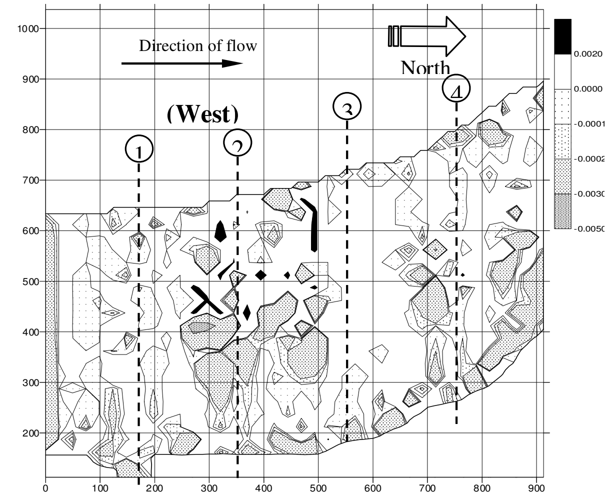

Figure 11: Scour and silting rates at studied reach

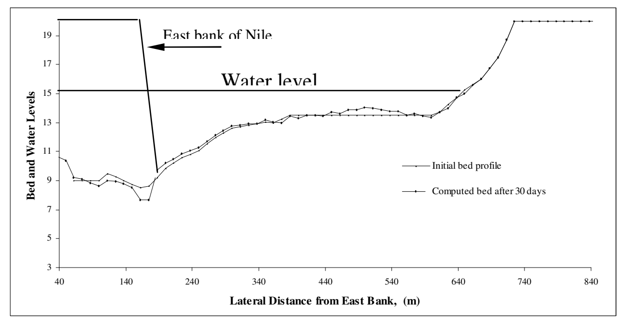

Figure 12: Comparison between bed levels at Sec. (1) for initial bed, predicted one after 30-days

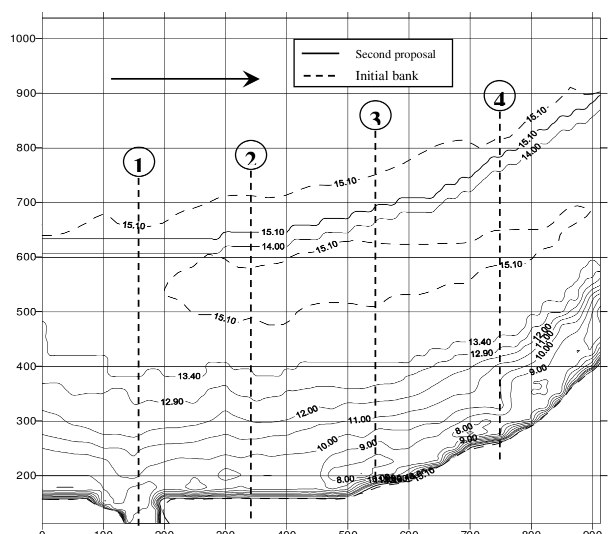

Figure 13: Bed topography at studied reach for the second proposal

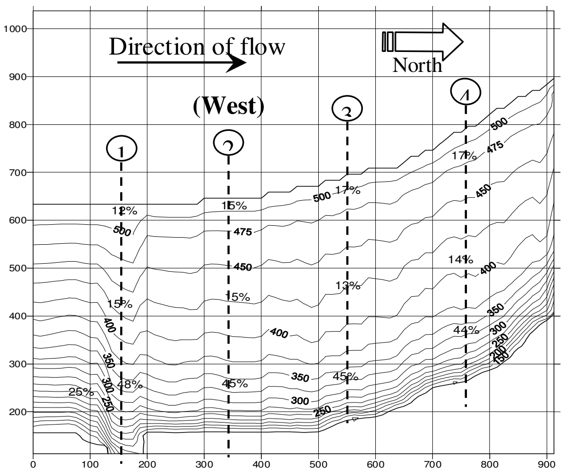

Figure 14: Discharge distribution for the second roposal

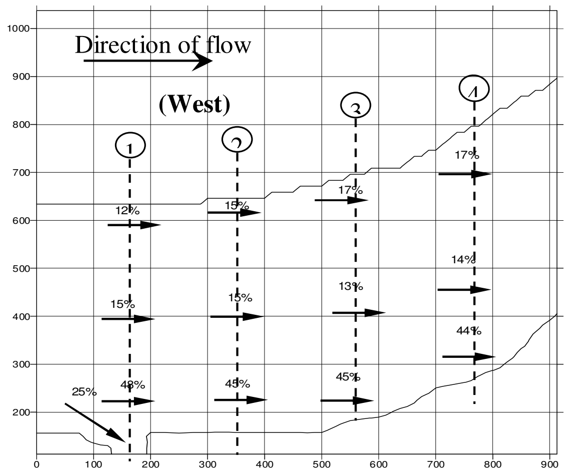

Figure 15: Discharge distribution %age for the second proposal

Figure 16: Average longitudinal velocity distribution

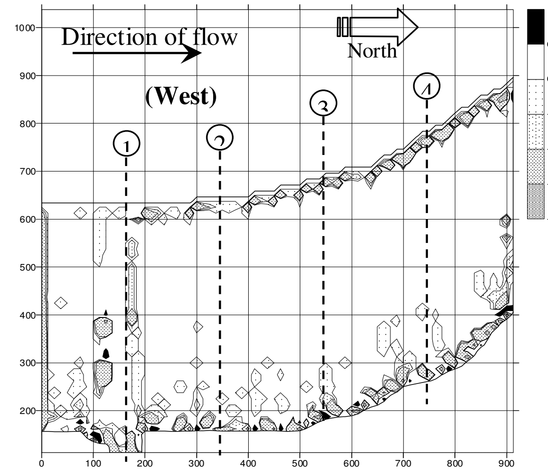

Figure 17: Scour and silting rates at studied reach

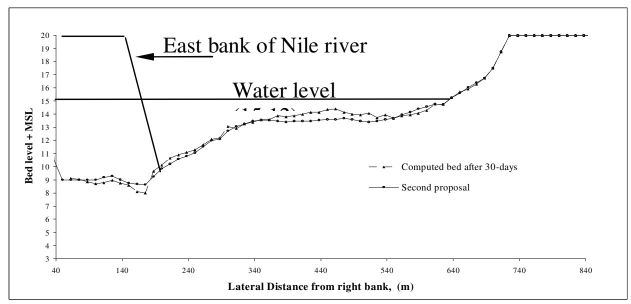

Figure 18: Comparison between bed levels at Sec. (1) for initial bed, predicted one after 30-days

It is clear that the second proposal may be the safest one to the pyara problem, it is more effective in distribution discharge uniformly. Its effect along reach is very small with respect to the changes occurs now. But also its cost is larger with respect to the cost of the first proposal.

CONCLUSION

Two previously developed computational models (HYD-2) and (SED-2) were used to suggest proper solution for scouring problems at a particular reach of the Nile. The HYD-2 model was used to simulate the velocity patterns and discharge distribution for each suggested proposal. The SED-2 model was used to simulate the scouring and silting process for the same proposals.

Two proposals were investigated to indicate the use of the models. Comparing the results concluded that the second proposal is more safe that proposal one.

ACKNOWLEDGMENT

The authors wish to thank all the engineering staff of the Hydraulic Research Institute, National Water Research Center, Delta Barrages, Egypt for great help and facilitating the necessary field data required for the verification procedure.

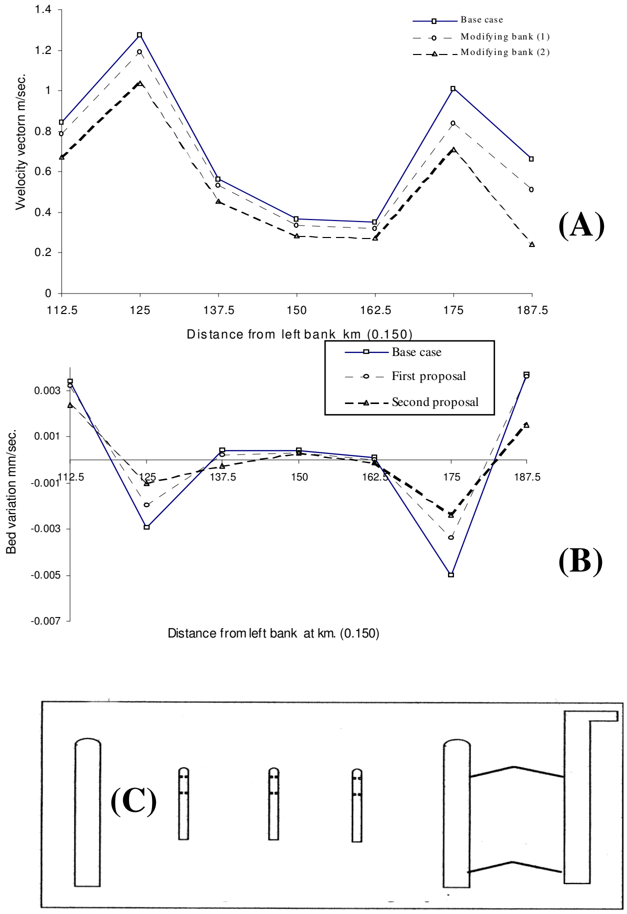

Figure 19: (A) Velocity (B) Scour and silting variation (C) Definition sketch for the site

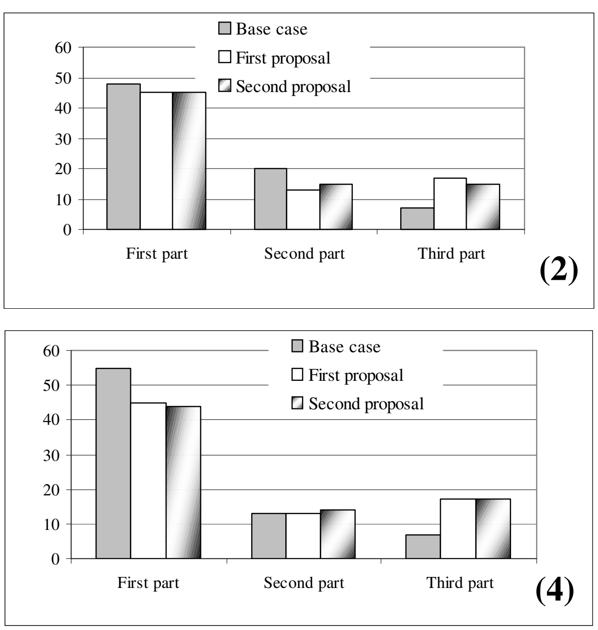

Figure 20: Percentage of discharge distribution at the alternative sections (2 and 4)

NOMENCLATURE

$\bar{c}$ is the depth averaged sediment concentration

c_* is the sediment carrying capacity,

F is the external deriving force

G is the gravitational acceleration

H is the flow depth, ρ is the water density

$\bar{u}$ the depth-averaged velocity component in x direction

$\bar{v}$ the depth-averaged velocity component in y direction

z_s is the elevation of water surface above reference plane

α is the ratio of sediment concentration near the bed to the averaged concentration.

ε_f is the horizontal fluid diffusion coefficient

ε_s is sediment horizontal diffusion coefficient

τ_b is the bottom shear stress

REFERENCES

[1] B. P. Greimann1, M. Muste, F M. Holly Jr.,"Two-Phase Formulation Of Suspended Sediment Transport ", J. of Hydraulic Research, Vol. (37), No. (4), 1999.

[2] J. Zeng, G. Constantinescu, L. Weber, " A 3d Non-Hydrostatic Model To Predict Flow And Sediment Transport In Loose-Bed Channel Bends", J. of Hydraulic Research, Vol. (46), No. (3), 2008.

[3] M. M. Elfiky, Y. R. Marmoush, and G. M. Abdel-Aal, "A 2-D Model Simulating the Flow Patterns in Rivers", The Egyptian Journal For Engineering Sciences and Technology (EJEST), Faculty of Engineering, Zagazig University, Jan. Vol. (1), No. (1), pp.60-67, 1997.

[4] M.M. Elfiky, A.M. Negm, T.M. Owais, and Nassar, M.H., "A 2-D Model Simulating Sediment Transport in Shallow-Wide Streams (SED-2)", Proc. of 5th Int. Conf. on Hydro-Science and Engineering, Sep. 16-21, Published on CD-ROM Warsw, Poland, 2002.

[5] M.M. Elfiky, A.M. Negm, M.I. Attia, and M.H. Nassar, "Study Of Navigation Requirements in The Nile River At Elbogdady Area Using A 2-D Sediment Transport Model", Proc. of 2nd Int. Conf. On Fluival Hydraulics June 23-25, 2004, Naples, Italy, Riverflow 2004.

[6] M. Shahin, "Hydrology of the Nile Basin", Elsevier Science Pub. Comp., the Netherlands, 1985.

[7] Q. Guo, C.Hu, K. Takeuchi, H. Ishidaira and W. CAO, "Numerical Modeling Of Hyper-Concentrated Sediment Transport In The Lower Yellow River", J. of Hydraulic Research, Vol. (46), No. (5), 2008.

[8] S. Ouillon and B. Guennec, “Modelling Non-Cohesive Suspended Sediment Transport In 2d Vertical Free Surface Flows”, J. of Hydraulic Research, Vol. (34), No. (2), 1996.
[9] W. Wu, S. S.Wang, “One-Dimensional Explicit Finite-Volume Model For Sediment Transport With Transient Flows Over Movable Beds”, J. of Hydraulic Research, Vol. (46), No. (1), 2008.

