LOCATION OF TOSHKA PROJECT FROM SEDIMENTATION POINT OF VIEW

Tarek Mohamed Abdel Aziz

Head of Hydrographic Survey and Mapping Unit, Nile Research Institute (NRI)
National Water Research Center (NWRC), EL-Qanater, P.O. Box 13621, Egypt
E-mail: Aziztm@hotmail.com

ABSTRACT

The south valley canal aims to create a new civilization and society where it is expected to serve water for the agriculture of about 540000 feddans. The entrance of this canal is located 10 km downstream Toshka spillway (256 km upstream Aswan High Dam-AHD). The most important component of Toshka project is the huge pump station. It consists of 24 pumps (18 are operational, 3 are stand by and 3 for the future expansion). The pumps take water from AHD reservoir through an open channel intake of about 4.5 km length extends from AHDR to the suction basin of the pump station. It is of extreme importance to predict the amount of sediment at the location of this intake and also the time needed for sediment to reach this channel. Two models were used for this purpose for the importance of Toshka project. The first one is a two dimensional model for prediction of bed profile in the longitudinal and transverse directions in Aswan high Dam reservoir (AHDR-2D). This model consists of empirical equations derived for fixed cross sections along AHDR using the actual measurements during the period from 1964 to 1995. The second model is Surface Water Modeling System (SMS). This model includes two-dimensional finite element, two-dimensional finite difference and one dimensional backwater modeling tools. This model shows that the average thickness of deposited sediment at Toshka cross section is 0.35 m in year 2005 from the beginning of reservoir operation (in May 1964). This is very close to the actual measurements and very close also to the results of the first model. Consequently, more runs were done for SMS model to predict the average thickness of deposition in year 2040. It is expected to reach about 1.27 m, which indicates that the rate of deposition is about 0.026 m every year at the location of pump station. Accordingly, it is concluded that the location of Toshka project (pump station and an open channel intake) is very suitable from sedimentation point of view.

Keywords: Toshka project, sedimentation, two-dimensional model, Aswan High Dam reservoir.

INTRODUCTION

The high density of population in the River Nile valley and delta and the spread of shanties that could threaten social peace and security made of expansion and redeployment of Egyptian communities, a necessity and not an option. The triggering of the first signal announcing the implementation of “South Egypt Development Project” Toshka is a true expression of the dream that the Egyptians have entrained, since time immemorial, and longed for its realization. Toshka project is a strategic vision that will drive Egypt to the horizons of the 21st century, embracing a number of development fields covering activities in the field of agriculture, industry, transport, communication and roads, as well as social aspects and services.

For the agricultural water requirements, it has been estimated that the average evapotranspiration for the project area is 4.97 mm daily. Accordingly the annual water required for each feddan within the area has been calculated to be within the range of 8000 m^3 including leaching requirement which is estimated at 20 % of the total water requirement. This amount can definitely be much less in case of using modern irrigation technology. The total amount of water required will be within Egypt’s share of Nile water, defined by the 1959 Nile Water Agreement with Sudan.

The project starts with a giant major pumping station to be set up on the left bank of Aswan High Dam Reservoir 10 km north of Khor Toshka, as indicated in figure 1, to be constructed in 4 years starting 1st January 1998. The station has been designed to have a maximum static lifting of about 52.5 m to guarantee its operation when the water level in Aswan High Dam reservoir reaches its lowest level of storage (147 m above Mean Sea level). 24 pumps, each with a discharge capacity of 16.7m^3/sec. will be housed inside the pumping station, 18 pumps of which will be on duty, 3 will act as standby units, while the rest 3 will be for future expansion. The most important component in the project is the pump station, the designed discharge of pumping station was estimated to be about 300 m^3/sec (25 million m^3/day) subject to rise if necessary while withdrawal would be from the intake through an open basin and discharge through pipelines. So it is very important to keep this intake free of sediment. Therefore the prediction of sediment transport and its rate towards the intake of the pump station is necessary to find out the suitable way and time to deal with the sediment in the open basin. Two models were used for this prediction. The first one calls (AHDR-2D) prepared by (Abdel-Aziz [1]) and the second one calls SMS (surface water modeling system) prepared by (Thomas & McAnall [2]).

THE FIRST MODEL (AHDR-2D)

The bases of this model are group of empirical equations derived for fixed cross sections along AHDR using the actual measurements during the period from 1964 to year 1995. It should be mentioned that there is only one scientific trip every year to measure cross section, velocity, suspended sediment concentrations, bed material and water level at these cross sections. The derived empirical equations for Toshka cross section were based on the data for the period from 2000 to 2004. The different steps of calculation and the derived empirical equations and its application at Toshka cross section; where the location of pump station and its open channel intake, (256 km upstream Aswan High Dam) is as follow:-

1- Estimation of sediment load

The sediment load is a function of water discharge, suspended sediment concentration, and time. The following equation was used to get the value of sediment load (El-Moattassem & Makary [3])

$$Q_s = Q_w * C_{ss} * T \tag{1}$$

where Q_s is the sediment load in Kg, Q_w is the discharge at the section in m^3/sec, C_{ss} is the suspended sediment concentration in ppm, and T is time in sec.

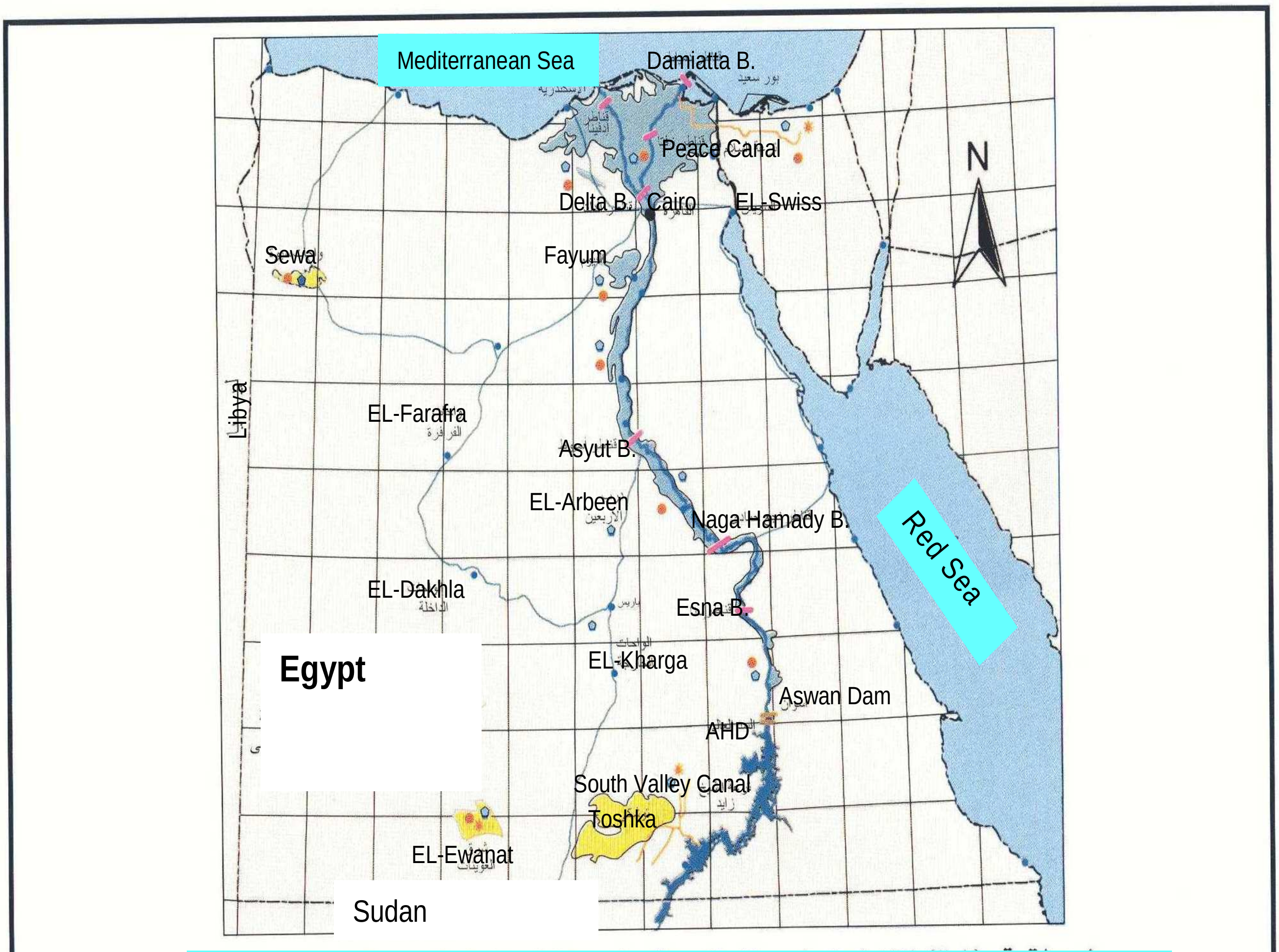

Figure 1: Location of Toshka Project in Egypt

The estimation of sediment load Q_s for a certain time period needs a continuous record of discharge and the corresponding suspended sediment concentration for the whole period at each section. Since there is no continuous record of discharge or suspended sediment concentration at the measured cross sections, and knowing that the only available continuous record of discharge is at Dongola station (780 km upstream Aswan High Dam), therefore the records of Dongola station were used to estimate the corresponding suspended sediment load at the measured cross sections including Toshka cross section. The relationship was found to have the following form:-

$$C_{ss} = A * Ln(Q_w) + B \qquad (2)$$

In which C_{ss} is the suspended sediment concentration at cross section in ppm, Q_w is the corresponding discharge at Dongola in million m^3/day, A and B are constants. The derived equation for Toshka cross section is indicated in figure 2.

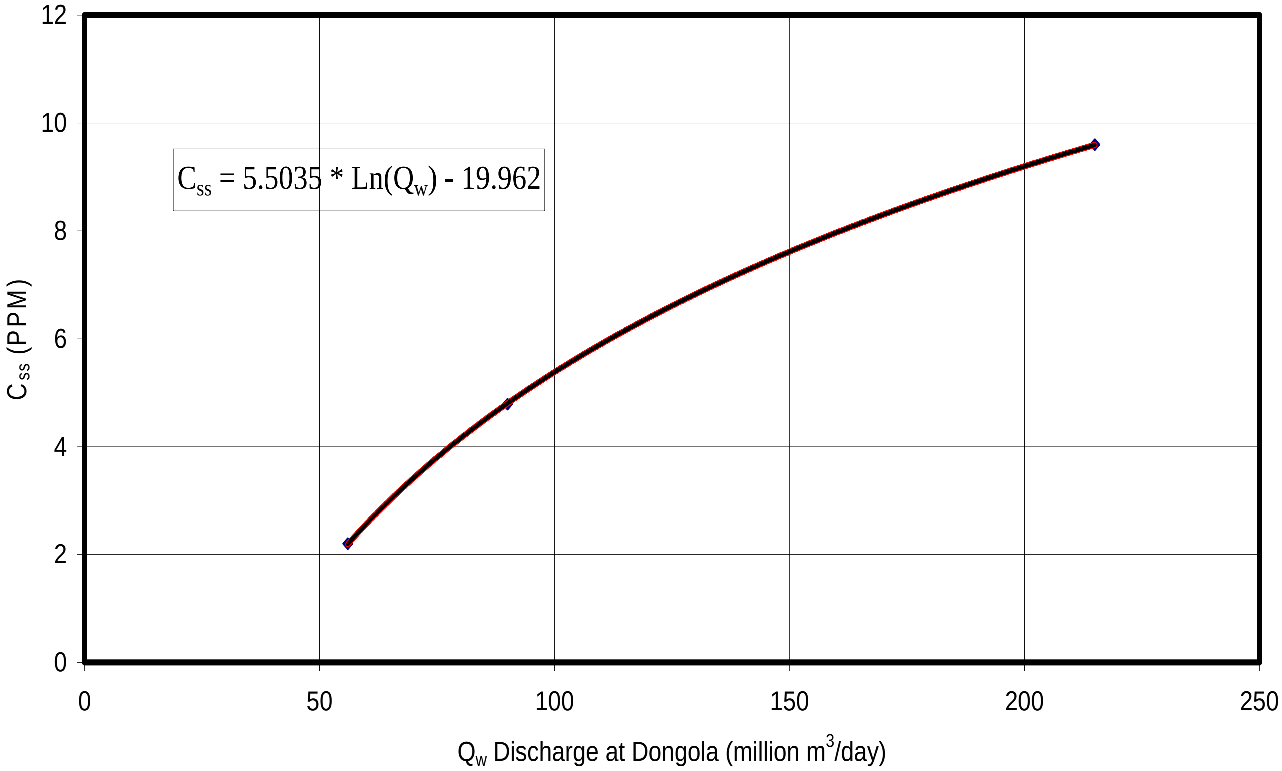

Figure 2: Correlation between discharge at Dongola and suspended sediment concentration at Toshka cross section

The sediment load at any cross section is corrected considering the ratio of the discharge at Dongola to the corresponding measured discharge; during the scientific trip, at this cross section. This corrected ratio will be introduced as an adjustment factor for the discharge (R).

2- Adjustment factor for the discharge (R)

The discharge at any cross section at a certain time was calculated using the measured cross section, the water level, and the measured velocities at the three vertical lines across the section by applying the equation of (Jansen [4]) as follows:

$$Q_w = \sum (A_i * V_i) \quad (3)$$

where Q_w is the discharge in m^3/sec, A_i is the area of one strip of the three strips of the section in m^2, V_i is the mean velocity at this strip in m/sec.

Knowing the discharge at Dongola, the corresponding discharge at any cross section can be obtained using the factor R considering the lag time of discharge between Dongola and this cross section. The calculated value of the adjustment factor for discharge in case of Toshka cross section R = 25.123 as indicated in table 1.

Table 1: The adjustment factor for discharge (R) at Toshka cross section

Date	**W.L. (m)**	**x-section area (m^2)**	**Average velocity m/s**	**Q_w at Toshka m.m^3/d**	**Q_w at Dongola m.m^3/d**	**Adjustment Factor (R)**
Nov.2000	180.62	272450	0.095	2236.2	215	10.4
Jan. 2002	179.96	271538	0.119	2791.8	90	31.02
Mar. 2004	176.19	249334	0.104	2240.4	66	33.95
Average						**25.123**

The high values of (R) may be explained by many reasons. The first one is the limited number of velocity measurements; only three locations along the transverse direction and once per year. The second one is the width of the cross section which is very wide; about 10 km. The third one is the big distance between Toshka and Dongola cross sections; about 424 km. The fourth one is the lag time between these sections; about 5 days. All theses reasons may cause a big deviation between the calculated discharge at Toshka and the corresponding measured discharge at Dongola.

3- Estimation of deposited sediment volume

The density of deposited sediment at any time step is required to get the sediment volume. The theoretical work has not progressed to the point at which it can be used to predict densities of reservoir deposits. The empirical relations for estimating the density of deposited sediment in rivers or reservoirs give the density of deposits in reservoirs at the end of definite number of years or the average density of sediments after any number of years of operation during which deposits accumulated at a uniform rate. In the present study, the density of sediments is needed for each time step where the rate of deposition is not uniform. Therefore, an empirical relation was used for this purpose. This relation was presented by (Abdel-Aziz [5]). In this equation the average bed density is calculated as a mass balance of the existing consolidating sediments influenced by deposition or erosion.

4- Estimation of deposited area

It is assumed that each cross section represents a certain reach considering that the section is in the mid distance of this reach. It is assumed also that the calculated deposited volume for each cross section will be distributed uniformly along the reach represented by this section. Using the estimated deposited volume and the lengths of different reaches we get the deposited area as follows:

$$A = Vol / L \qquad (4)$$

where A is the deposited area at each cross section in m^2, Vol: is the deposited volume along the reach represented by this section in m^3, and L is the length of this reach in m.

5- Adjustment factor for deposited area (Z)

The calculated deposited area at each cross section should represent the measured deposited area during the same period. In order to satisfy this condition the calculated deposited area is to be adjusted accordingly. The calculated deposited area was compared to the measured one during successive periods of two years starting 1980 to 1992. As the field trips usually do not take place at the same date every year, the measured and estimated deposited areas were calculated for different time periods depending on the actual dates of the field trips. For example a period of 17 months from 20th of June 1980 to 10th of October 1981 was used for calculation as a first time span and 8 months from 10th of October 1981 to 20th of June 1982 were used as a second time span. The first time span (17 months) contains two periods of the rising stage, where most of the sediment loads come with water flow and one period of the falling stage, where the sediment load is low. While the second time span (8 months) does not contain any rising stage, therefore the sediment load was low. This may explain the difference between the estimated deposited areas in the successive periods. To overcome this condition it was proposed to add the calculated deposited area of two successive years and compare it with the measured values for the same period. This has been done for four periods namely the years from 1980 to 1982, 1986 to 1988, 1988 to 1990, and from 1990 to 1992 to get the ratios Z1, Z2, Z3, and Z4 respectively. The arithmetic mean of these ratios was calculated to get the average value. This is called the adjustment factor for the deposited area Zi (i is the section number). This factor adjusts the calculated deposited area at any section during any period. So the calculated deposited area will be divided by this adjustment factor to get the corrected deposited area that will be distributed in the transverse direction as follow:

$$Ad = A/Zi = (Vol / L) / Zi \qquad (5)$$

where Ad is the adjusted calculated deposited area in m^2, A is the calculated deposited area in m^2, Zi is the adjustment factor for the deposited area, Vol is the deposited volume in m^3, and L is the length of the reach in m and it equals 27000 m at Toshka. In case of Toshka cross section two periods were used; the first one from 18th November 2000 to 1st January 2002 and the second one from 1st January 2002 to 1st

March 2004. These are the actual dates of field trips. The results are indicated in table 2, where it was estimated that the adjustment factor for deposited area at Toshka cross section = 95.37.

Table 2: The adjustment factor for the deposited area (Z) at Toshka cross section

Period	Q_w m.m^3/d	C_{ss} Kg/m^3	Q_s Kg	density Kg/m^3	Volume m^3	Cal. Area m^2	Meas. Area m^2	Z
1st	2791.8	4.79	$4.71411*10^{11}$	1100	$4.28555*10^{8}$	15872	239	66
2nd	2240.4	2.2	$3.3217*10^{11}$	1100	$3.01972*10^{8}$	11184	90	124
Average								**95**

The high values of (Z) may be due to the same reasons of high values for (R) beside the long distance represented by Toshka cross section which equals 27 km. All theses reasons may cause a big deviation between the calculated deposited area and the corresponding measured one at Toshka cross section.

6- Estimation of deposited depth

It is assumed that the calculated deposited area will be distributed in the transverse direction similar to the velocity distribution curve to get the deposited or eroded depth. The velocity distribution at each cross section is a function of the longitudinal distance, the transverse distance, and time. Then each cross section is divided into strips of equal widths of 20 m. The average of the two depths at the beginning and the end of each strip is calculated and considered constant along the total width of the strip. The velocity curve is represented by the following equation:-

$$V = C_1 + C_2X + C_3X^2 + C_4X^3 + C_5X^4 \qquad (6)$$

where V is the calculated velocity in m/sec X: is the measured distance in the transverse direction starting from the left bank in meter, C_1, C_2, C_3,C_4, and C_5 are coefficients developed by (Abdel-Aziz [1]). Then the thickness of deposited / eroded depth will be added / subtracted to the depth of each strip to get the new depth of the strip. These new depths of the different strips will give the new cross section. This calculated cross section will be compared to the measured cross section at the same date. The one-dimensional model presented by (Abdel-Aziz [5]) was first applied to check weather deposition or erosion will take place at each section of AHDR during any period. The estimated velocity curve in the transverse direction at Toshka cross section derived from the actual measurements during the period from 2000 to 2004 and indicated in figure 3. The coefficients for distribution curve of velocity at Toshka cross section are: $C_1 = 9.7*10^{-13}$, $C_2 = 7.3*10^{-5}$, $C_3 = -1.67*10^{-8}$, $C4 = 1.33*10^{-12}$, $C_5 = -1.99*10^{-16}$.

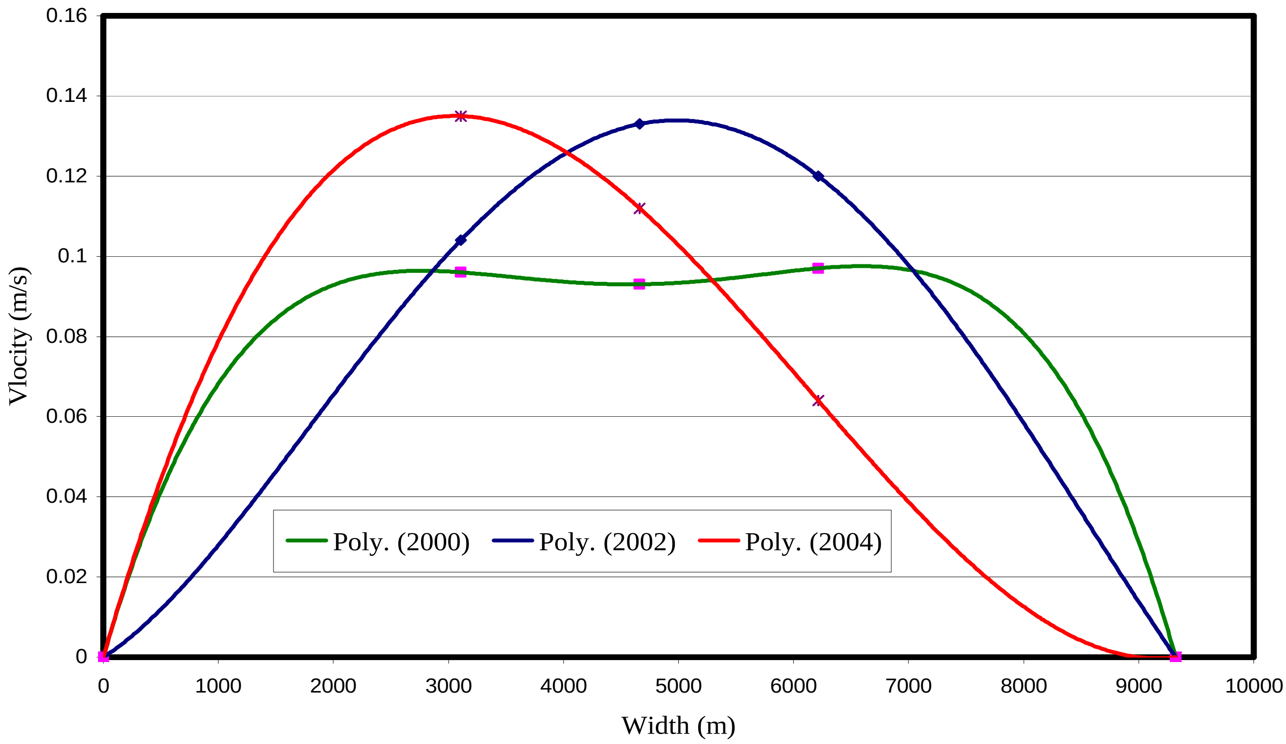

Figure 3: Velocity Distribution at Toshka cross section

7- Verification of results

The measured cross section in November 1992 was taken as reference, and the cross section in March 2004 was estimated using the proposed methodology without any change in the adjustment factors. The estimated cross section was compared to the measured one and it is noticed that there is a good agreement between both of them as shown in figure 4. Accordingly, it is concluded to use the same method to predict Toshka cross section until year 2040 and to estimate the thickness of deposition at the location of pump station and the open channel intake.

8- Prediction of deposited depth until year 2040

Based on the measured cross section in March 2004 and assuming that the discharges at Dongola will continue in the same way of filling the reservoir to reach a water level of 182 m and then decreasing until water level 150 m, the predictions for the discharge at Donola station and suspended sediment concentration, the sediment load, the density of deposited sediment, the sediment volume, the deposited area, and the deposited depth at Toshka cross section have been calculated; using the equations from 1 to 6, to get the deposited depth in January 2040. The prediction shows that the deposition will continue in a similar way at the whole width of Toshka cross section and the rate of deposition will equal 0.02 m per year with a total depth of deposition from March 2004 to January 2040 equals 0.72 m only.

It should be mentioned that AHDR-2D model was developed especially for AHDR. In spite of its good results; and because of the high importance of Toshka project to Egypt, It was seen to assure these results with another international model. Accordingly, SMS model was applied at the area of Toshka pump station as follow.

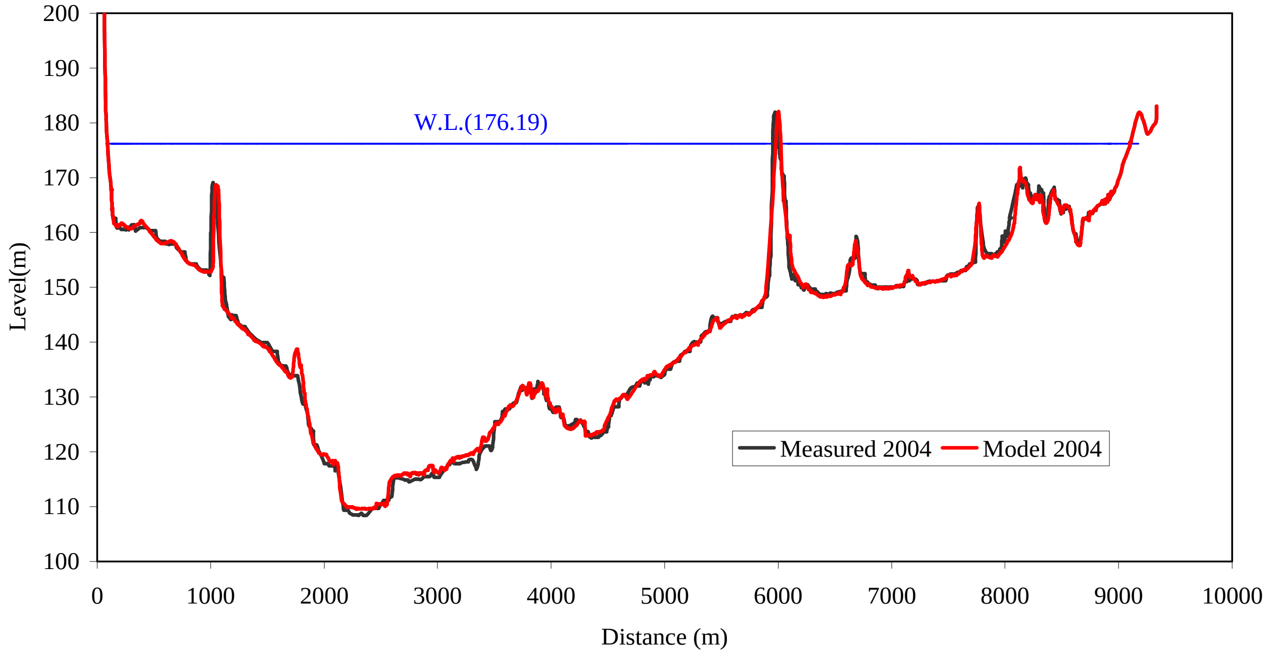

Figure 4: Measured and estimated Toshka cross section

THE SECOND MODEL (SMS)

Surface Water Modeling System (SMS) consists of a family of numerical models that provide multidimensional solutions to open-channel flow and sediment transport problems (Thomas & McAnally [2]). The SMS modeling system is the Corps of Engineers' standard for general-purpose modeling of two-dimensional, depth averaged open-channel flow and sediment transport problems. The SMS package consists of Finite Element Surface Water modeling System (FESWMS) model and SED2D model. The FESWMS model is a two-dimensional, depth-averaged hydrodynamic model used to compute water levels and depth averaged velocities. SED2D model is a two-dimensional, depth-averaged sedimentation model used to compute the scour, sediment transport, and deposition of bed sediments. During a simulated flood event, FESWMS was used to compute water depth and depth-averaged velocity at each node in the mesh. Then these data were used by SED2D to compute bed shear stress. SED2D compares the bed shear stress with the measured or estimated physical properties of the bed material to compute the sediment transport rate and cumulative scour or deposition at each node of the mesh in the study area. This indicates that the solution of the flow characteristics and bed profiles changes are uncoupled, i.e. the flow characteristics were solved first by

FESWMS, and then the results were used as an input to the SED2D to solve the sediment problems and to estimate the bed changes.

The most recent data was collected for the period from 1998 to 2004. These data includes bathymetric survey, bed material samples, and velocity measurements. Condensed hydrographic survey was carried for the area from 14 km upstream Toshka cross section (270 km upstream AHD) to 14 km downstream Toshka cross section (242 km upstream AHD) with 29 cross sections with an interval of about 1km.

1- Mesh Generation

The study area is defined by unstructured grid composed of quadrangular and triangular elements. Water depths are specified at the nodes of each element composing the mesh. Water surface elevation and components of velocities are computed at the nodes. Figure 5 shows the finite element mesh, developed for the area of study before dredging the pump station intake in AHDR. The mesh was developed from the bathymetric data.

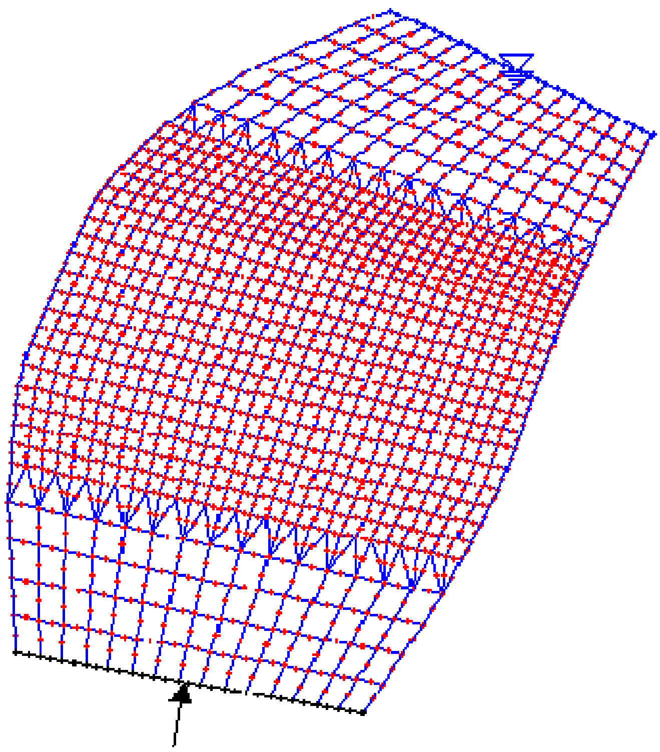

Figure 5: The finite element mesh for the area of study

The coordinates of the nodes were referenced to the WGS84 ellipsoid with Universal Transverse Macerators (UTM) Projection. The bed levels of the mesh nodes were calculated by the linear interpolation between the mesh nodes and the bathymetric data. Figure 6 represents the bed elevation of the mesh geometry for the area of study.

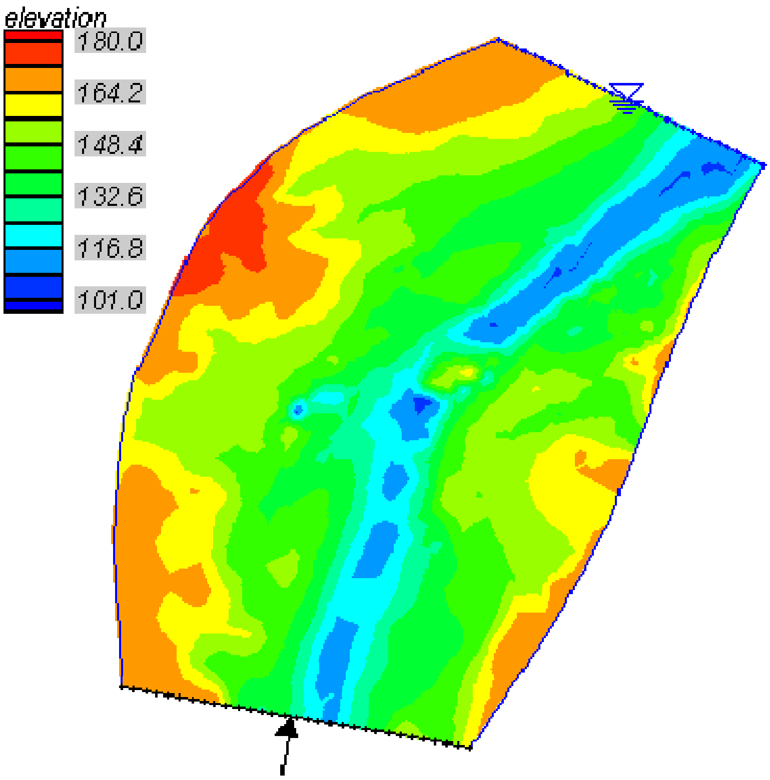

Figure 6: The bed elevation of the mesh geometry for the area of study

2- Initial conditions and boundary conditions

In addition to mesh geometry, the hydrodynamic model FESWMS requires input data describing initial and boundary conditions. The initial conditions were defined as the initial bed elevations for all nodes of the grid, which were collected during the field survey in 1998. The boundary conditions are inflow, outflow, and side boundary conditions. The inflow boundary condition is defined as the inflow discharge to the beginning of the study area. It was taken as the discharge into AHDR at Shalal Dal (500 km upstream AHD), since there is no lateral inflow or outflow from Shalal dal to the study area. The outflow boundary condition is defined as the upstream water level at the end of the study area and it was taken as the water level just upstream Aswan High Dam corresponds to the inflow discharges into AHDR. The initial conditions of bed gradation for the study area were based on the analysis of the collected samples. The samples were analyzed to determine particles size distribution, the particle D_{50} and the associated fall velocity of suspended sediment particles.

3- Model simulation and calibration

Model simulation and calibration were performed to ensure adequate prediction for hydrodynamic conditions. The model was simulated and calibrated using the available data in the period from 1998 to 2000 by using water discharge to AHDR and water level just upstream Aswan High Dam as an upstream and downstream boundary conditions as shown in table 3.

Table 3: Water discharges and water levels for the calibration process

Date	Discharge (million m^3/day)	Water Level upstream AHD (m)
March 5, 1998	80.00	177.00
July 12, 1999	183.50	175.84
May 1, 2000	98.00	178.44

During the model calibration, the original bed levels before dredging the pump station intake were used. Calibration was performed primarily through adjusting the friction coefficient (Manning coefficient) which was specified globally throughout the model domain. A comparison between the calculated and measured velocities, as presented in table 4, shows a good agreement between the measured and calculated velocities in the area of study.

Table 4: Calculated and measured velocities for the calibration period

Year		Water Velocity at Axis of Pump Station Intake (m/sec.)		
		East	Middle	West
1998	Calculated	0.017	0.033	0.042
	Measured	0.010	0.030	0.050
1999	Calculated	0.048	0.078	0.032
	Measured	0.066	0.073	0.051
2000	Calculated	0.074	0.101	0.073
	Measured	0.096	0.093	0.097

4- Model Verification

The model was verified using another set of data for water discharge and water level in AHDR for the period from 2001 to 2004 as shown in table 5.

Table 5: Water discharges and water levels for the verification period

Date	Discharge (million m^3/day)	Water Level upstream AHD (m)
July 26, 2001	219.00	175.74
January 1, 2002	210.00	179.96
March 20, 2004	71.50	176.19

A comparison between the calculated and measured velocities in front of the pump station intake in the verification period shows a good agreement also as shown in table 6. Accordingly, it was concluded that the model adequately simulates hydrodynamic processes. Figure 7 shows the values and directions of velocities in the area of study for water level (177.00) upstream Aswan High Dam.

Table 6: Calculated and measured velocities for the verification period

Year		Water Velocity at Axis of Pump Station Intake (m/sec.)		
		East	Middle	West
2001	Calculated	0.006	0.022	0.008
	Measured	-	-	-
2002	Calculated	0.095	0.102	0.103
	Measured	0.104	0.133	0.120
2004	Calculated	0.098	0.088	0.055
	Measured	0.135	0.112	0.064

5- Model Prediction

The model was applied to predict the changes of bed elevation within the study area due to sediment transport in front of pump station intake. The hydrograph of the water levels and inflow discharges inside AHDR was applied from year 1998 to year 2015. It was taken into consideration that the maximum suction by the pump station from AHDR is 25m.m^3/day. The results show that the open channel intake will be deposited with an accumulated depth of 0.35 m at year 2005, and 0.48 m at year 2010, and 0.63 m at year 2015. Figure 8 shows the distribution of deposited sediment within the study area. The results of deposition rate were used to predict the accumulated deposition until year 2040 in front of the pump station intake and it was found that the deposition depth at year 2040 will be about 1.17 m. This indicates that the rate of deposition from year 2005 to year 2040 using SMS model will be 0.026 m every year with a total depth equals to 0.92 m. It should be noted that this result is very close to the predicted value by the first model (AHDR-2D) which equals to 0.72 m.

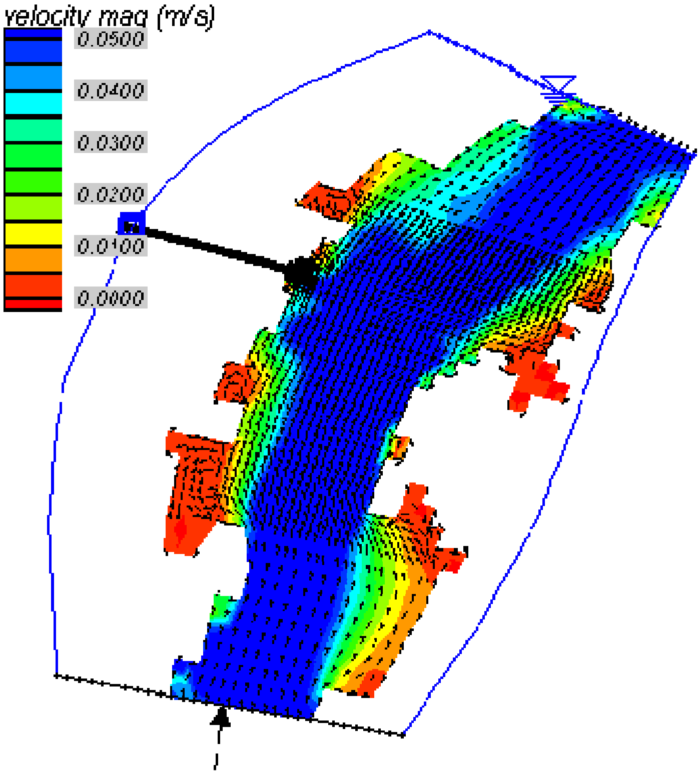

Figure 7: Values and directions of velocities for water level 177.00 upstream AHD

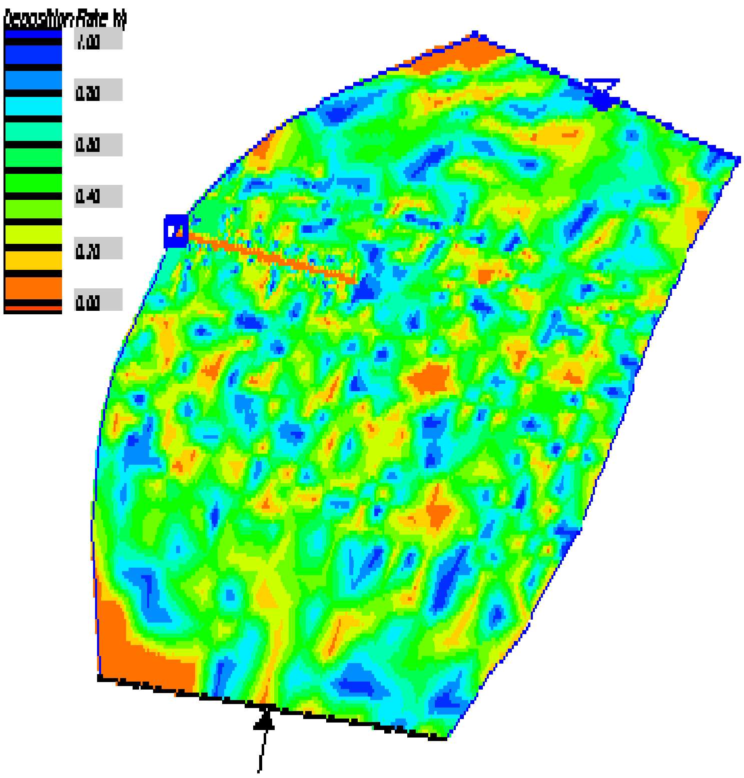

Figure 8: The distribution of deposited sediment within the area of study

CONCLUSIONS

Based on the results of the two dimensional model (AHDR-2D) for prediction of bed profile in the longitudinal and transverse directions in AHDR in the region between inlet cross section and location of pump station, it was concluded that:

1. The estimated bed shape is close to the measured one at the location pump station and the open channel intake.
2. The rate of deposition at the location of pump station intake is about 0.02 m every year. Consequently the accumulated deposited depth will be 0.72 m by year 2040.

Based on the results of the two dimensional surface water modeling system (SMS) the dredged channel in front of the pump station will be deposited with a rate of 0.026 m every year. Consequently the accumulated deposited depth at the location of pump station and the open channel intake will be 0.92 m by year 2040, which is very close to the results of (AHDR-2D).

Finally, it was concluded that the location of Toshka project (pump station and open channel intake) is very suitable from sedimentation point of view where it is expected to stay stable for about 35 years at least. Additionally, when it starts suffering from deposition, the rate will be very small.

RECOMMENDATIONS

1- The bathymetric survey and the other field measurements should be carried out regularly two or three times per year instead of one, especially around the location of pump station to follow up the amount of deposition in the open channel intake.

2- Production of contour maps for the bed levels around location of Toshka project during the field trip will help to find out any change around the pump station very fast and consequently the suitable action will be taken.

REFERENCES

1. Abdel-Aziz, T.M., Prediction of bed profile in the longitudinal and transverse directions in AHDR, Ph.D. Thesis, Cairo University, Cairo, Egypt, 1997.

2. Thomas, W.A., McAnally, W.H., Finite Element Surface Modeling System, Two Dimensional Flow in a Horizontal Plane. User’s Manual, Highway Research Center, McLean, Virginia, 2101-2296, 1984.

3. El-Moattassem, M., and Makary, A.Z., Sedimentation balance in the Aswan High Dam Reservoir, Report No.110 Nile Research Institute, Cairo, Egypt, 1988.

4. Jansen, P.Ph., L. Van Bondegom, J. Van den Berg, M. De Vries, and A. Zanen, Principles of river engineering, The non-tidal alluvial river, London, 1979.

5. Abdel-Aziz, T.M., Numerical modeling of sediment transport and consolidation in the Aswan High Dam Reservoir, M.Sc. Thesis, Laboratory of hydrology, Free University of Brussels, VUB, Belgium, 1991.

6. Abou Seida et al., Effect of Sediment Transport in High Aswan Dam Lake on the Entrance to the Pump Station for Sheikh Zaid Canal, Center for Water Projects Study and Design, Cairo University and Nile Research Institute, National Water Research Center, Cairo, Egypt, 2000.

7. Ahmed, F.A. et al., Annual reports of Sedimentation in Aswan high Dam Reservoir, Nile Research Institute, National water Research Center, Cairo, Egypt, 1998 - 2004.

8. Donnell, B.P., Joseph, V., Letter, Jr., Roig, L.C., Thomas, W.A., McAnally, W.H., and Adamec, S.A., Jr., User Manual of SED2D, McLean, Virginia, U.S.A., 2000.