RIVER REGULATION DOWNSTREAM NEW ESNA BARRAGE USING MATHEMATICAL MODEL

Karima Attia* and Hossam El- Sersawy**

*Associate Prof., General Secretary, Nile Research Institute, National Water Research
Center New Building, Qanater P.O. 13621, Egypt
Email: karima_attia@hotmail.com
**Researcher, Nile Research Institute, National Water Research Center New Building,
Qanater P.O. 13621, Egypt
Email: hossam_elsersawy@yahoo.com

ABSTRACT

Channel regulation works aim at adapting the channel dimensions, starting with the plan form. Many reasons exist for channel regulation works. Some of them are attributed to improvement of navigation channel or preventing erosion to provide a stable river stretch to guarantee the stability of infrastructures such as bridges and towns, some others are to increase the flood discharge capacity. Channel regulation works may be carried out by permanent works such as channel realignment and groins but also temporary works such as dredging, resulting in a temporary effect unless the dredging is pursed for maintenance and repeat. This research aims at finding and introducing suitable regulation works downstream new Esna barrage at km 167.75 downstream Old Aswan Dam (OAD) to rehabilitate the channel for navigation at the location of the new tourist berth on the west side of the channel. This rehabilitation is mainly to regulate the channel depth and especially for fixing the low water channel to concentrate the flow in it, so as to increase as far as practicable the navigation depth at the lowest stage of the water level. This requirement was achieved by dredging the channel to maintain a depth of 2.3 m at low water stage. Also, the study suggested realigning the channel plan form to guarantee the removal of soft bed material from accumulation downstream of the intended additional new lock in the left side of the barrage location. Two-dimensional mathematical model was used to evaluate the impact of the proposed solutions on channel different characteristics when passing various discharges. Extensive field reconnaissance was conducted to collect different type of data for model application and berth design. The model proved that the required bed regulations are achieved by the proposed solutions however; the study recommended that field survey should be repeated after field implementation to retest the impact especially on sediment transport.

Keyword
River regulation downstream Esna barrages, navigation, mathematical model, field data.

INTRODUCTION

A number of basic requirements for human life, such as water supply, means of transport by navigation, hydropower, drainage and discharge of waste water, are provided by rivers. However, also some negative manipulation of river can be occurred and affect human living conditions. Examples are floods; if they are above certain limits they have great destructive and devastating forces on the river close residents and environment. Erosion, covering watershed and lands, river-bed and bank scour, sedimentation at storage reservoirs and intake structures and hampering transport across the river are also some negative aspects of rivers to human life. River regulation works are tools regulate the relationship between natural river and human life. They are selected and decided through human interference with natural River by planning, design and implementation. The main objectives are to minimize the natural adverse effects to human interests, and optimize the benefits to human requirements. This paper introduces regulation works needed to achieve certain requirements in the location of the new Esna barrage which is located 167.75 km downstream Old Aswan Dam (OAD) and 1.1 km downstream the old Esna barrage. This national project intends to implement new lock to serve navigation requirements. Also a new berth accomplish with a recreation area will be designed about less than 1 km downstream the new intended lock. Therefore river regulation works are mainly required to achieve two objectives. The first is to maintain and rehabilitate the river channel at the location of the new berth downstream new Esna barrage for navigation. Second, is to guarantee the removal of soft bed material from accumulation downstream the intended additional new lock in the left side of the barrage location. The expected accumulation of sediment is mainly attributed to channel width constriction to about 75% of the original width at the barrage location. Two types of regulation works are proposed. The first one is a permanent type regulation work. It involves the channel plan form realignment at the location of channel width constriction. This solution will reform the stream flow direction to have easy alignment. As a result the flow will be concentrated in front downstream part of the lock and no flow diversion will be experienced. The second regulation work is a temporal one to satisfy navigation requirement in front of the new berth location. It involves dredging the river bed to increase as far as practicable the navigation depth at the lowest stage of river to maintain a depth of 2.3 m. The two solution implementations are tested by two dimension mathematical model. Their impacts on channel morphology at different water releases including the future releases are also checked. The model results prove that the proposed solutions achieved the intended objectives however; some new model tests should be applied after field implementation because the barrage still under testing operation conditions as the measured field velocity was very low.

A BRIEF DESCRIPTION OF THE PROJECT

The old Esna barrage consists of 120 opening, each of 5 m in width. The total length of the barrage is 900 m, with navigation lock of 80 m length and 16 m width. The old barrage was rehabilitated by a new one. The reason of the replacement that the head difference in continuously increased as a result of degradation process, HRI [1]. Some problems pertaining to the stability of the structure are found. It is also deemed necessary to increase the upstream water levels to insure the irrigation requirements and to increase the navigation efficiency by constructing a new lock. For the purpose of hydropower generations a new head difference should be created.

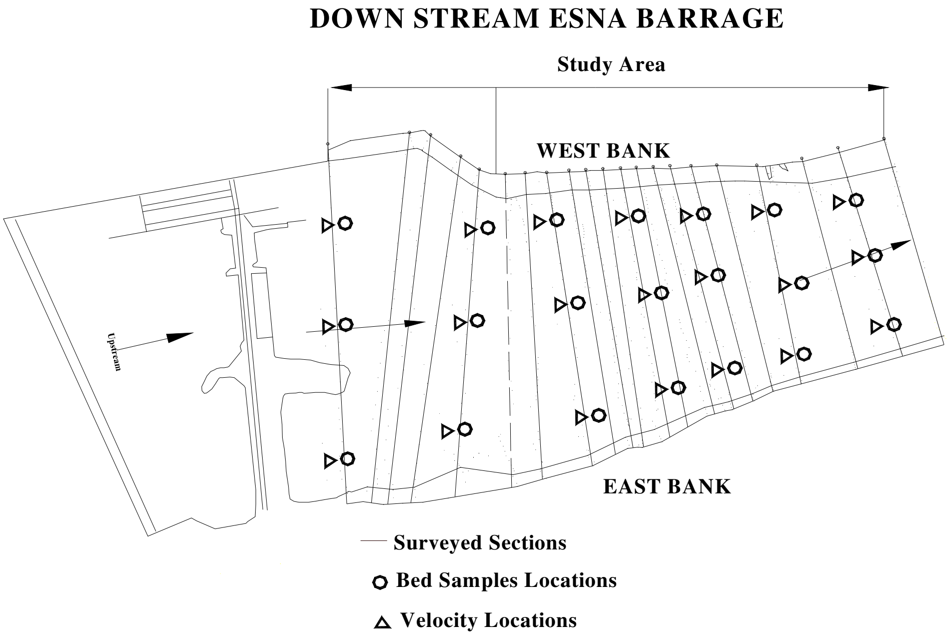


Figure 1: Layout of the project area and data collection program

The new Esna barrage Figure 1 is located 1.1 km downstream the old barrage. The project construction was started in 1989 and ended in 1994. The barrage has some trimmings and recreation area in the downstream direction. It consists of navigation lock located on the left side of the river bank. Its has the dimension of 160 m as length, 17 m as width and the minimum draught is 3 m. The navigation lock is filled and emptied by culverts in the base level of the lock. A hydropower plant is adjacent to the navigation lock on the left side of the river bank. It consists of six bays each of which has a width of 12 m. This hydropower plant generates electricity via six bulb units of 85.68 MW capacities. A spillway is located just after the hydropower plant separated by a dividing pier. It consists of 11 bays, each of which has a width of 12 m equipped with radial gate of 14 m radius. The main purpose of the spillway is to maintain a pool level of 79 m in the upstream direction and allow emergency floods of 7000 m^3/s (605 m m^3/day) to be regulated. A rockfill dam is constructed to complete the closure of the river in right bank side in the deepest section of the river used by navigation during the construction phase. Additional new lock was added to the new barrage and comprising of resemble characteristics and dimensions of the original lock. Less than 900 m in the downstream direction it will be a recreation area connected to a new berth of length 500 m to be used for tourism boats and vessels.

DATA COLLECTIONS

A comprehensive field reconnaissance, NRI [2], [3], and [4] was conducted to gather a variety of data (see figure 1). More than 20 cross sections were surveyed to cover a distance of 1.39 km located between km 168.42 to 169.81 downstream OAD. The distance between the cross sections varied from 30 to 135 m as shown in figure (2). The vertical distributions of the velocity are determined for 6 cross sections. Three verticals at least are measured for each cross section. In each vertical five locations are measured, at 0.5m downward the water level, 25%, 50%, 75% of the total water depth and the last location at 0.75 m upward the bed level. Bed material samples are obtained using a grab sampler from four cross sections. Three samples are taken from each cross section, east, middle, and west. Vertical integrated water samples are collected from six cross sections to define the suspended sediment concentration at the site. The vertical individual samples are at the same locations of velocities. .

HYDROLOGICAL STUDY

A hydrological study was carried out to determine the different stages of the water levels and discharges. Actual data of water level and discharge on daily basis were analyzed since operating the new Esna barrages. Also the water levels corresponding to the future releases of 350 m m^3/day (4050 m^3/sec) are defined using one dimensional model. In addition, the barrages design discharge of 605 m m^3/day (7000 m^3/sec) is simulated. The objectives of defining the different stages of water levels and discharges covering a period of time are to test the impacts of the proposed regulation works when applying different hydrological parameters. Two water level gauge stations are used for the analysis; the first is the gauge just downstream the barrage and the second is Armant gauge station which located at km 203.8 downstream OAD. The hydrological study has resulted in the following:

- The minimum recorded discharge at the barrage location since the operation period between 1995 and 2003 is 59.01 m m^3/day (682.75 m^3/sec).
- The maximum recorded discharge at the barrage location since the operation is accounted to 239.9 m m^3/day (775.64 m^3/sec).
- The actual measured discharge at the barrage location in the time of data collections (Dec. 2003) was equal to 79.65 m m^3/day (922 m^3/sec).
- The resulted minimum water level at the end of the study location is equal to 70.9 m while the maximum water level at the same location is amounted to 75.2 m
- The water level corresponding to future release of 350 m m^3/day (4050 m^3/sec) is 76.5 m

PRESENT SITUATIONS

Table (1) indicates the variation of velocity measured in the study area (six cross sections) in terms of the cross location of the channel as well as the average vertical distribution and the average velocity of the entire study area.

Table (1): Range of variations for the measured velocity along the study area

	velocity m/s					
item	**cross channel**		**average vertical distribution**		**average study area**	
	min.	**max.**	**min.**	**max.**	**min.**	**max.**
value	0.15	0.67	0.21	0.52	0.29	0.41
section no.	5	5	3	5	3	5
position	east	middle	East	middle	-	-
water depth	4.75	0.5	-	-	-	-
location OAD	169.10	169.10	169.00	169.10	169.00	169.10

Table (2) shows the grain size distribution of 12 bed material samples collected during the field observations. The analysis proves that the common type of bed materials is medium sand. The characteristics of these samples will be used as an input to the model to represent sediment transport process. Sediment is moved along the river bed by rolling, sliding, or skipping within a few grain diameters of the bed.

The analysis of the suspended material samples is shown in table (3). These samples are an indicator for the sediment that is supported by the fluid of a river and maintain in suspension by the net upward component of turbulence. The table indicates that homogeneity is found to some extend between the different collected samples.

Table 2: Average grain size distribution at the study area

km	**D_{50} mm**	**% gravel**	**% sand**				**% silt**
			coarse	**medium**	**fine**	**total**	
169	0.24	6.58	4.84	50.23	36.67	91.75	1.67
169.1	0.32	6.08	8.60	69.12	16.15	93.88	0.04
169.2	0.33	5.54	12.73	70.23	11.50	94.46	0.00
169.35	0.38	5.96	18.87	67.48	7.70	94.04	0.00

Table 3: Average suspended sediment concentration ppm

Km OAD	169	169.1	169.2	169.35	169.5	169.7
Concentration	33	25	28	39	36	37

Figure 2 is the developed contour map for the study area. The morphological and hydrological data indicated that the stream flow lines have smooth alignment especially at the location 100 m distance from the west side of the river at the barrage location. The available depths are satisfying the navigation requirements at the lower stage of the river. However, and due to channel constriction in the downstream direction at the location of the intended tourism berth some temporal regulation works involves dredging should be established at the berth location. Shallow areas of width 500 to 750 m are observed near the east side of the channel and covering most of the surveyed cross sections with varied widths.

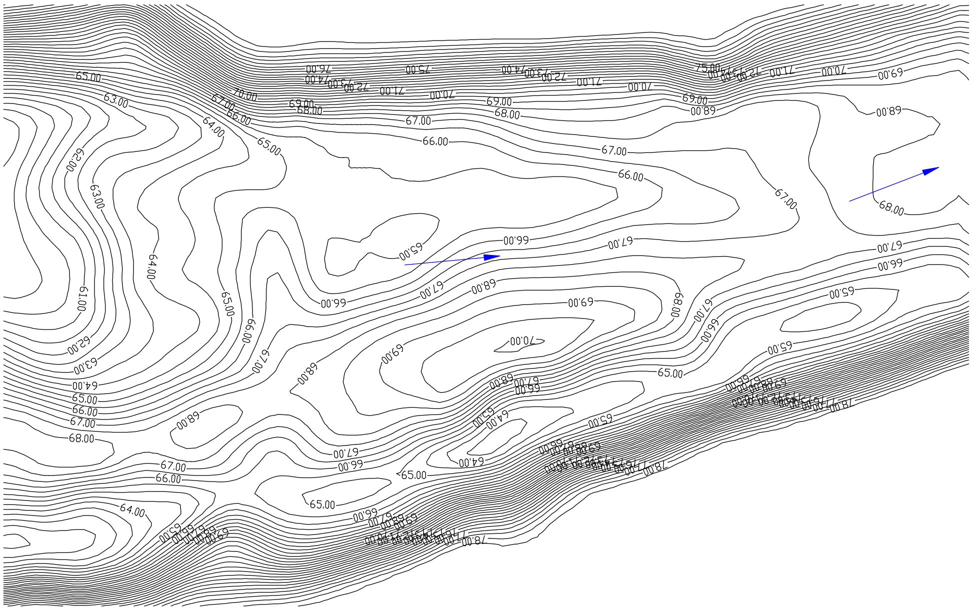


Figure 2: Developed contour map for the study area

These areas are gradually decreased in width to about 250 and covering the middle part of the channel at the location of cross sections (7-17). The shallow areas are decreased gradually with the increase of channel constriction in the downstream part to the end of the study area. The collected data indicated that at the time of survey there is no sediment accumulation at the start of channel constriction. Therefore, a very simple realignment of the channel plan form as a permanent regulation work will be proposed taking into consideration that the new barrage is still under experimental operation. Figure 3 illustrates the proposed regulation works and the table in the figure indicates the cross section numbers and the distance of the new alignment between the bench mark of each cross section and the axis of the diaphragm wall. The new alignment will be achieved in the site as a diaphragm wall starting from the barrage location at km 167.75 to the end of the tourism berth at km 169.81 downstream OAD.

BERTH DESIGN

Designing the downstream berth for navigation (typical example, see figure 4) includes the determination of the diaphragm wall axis to satisfy smooth alignment and minimum irregularities. The main purpose is to avoid flow disturbances that can lead to local scour and subsequent undermining for protection work. Many levels for the berth are applied to cover the entire stages through a year including min., max., and future discharges. More than twenty cross sections are designed, the amount of cut and fill are evaluated and computed in an economical basis. A stable side slope for each cross

Section No.	Distance from bench mark (m)
1	7.4
2	12.2
3	11.6
4-1	-18.00
4-2	-27.00
5	-2.00
6	17.3
7	24.3
8	28.10
9	27.40
10	26.80
11	26.20
12	25.90
13	25.60
14	26.60
15	24.20
16	24.80
17	25.40

Figure 3: Proposed regulation works downstream Esna Barrage

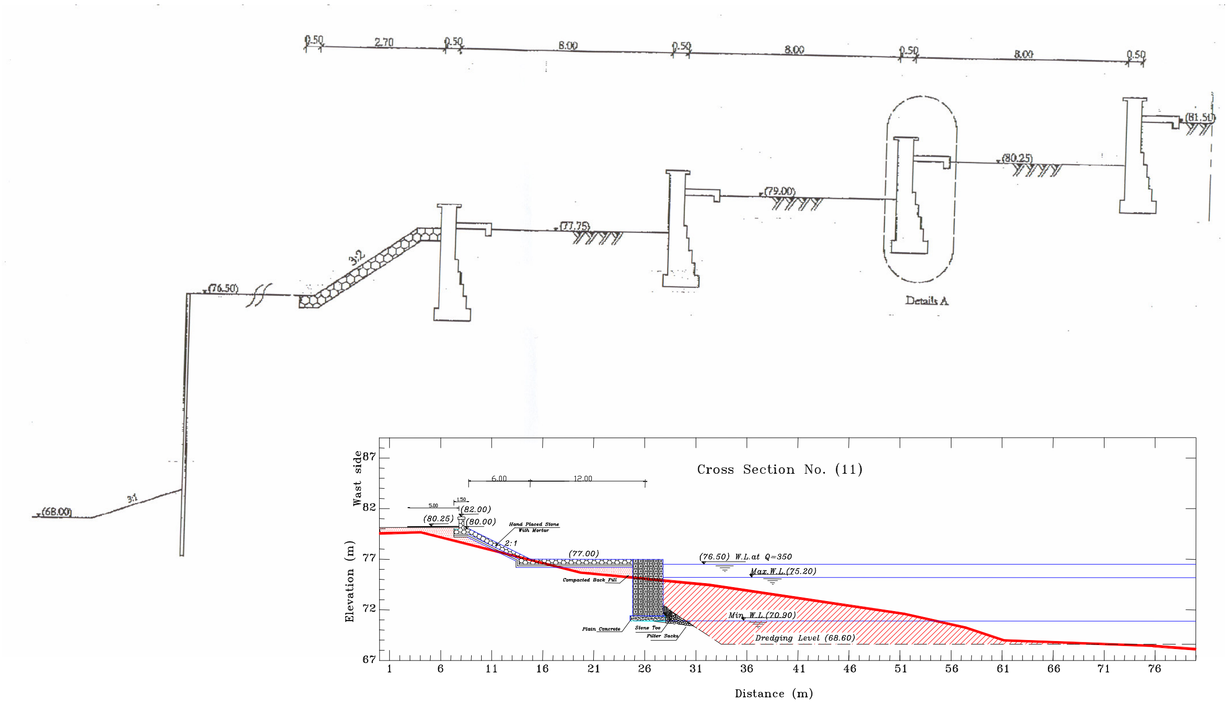


Figure 4: Typical design cross section at the berth location indicating the diaphragm wall

section of 2 horizontal and 1vertical was selected to avoid stone sliding. A filter layer was provided to prevent migration of the base material through the berth protection. Specific sizes for the filter material are taken into consideration that they must be permeable, fine enough to prevent the movement of the base materials and coarse enough that it will not move through the protective materials. The level of dredging was determined 2.3 m below the min. water level which resulted in dredged material of 64000 m^3.

MATHEMATICAL MODEL

A two dimension numerical model, the Surface Water Modeling System (SMS) is used to simulate the impacts of the proposed river regulation works. The model is developed by the Corps of Engineers. It consists of finite element surface water modeling (FESWAMS) model and SED2D model. The model includes two-dimensional finite, two-dimensional finite difference and one dimensional backwater modeling tools. The model can calculate water surface elevation and flow velocities for shallow water flow problems and support both steady and dynamic model. Additional tools are provided in SMS to support the modeling of sediment transport. A finite element mesh is created within SMS (see figure 5 for design mesh). The resulting solutions which contain water surface elevation, flow velocities, sediment concentrations, and any other functional data is calculated at each node of the designed mesh. There are some limitations when using the SMS model for long reach and long time especially in the number of the cross section which can be simulated.

The FESWMS model solves the depth-integrated equations of mass and momentum conservation in two horizontal directions. The depth-averaged surface water flow equations are derived by integrating the three- dimensional mass and momentum transport equations with respect to vertical coordinate from the bed to the water surface, assuming that vertical velocities and accelerations are negligible. The vertically integrated momentum equations are written as:

For flow in the x direction, and for flow in the y direction, the vertically integrated mass transport equation (continuity equation) is

$$\frac{\partial(HU)}{\partial t}+\frac{\partial}{\partial x}\left\{\beta_{uu}HUU+(\cos\alpha_{x}\cos\alpha_{z})^{2}\frac{1}{2}gH^{2}\right\}+\frac{\partial}{\partial y}(\beta_{uv}\mathrm{HUV})+\cos\alpha_{x}\mathrm{gH}\frac{\partial z_{b}}{\partial x}$$

$$-\Omega\mathrm{HV}+\frac{1}{\rho}\left[\tau_{bx}-\tau_{sx}-\frac{\partial(\mathrm{H}\tau_{xx})}{\partial x}-\frac{\partial(\mathrm{H}\tau_{xy})}{\partial y}\right]=0$$

$$\frac{\partial(HV)}{\partial t}+\frac{\partial}{\partial y}\left\{\beta_{vv}HVV+(\cos\alpha_{y}\cos\alpha_{z})^{2}\frac{1}{2}gH^{2}\right\}+\frac{\partial}{\partial x}(\beta_{uv}\mathrm{HVU})+\cos\alpha_{y}\mathrm{gH}\frac{\partial z_{b}}{\partial y}$$

$$+\Omega\mathrm{HV}+\frac{1}{\rho}\left[\tau_{by}-\tau_{sy}-\frac{\partial(\mathrm{H}\tau_{yx})}{\partial x}-\frac{\partial(\mathrm{H}\tau_{yy})}{\partial y}\right]=0$$

$$\frac{\partial H}{\partial t}+\frac{\partial(\mathrm{HU})}{\partial x}+\frac{\partial(\mathrm{HV})}{\partial y}=q$$

Where H = water depth; z = vertical direction; z_b is the bed elevation; $z_s = z_b + H$ = water surface elevation; u = horizontal velocity in the x direction; and v = horizontal velocity in the y direction; β_{uu}, β_{uv}, β_{vu}, and β_{vv} = momentum flux correction coefficients that account for the variation of velocity in the vertical direction; $\alpha_x = \arctan(\partial z_b/\partial x)$, $\alpha_y = \arctan(\partial z_b/\partial y)$, $\alpha_z = \arccos(1-\cos^2\alpha_x-\cos^2\alpha_y)$; g = gravitational acceleration; Ω = Coriolis parameters; ρ = water mass density, which is considered constant; τ_{bx} and τ_{by} = bed shear stresses acting in the x and y directions, respectively; τ_{sx} and τ_{sy} = surface shear stresses acting in the x and y directions, respectively; and τ_{xx} , τ_{xy} , τ_{yx} , and τ_{yy} = shear stresses caused by turbulence; q = unit source (inflow) or a unit sink (outflow) term.

The SED2D model calculates the suspended sediment concentration using the basic convection- diffusion equation, which it is presented in Ariathurai, MacAthur, and Krone as follows:

Where C = concentration; t = time; u = flow velocity in x direction; x = primary flow

$$\frac{\partial C}{\partial t}+u\frac{\partial C}{\partial x}+v\frac{\partial C}{\partial y}=\frac{\partial}{\partial x}\left(D_{x}\frac{\partial C}{\partial x}\right)+\frac{\partial}{\partial y}\left(D_{y}\frac{\partial C}{\partial y}\right)+\alpha_{1}C+\alpha$$

direction; v = flow velocity in y direction; y = direction perpendicular to x; D_x = effective diffusion coefficient in x- direction; Dy = effective diffusion coefficient in y-direction; α_1 = a coefficient for the source term; α_2 = the equilibrium concentration portion of the source term.

Several options are available in the SED2D model for computing bed shear stresses using $\tau_b = \rho(u^*)^2$, where; ρ = water density and u* = shear velocity which calculates by using either of smooth wall log velocity profile, and the Manning shear stress equation. The sediment load transport determines by using Ackers-White [5] formula which was adopted for this model because it performed satisfactorily in tests because it seems to be complete, and because it is reasonably simple. It is based on analysis of 925 sets of laboratory and field data. The following empirical formula was proposed:

$$S_t = Kb\,\bar{u}\,d_{35}\left[\frac{\bar{u}}{u_{*,b}}\right]^n\left[\frac{Y - Y_{cr}}{Y_{cr}}\right]^m$$

In which:

$$K = e^{\left[2.86\ln(D_*) - 0.434\,(\ln D_*)^2 - 8.13\right]}$$

$$D_* = d_{35}\left[\frac{\Delta g}{\nu^2}\right]^{\frac{1}{3}}$$

$$Y_{cr} = \frac{0.23}{D_*^{.5}} + 0.14$$

$$m = \frac{9.66}{D_*} + 1.34$$

$$Y = \left[\frac{(u_{*,b})^n}{(\Delta g d_{35})^{0.5}}\right]\left[\frac{\bar{u}}{5.66\quad\log\left(\frac{10R_b}{d_{35}}\right)}\right]^{1-n}$$

Where S_t = total sediment load transport, u^{-} = mean flow velocity, Δ = relative water density (1.65), b = flow width, υ = kinematic viscosity, $u_{*,b}$ = bed shear velocity, R_b = hydraulic radius, d_{35} = particle diameter of bed material. The numerical technique used to solve the governing equations is based on the Galerkin finite element method.

The model was used to define the water levels and velocities and amount of sediment transport for the study area. The initial boundary condition is defined as the initial water levels as well as the bed elevation in terms of xyz data points. The initial water levels were used to simulate the flow characteristics. The boundary conditions consist of three conditions, inflow, outflow, and side boundary conditions. The inflow boundary was defined as the inflow discharge to the study area which is defined as the discharge downstream New Esna Barrage. The outflow boundary condition was used as water level at the end of the study reach. The simulation carried out using the field observation water level of 71.50 m for calibration, verification runs between min. water level of 71.90 m and max. water level of 75.20 m, and the prediction runs between water level of 76.5 m which corresponding to discharge of 350 m m^3/day (4050 m^3/sec) and 79.6 m which is corresponding to barrage design discharge of 605 m m^3/day (7000 m^3/sec).

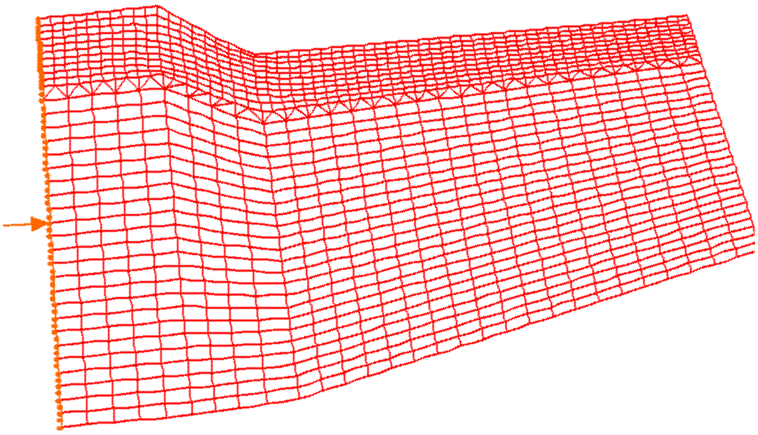


Figure 5: Mesh network for the study area

The side boundary condition defined by the cross section geometrical characteristics consists of banks and plan form in the study area. The simulated runs were performed to predict the effect of different releases covering most of the year on the water surface profile, velocity distribution and sediment transport at the study area. On the sediment transport simulating runs it was considered that the bed level of the field observations is the same after one year of operation. Similar runs are carried out after adding the proposed regulation works and then each output was compared to the base case without the proposed solutions using the same upstream and downstream boundary conditions. The model calibration results are presented in figure 6.

IMPACTS OF REGULATION WORKS

The results of numerical model simulation show general increase of water level associated with simulated discharges. The proposed regulation works have resulted in insignificant change in the water levels for similar discharge. However, more depths are being available near the west side of the channel where the regulations are proposed. That is attributed to bed deepening as results of dredging. Water depths of more than 2.5 m are available in case of min. stage of the river. Simulating the velocity at different discharges has resulted in similar trend that the increase of velocity values associated with the discharge increase. No significant increase in velocity values are found when implementing the regulation works. However, the velocity vectors reflect direction improvement in the stream currents which indicate smooth path to satisfy removal of sediment material from accumulations. The variations of sediment transport as a result of passing min. and max. discharges for 100 days are very limited. These results may indicate minor effects of time on the design navigation bed levels. This finding should be retested due to the fact that the construction phase of the barrage is not finished yet. Also this may be attributed to the experimental operation of the barrage which results in low velocity values at the time of field investigations.

CONCLUSIONS AND RECOMMENDATIONS

This research introduces two types of regulation works to be applied downstream new Esna barrages at km 167.75 downstream OAD. The first is to realign the channel plan form about 1 km downstream the barrages. At that location, the width experienced constriction to about 75% of the original width at the new barrage location. The main objective is to guarantee straighter course to the current at the exit outlet of the new intended lock accompanied the barrage. The smooth movement of stream current will secured the removal of sediment particles from accumulation at the width constriction location. The second is to rehabilitate the navigation needs at the location of the new berth in the downstream direction. This requirement is insured by dredging the bed material through more than 20 cross sections used to design the berth. A diaphragm wall was used in the location of the lock wall and extended to cover the berth location. Navigation reliability was provided through a water depth of 2.3 m at the lowest stage of the river. A two dimension mathematical model is used to test the performance of the applied regulation work at different stages of the river including both future release of 350 m m^3/day (4050 m^3/sec) and the barrage design discharge of 605 m m^3/day (7000 m^3/sec).

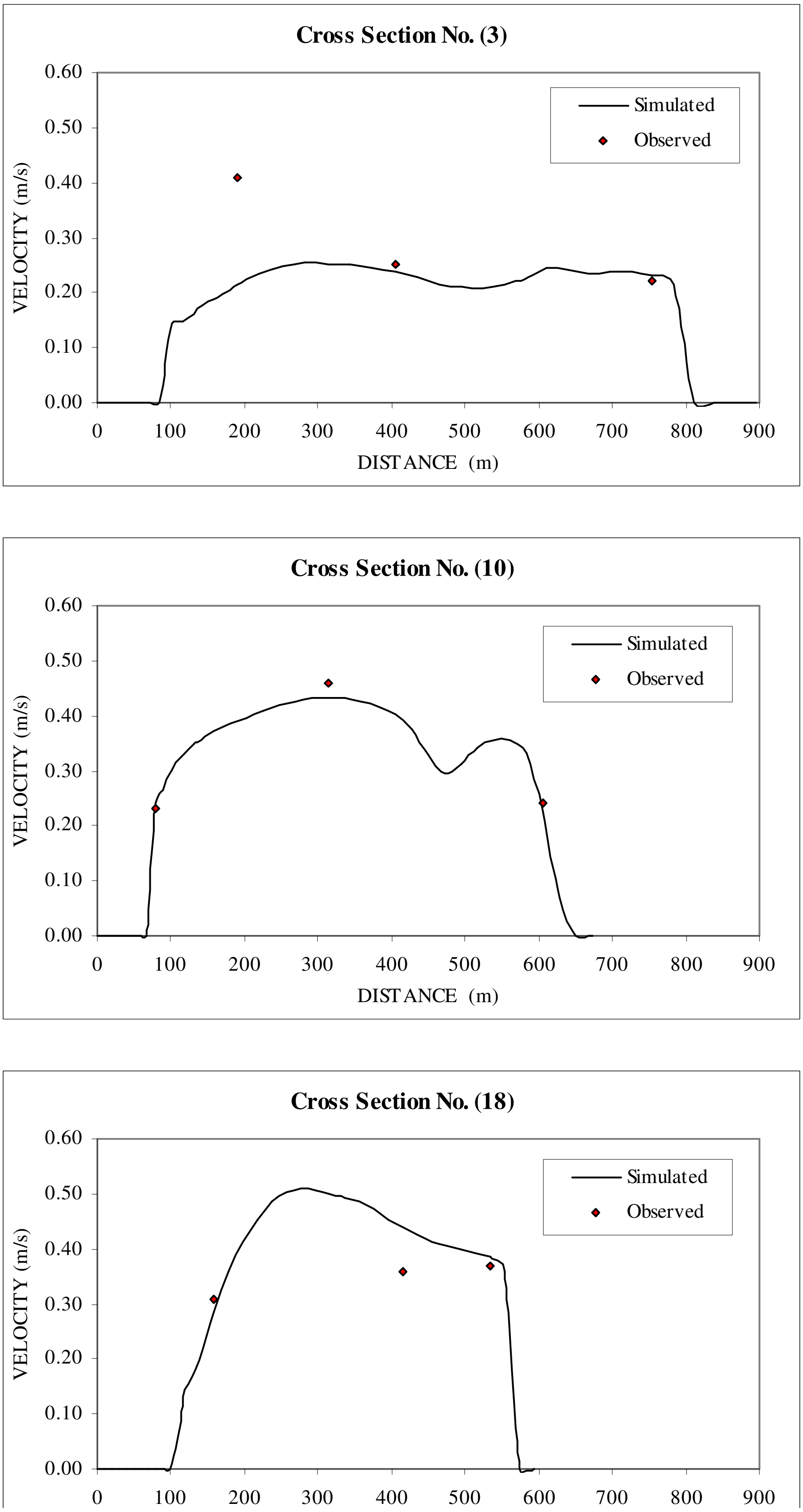
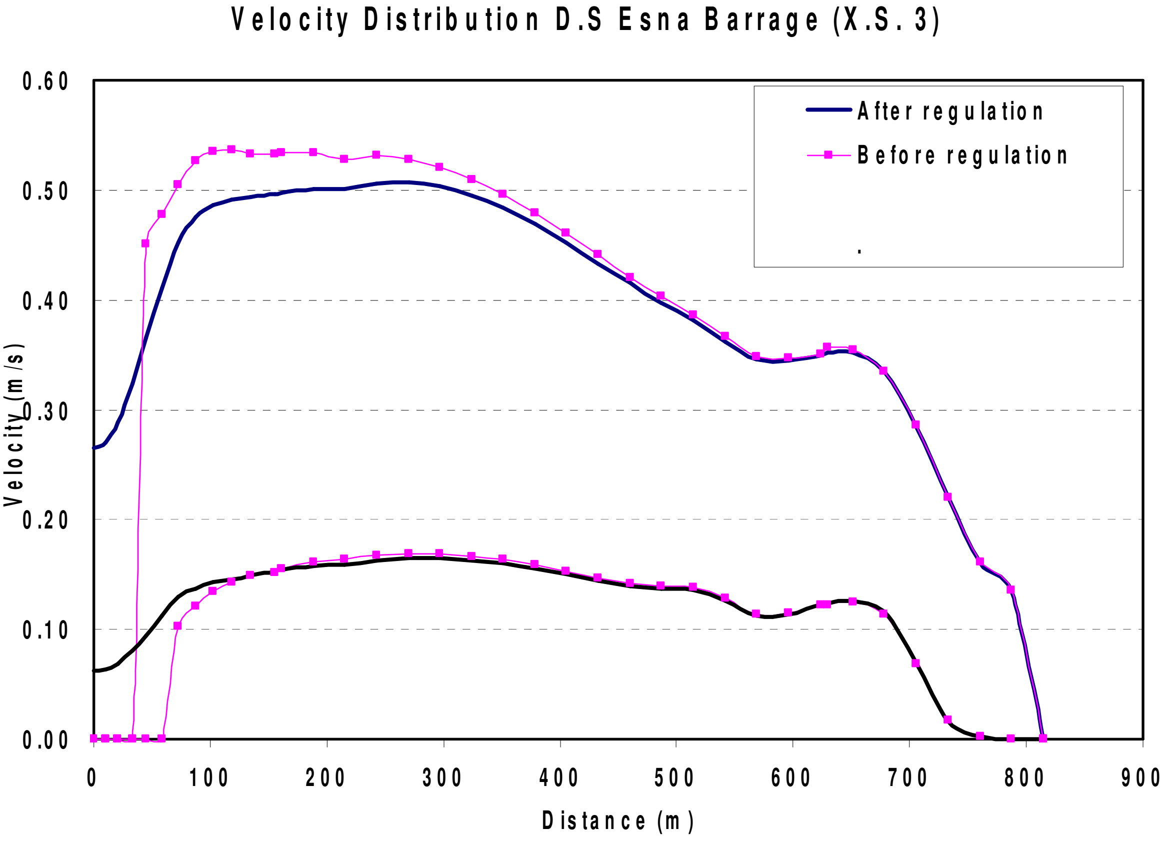


Figure 6: Model calibration results



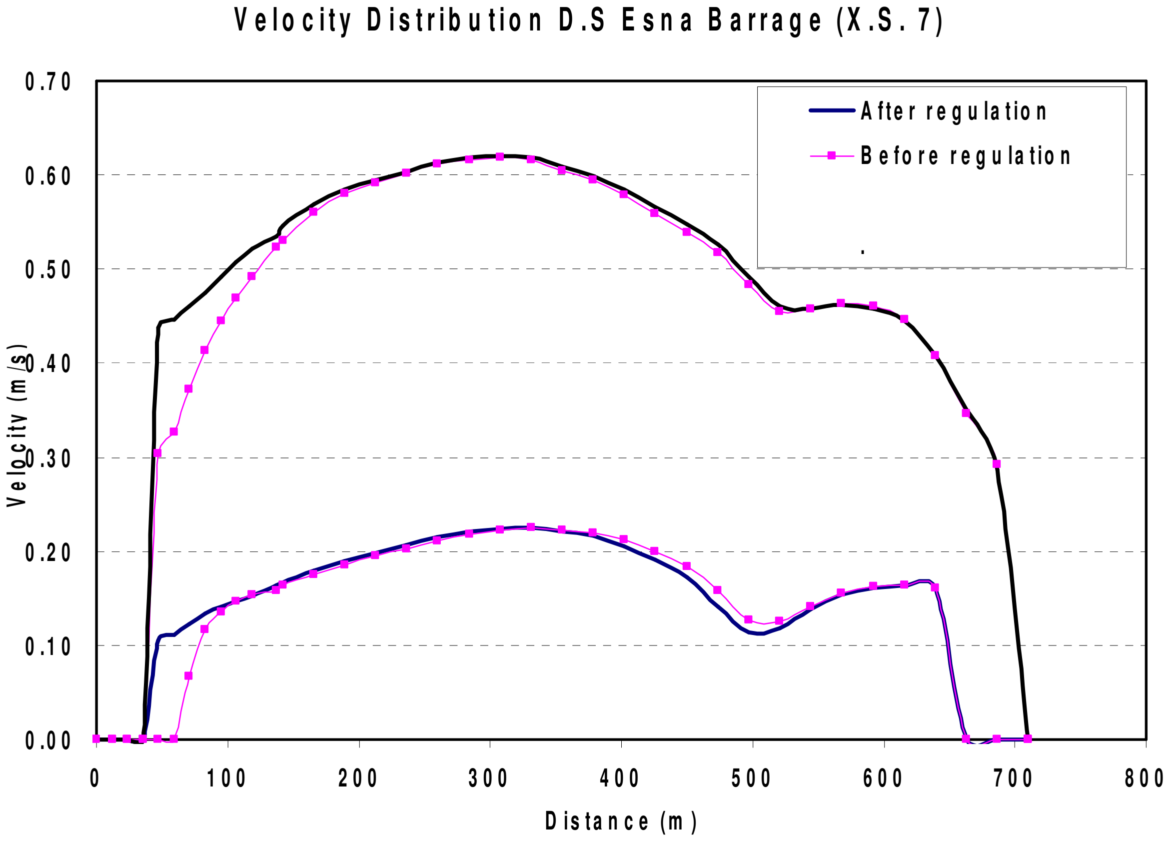


Figure 7: Numerical model simulation for the impacts of regulation work on velocity

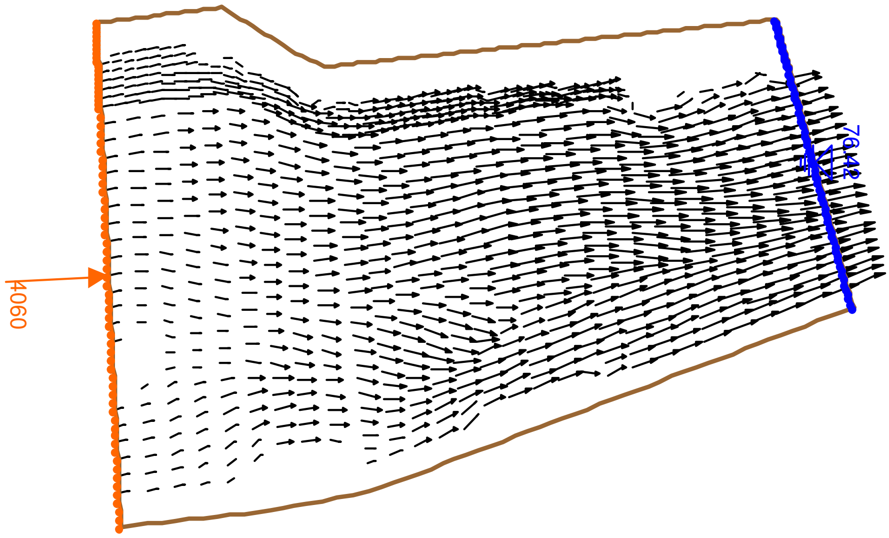


Figure 8: Velocity vectors after applying the regulation works

The model results indicate that there are no adverse impacts for the applied work in terms of morphological parameters. However the prediction of sediment transport process need to be retested after field implementations. This may be attributed to the fact that the measured field velocity was quite low. As the barrage is still under experimental operation and some of the construction phases are continuous. The proposed regulation works satisfied the required improvements. These findings prove that models can give technical support to the decision making system for future development. As one of the proposed regulations was temporary, the study recommended that dredging should be periodically tested and repeated where deepening is needed.

List of symbols

The following symbols are used in this paper and they are defined wherever they first appear:

H = water depth
z = vertical direction
z_b = the bed elevation
$z_s = z_b + H$ = water surface elevation
u = horizontal velocity in x direction
v = horizontal velocity in y direction
β_{uu}, β_{uv}, β_{vu}, and β_{vv} = momentum flux correction coefficients
$\alpha_x = \arctan(\partial z_b / \partial x)$
$\alpha_y = \arctan(\partial z_b / \partial y)$
$\alpha_z = \arccos(1-\cos^2 \alpha_x - \cos^2 \alpha_y)$
g = gravitational acceleration
Ω = Coriolis parameters
ρ = water mass density, which is considered constant;
τ_{bx} and τ_{by} = bed shear stresses acting in the x and y directions, respectively;

τ_{sx} and τ_{sy} = surface shear stresses acting in the x and y directions, respectively;
τ_{xx} , τ_{xy} , τ_{yx} , and τ_{yy} = shear stresses caused by turbulence;
q = unit source (inflow) or a unit sink (outflow) term.
C = concentration;
t = time;
u = flow velocity in x direction;
x = primary flow direction;
v = flow velocity in y direction;
y = direction perpendicular to x;
D_x = effective diffusion coefficient in x direction;
Dy = effective diffusion coefficient in y direction;
α_1 = a coefficient for the source term;
α_2 = the equilibrium concentration portion of the source term.
ρ = water density
u^* = shear velocity
S_t = total sediment load transport,
u^{-} = mean flow velocity,
Δ = relative water density (1.65),
b = flow width,
υ = kinematic viscosity,
u_{*b} = bed shear velocity,
R_b = hydraulic radius,
d_{35} = particle diameter of bed material
ppm = part per million

ACKNOWLEDGEMENT

The authors are highly recognized The General Governorate of New Esna barrages for their support and assistance. Also thanks are due to NRI hydrographic survey team for data collections.

REFERENCES

[1] HRI, Additional Esna Lock Project, Final Report No. 28/2002, by Roshdy, M., and El- Kassabgy, M. under the supervision of El-Desouky, I., January 2002.
[2] Attia, K., and El Sersawy, H., Morphological Characteristics of the Nile River Downstream New Esna Barrages, Nile Research Institute (NRI) Technical Report in Arabic, April 2004.
[3] Attia, K., and El Sersawy, H., Design of Tourism Berth Downstream New Esna Barrages, NRI Technical Report in Arabic, May 2004.
[4] Attia, K., and El Sersawy, H., study on Realignment of West Side of the River Nile Downstream New Esna Barrages Using Mathematical Models, NRI Technical Report in Arabic, July 2004.
[5] Ackers, P., and White, W. R., Sediment transport: new approach and analysis, Hydraulics div., ASCE, Vol. 9, No. HY11, 1973.