Available online www.jsaer.com

Journal of Scientific and Engineering Research, 2016, 3(4):302-312

Research Article

ISSN: 2394-2630
CODEN(USA): JSERBR

Sedimentation Analysis and Prediction for Aswan High Dam Reservoir

Gamal H Elsaeed[1], Medhat S Aziz[2], Wael M Ziada[2]

[1]Department of Civil Engineering, Faculty of Engineering, Shobra, Banha University, Cairo, Egypt
[2]Nile Research Institute, National Water Research Center, Cairo, Egypt

Abstract The High Aswan Dam has been constructed during the sixties to protect Egypt from high flood hazards and to provide the required water demand during low flood years. Due to the dam construction and lake formation, the flow downstream the dam has become more controlled and the suspended sediment concentration peaks have been reduced significantly and deposited upstream the dam. These deposited sediments are affecting the storage capacity of the lake by reducing the storage capacity of the lake. This paper is an attempt to predict the future deposition in the Aswan High Dam Reservoir, in order to estimate the effective life span of the reservoir. A numerical model (Delft3D) was implemented to simulate the sedimentation along the reservoir. During the course of this study, the calibration and validation of the model for flow and sediment deposition were applied during the period 2010–2012. A good agreement, between the observed and modeled results for the whole domain, was obvious. Confident with the obtained results, the model was further used to predict the sediment deposition in the reservoir during the period 2010–2025.

Keywords Aswan High Dam Reservoir, Aswan High Dam, Reservoir Sedimentation, Lake Modeling, Delft3D.

Introduction

Many dams exist along the Nile River for various purposes. The sedimentation, within their reservoirs, reduces their capacity and their practical life span. The Sennar Dam was constructed on the Blue Nile (Sudan) for irrigation purposes. Due to the sediment deposition over a span of 61 years, the reservoir had lost 71% of its original capacity. The Roseires Dam was constructed on the Blue Nile (Sudan) to store water for irrigation. It lost 36% of its original capacity in a span of 28 years, [1].

As for the Aswan High Dam, it created a reservoir on upstream which is Aswan High Dam Reservoir (AHDR).AHDR is the second largest man-made reservoir in the world it extends from the southern part of Egypt to the northern part of Sudan with total length of about 500 km (350 km belongs to Egypt and 150 km belongs to Sudan). The Aswan High Dam was created (1964–1968). The width depends on the water level it averages about 12 km. The water level varies between 152 and 182m above the sea mean level.

It has storage capacity about 162 billion m distributed as follows:

- 90 BCM: live storage capacity between level 147m and 175m.
- 31 BCM: dead storage.
- 41 BCM: storage for high flood waters between levels of 175m and 182m.

This study was thus initiated with the objective of predicting the deposition volume in the Aswan High Dam Reservoir in order to estimate its effective life span. This was achieved by:

- Reviewing the literature related to reservoir deposition.
- Accumulating and analyzing data, choosing a study area and describing it.
- Defining the study area problem.
- Setting the study objectives.
- Planning the research methodology.
- Accumulating measurements.
- Simulating the reservoir area.
- Analyzing the results.

Literature Review

Based on the reviewed literature it had been found that the investigations that were executed to simulate and predict the sediment deposition in the Aswan High Dam Reservoir (AHDR), were concerned about two periods (i.e. pre-1985 period and post-1985 period). During the pre-1985 period, investigators concentrated on collecting and analyzing field data to study the characteristics of the reservoir and to deduce relationships between flow and sediment load. While in the post-1985 period, researchers started to develop mathematical models to describe the motion of both water and sediment flow to simulate the water surface and bed profile in the longitudinal direction. Among the researchers, that were concerned with reservoirs, were [2-5], and [6], and the following table (1) summarize their results.

No coarse sand was present in the reservoir. It was stated that 30%, of the sediment, by weight was carried as sand fraction, 40% silt, and 30% as clay fraction [2].

It was concluded that the average annual rate of sediment inflow was 130 million tons and the average annual rate of outflow was 6 million tons. Therefore, it was stated that the average annual sediment deposition was 124 million tons. The deposited sediment was estimated to be 1570 million tons during the 15 year observation [3].

The sediment balance in AHDR was studied during the period of May 1964 to December 1985. It was estimated the deposited volume to be 1650 million m^3. The calculated deposited volume from the hydrographic survey for the same period was 1657 million m^3 [4].

A one-dimensional numerical model was deveoped based on the continuity equation, the momentum equation, and the sediment continuity equation to estimate the change in the river bed profile in the longitudinal direction. It was concluded that the total volume of deposits accumulated inside the reservoir was 2650 BCM for the period 1964 to 1988. This value is nearly equal to the estimated deposited volume based on field measurements which had a value equal to 2760 billion m^3. As a result of these two models, it was concluded that the AHDR cross sections are highly irregular, especially in the transverse direction and that the change in the water depth is large. It was recommended that there was a need to develop a new approach based on two-dimensional models in order to predict the sediment deposition in the transverse and longitudinal directions [5-6].

Table 1: Life span related to pervious studies on Aswan High Aswan Dam Reservoir

Author	Year	Conclusion
[7]	Prior 1964	Dead zone 500 years
[7]	1970	Dead zone 750 years
[7]	1978	Dead zone 440 years
[3]	1980	Sedimentation 1570 million tons 15 years period between (1964–1979); dead zone 362
[8]	1982	Dead zone 408 year and total life 1580 years
[9]	1982	Dead zone 310 years
[10]	1997	Dead zone 311 years and live zone 1202 years
[11]	2008	Estimated that more than 6.285 billion tons (1964–2008)

Problem Definition

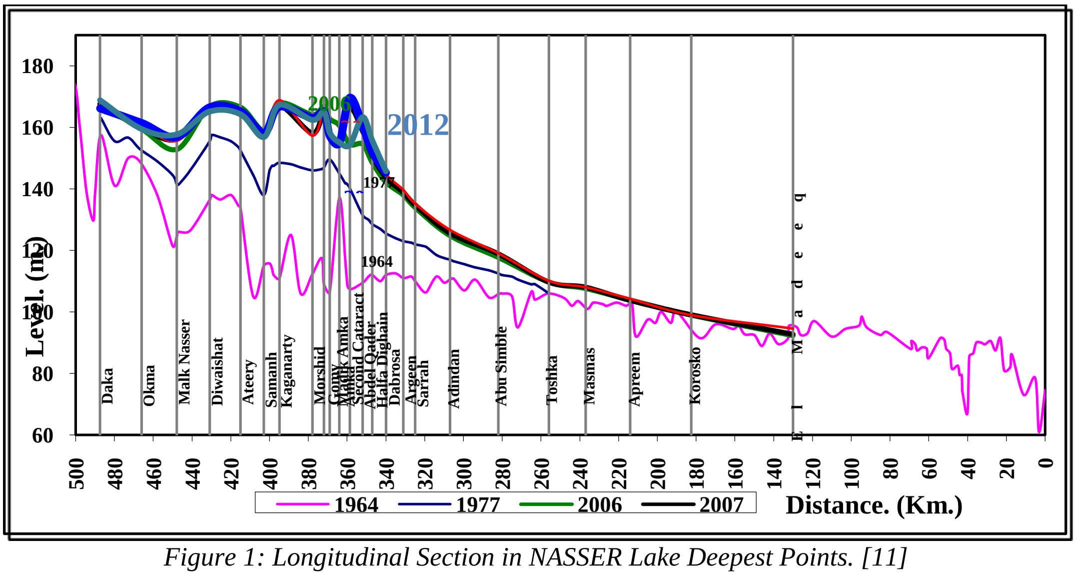


Figure 1: Longitudinal Section in NASSER Lake Deepest Points. [11]

The Aswan High dam reservoir bed level is undergoing continuous changes, such as deposition, erosion and delta formation. This change in bed levels occurred due to the flood suspended sediment load which affects the efficiency and the storage capacity of the lake. The Nile research institute monitors the bed levels, soil characteristics and water quality of the reservoir annually but only the southern part of the lake by 150 km length and unfortunately the sediment deposition is expanded further than this area.

So it was useful to use the available data to simulate the Aswan high dam reservoir to predict future progress of sediment transport along lake and monitor delta formation progress to determine life span of the lake and side effects of the future dam construction on lake sedimentation and storage capacity. The sediment deposition took place upstream AHDR, Fig. (2), and also the thalweg path during the period 1964-2012 is shown on Fig. (1).

Site Description

Aswan high dam reservoir AHDR is located at the southern part of Egypt (about 350 Km) and northern part of Sudan (about 150 Km) with total length 500 Km and average width 12 Km, this forms a huge surface area about 6500 square km at elevation182.00 AMSL and has a storage capacity about 162 km^3 of water. The average depth is about 25m and the maximum depth is 130m, the following figure shows the satellite image of the lake.

Figure 2 : Location of the Study Area

AHDR Bed Levels

A hydrographic survey of the study area was carried out by the Nile Research Institute "NRI" of the National Water Research Center during year 2010 and 2012. The survey was carried out along the area, between the two banks of the lake; by surveying cross sections spaced with varied intervals depend on the width of the lake at each cross section (ranged from 500m to 2000m spacing between cross sections) as illustrated in Fig (3).

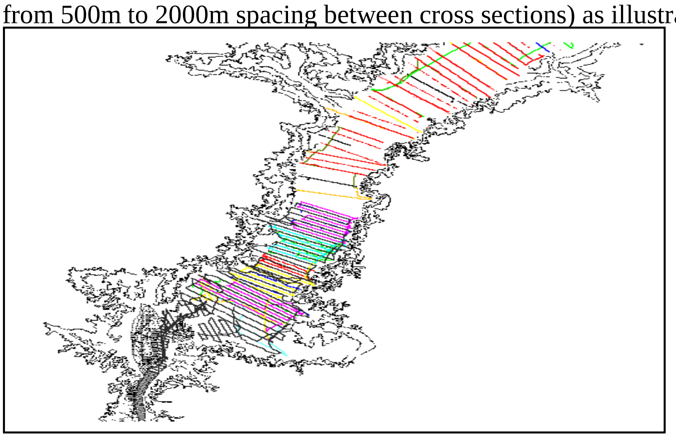


Figure 3 : Bathymetry Data of Study Area

In order to calibrate the selected mathematical model, vertical velocity distributions for twenty cross sections were measured as shown in Fig. (4). Velocity measurement locations were carefully selected to be expressive of the study area as shown in Fig. (4).

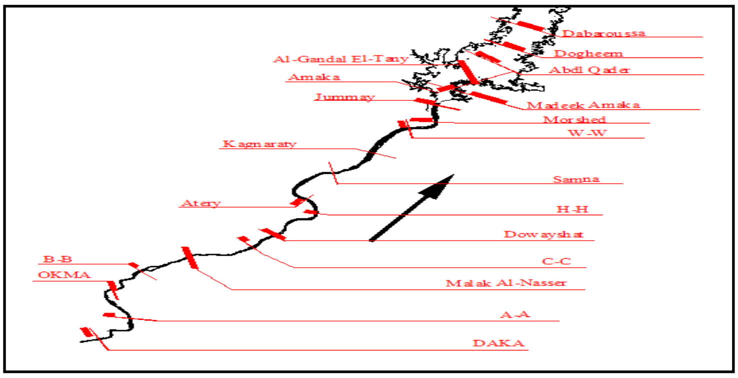


Figure 4: The Measured Velocity Locations

Also bed material properties are considered important parameters for calibrating the mathematical models as well as for their verification process. Many factors are interrelated to formulate the value of the roughness, grain size and concentration of suspended materials. Grab Sediment Sampler was used to collect 76 bed material samples from 20 cross sections.

The test result of collected bed samples revealed the following:

The geometric mean diameter D_{50} of the collected samples ranges between a maximum value of 0.433 mm which was recorded at point west side of C.S. El-Daka located at km 487 upstream HAD. While the minimum value of 0.0015mm was recorded at east side of cross section Abd El-Kader located at km 357 upstream HAD.

The mean diameter of the collected samples ranges between maximum value of 0.4962mm which was recorded at west side of C.S. El-Daka, While the minimum value of 0.0031mm was recorded at east side of cross section Abd El-Kader east

Also for The suspended sediment data available for the period 1966–1982 were used to establish a rising and falling stage rating curves for AHDR allowing for seasonal effects relating to the rising and falling stages.

The following equations were used for estimating the suspended sediment hydrograph at Dongola Station:

(i) For rising stage flow discharge hydrograph : $Q_s = 5.753*10^{-6}\ Q^{1.98}$

(ii) For falling stage flow discharge hydrograph: $Q_s = 2.695*10^{-7}\ Q^{2.347}$

Where Q is the discharge at Dongola Station in million m3/day and Qs is the sediment load in 10^9 kg/day. By applying these equations, the suspended sediment concentration hydrographs at the inlet boundary of the study area of the reservoir (Dongola Station) can be estimated for the period from 2010 to 2012 [12].

Hydrological Data

It is obvious that flow discharges and the corresponding water levels are essential data to simulate the hydrological characteristics of the study area. For this reason, daily monitoring of the passing discharges through the HAD and the upstream of AHDR and US HAD water levels. An average discharge of five years data between 2000 and 2012 were found for years 2002 to 2006 and these years were used for the simulation, as plotted in Fig. (5).

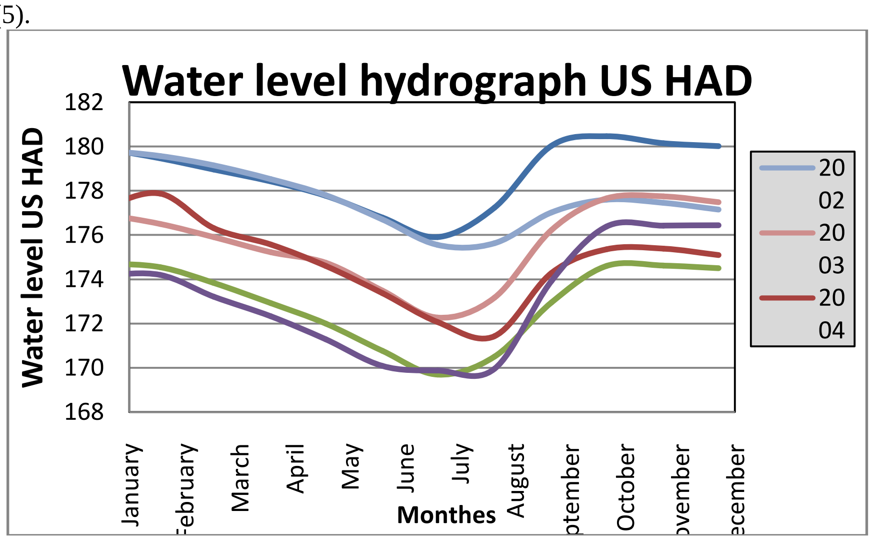


Figure 5: Water Level Hydrograph US HAD for Years 2002, 2003, 2004, 2005 and 2006

Research Plan

1. Compiling of previously published material relevant to the topic of research. All sources will be summarized and listed.
2. Mathematical model will be applied to many scenarios of sedimentation future progress at the High Aswan Dam Reservoir.
3. Calibrating and verifying the model with previous data of the High Aswan Dam Reservoir.
4. Predict of future changes in Reservoir characteristics of the High Aswan Dam Reservoir sedimentation.
5. Determine the effect of Sedimentation in the lake Nasser storage capacity at the future.

Model preparation

The steps generally taken to simulate surface-water flow using *Delft3D* are as follows:
Data assessment, network design, model calibration, model testing and model application.
These five steps are common to the operation of almost any type of numerical model.
The Delft3D modeling suite contains the grid generator program RGFGRID that allows you to generate a curvilinear grid. RGFGRID provides all kind of features to develop a grid, such as refine or de-refine the grid globally or locally for the reservoir grid the distance between nodes is 250m this resolution is suitable relative to the lake area. As shown in Fig. (6).

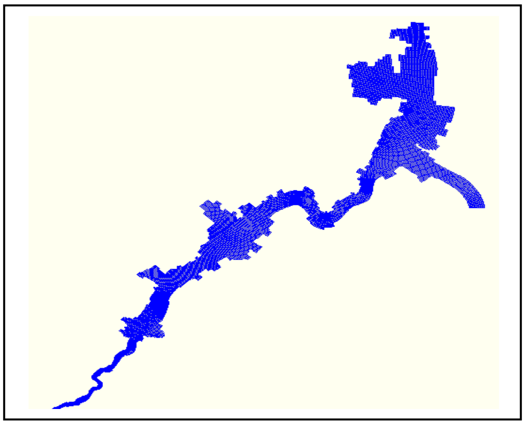


Figure 6: Study Reach Grid Elements Composition

Till this point the mesh is in the planer form, therefore the bed elevations should be assigned to each element composing nodal point at the same coordinates. Transforming coordinates of each scatter point and mesh node is automatically interpolated by the Delft3D Quickin program as shown in Fig 7 and 8.

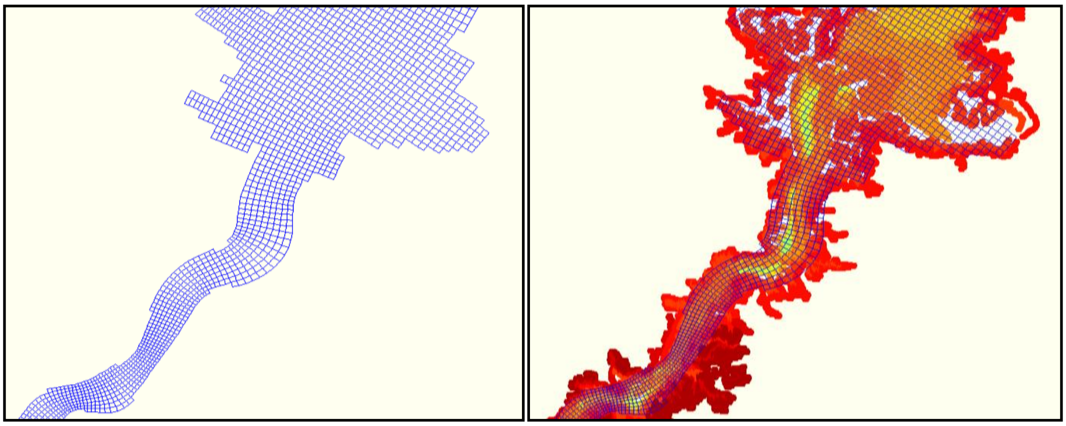


Figure 7: Model Mesh and Scatter Points

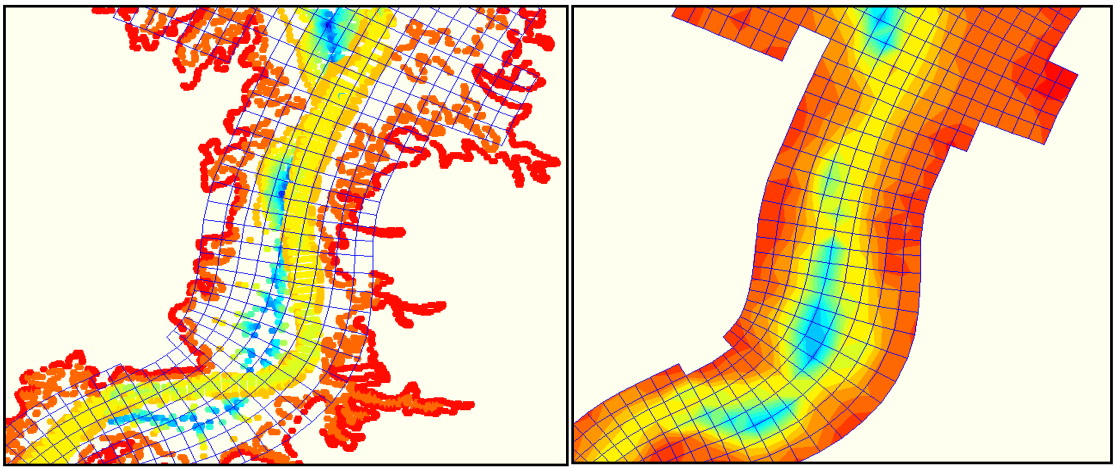


Figure 8: Mesh with Scatter Points and Mesh After Interpolating to Bathymetry Data

Calibration Results

Several model runs were made to achieve the best agreement between measured and resulted values from the model. This was carried out by adjusting model coefficients at various locations along the modeled study area till the best results are achieved.

Comparison of the measured field velocities and obtained velocity profiles at the several cross sections are shown in Fig. (10), also Fig. (9) is representing the accuracy of the velocity calibration results.

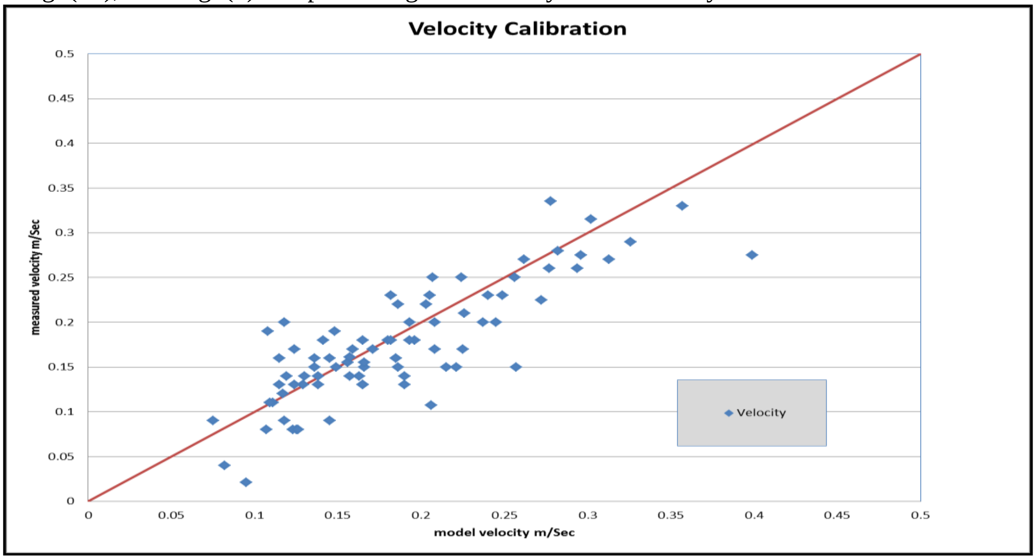


Figure 9: Velocity Calibration

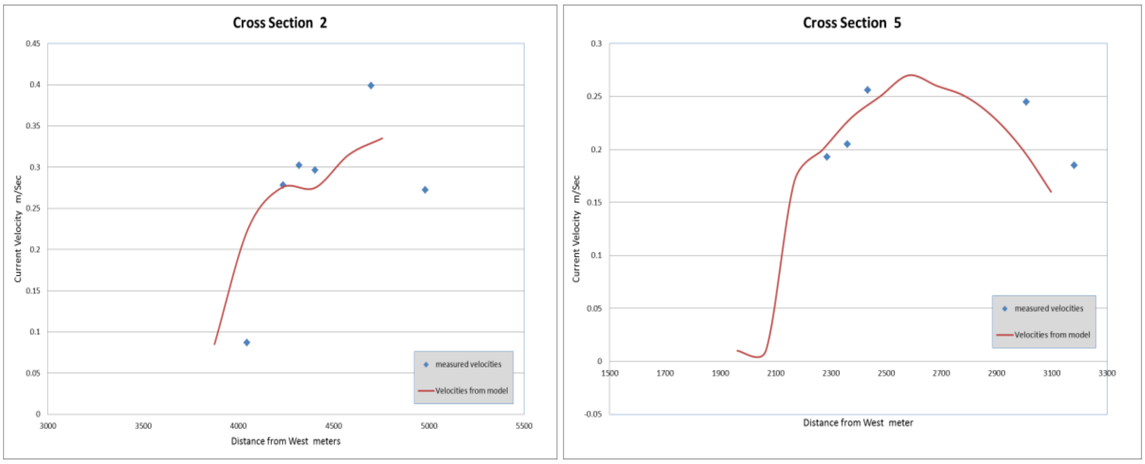


Figure 10: Comparison of Measured Velocity and Model Velocity at Cross Section 2 and 5

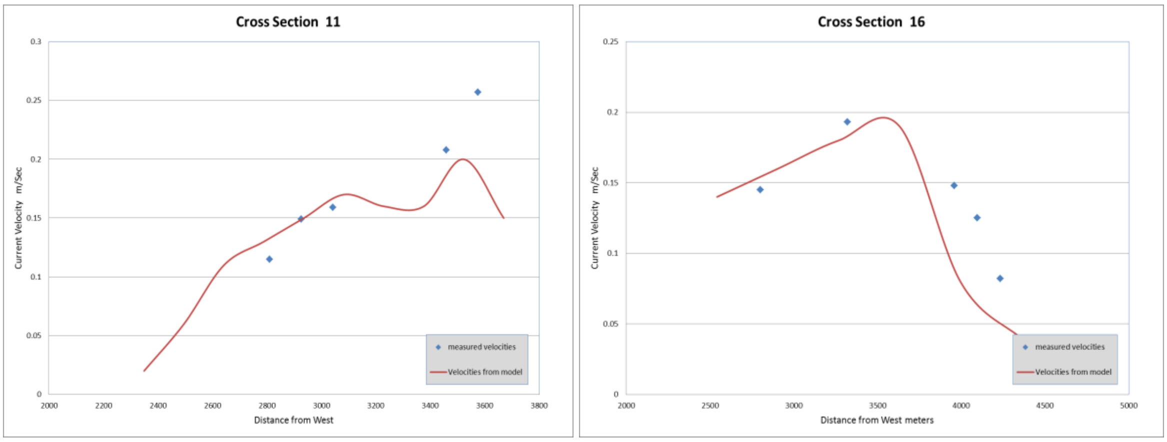


Figure 11: Comparison of Measured Velocity and Model Velocity at Cross Section 11 and 16

A good agreement between the measured and predicted cross-sections was evident although some slight differences are observed at the second cross section but can be neglected. The error in general is less in the channel part than that in the reservoir sides. This might be due to uncertainty of the flow condition of the reservoir.

Comparison of the measured field bed levels and obtained bed level profiles at the twenty cross sections are shown in Figs. (11 to 14), also Fig. (15) is representing the accuracy of the morphology calibration results.

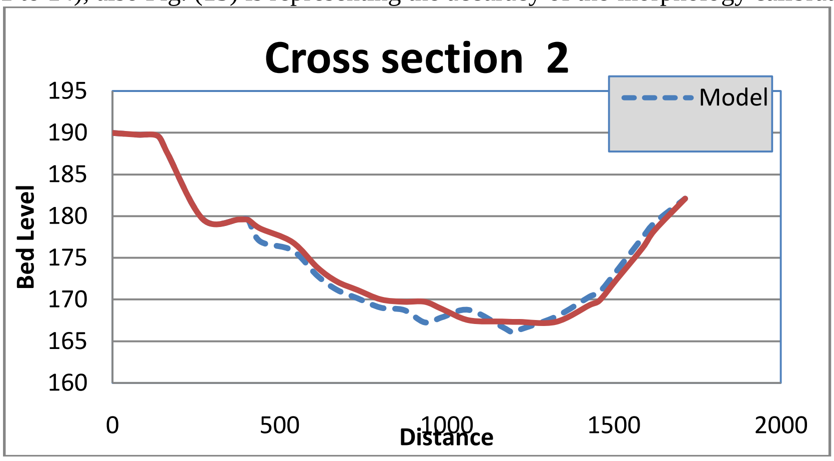


Figure 12: Comparison of Measured and Predicted Bed Level at Cross Section 2 for Year 2010 and 2012

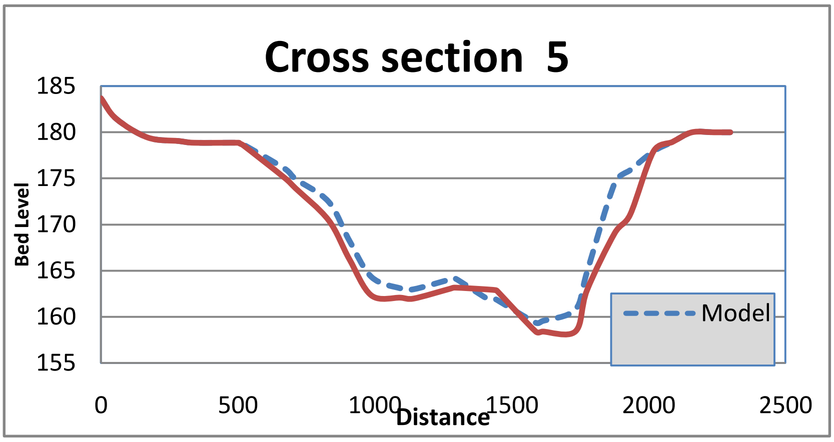


Figure 13: Comparison of Measured and Predicted Bed Level at Cross Section 5 for Year 2010 and 2012

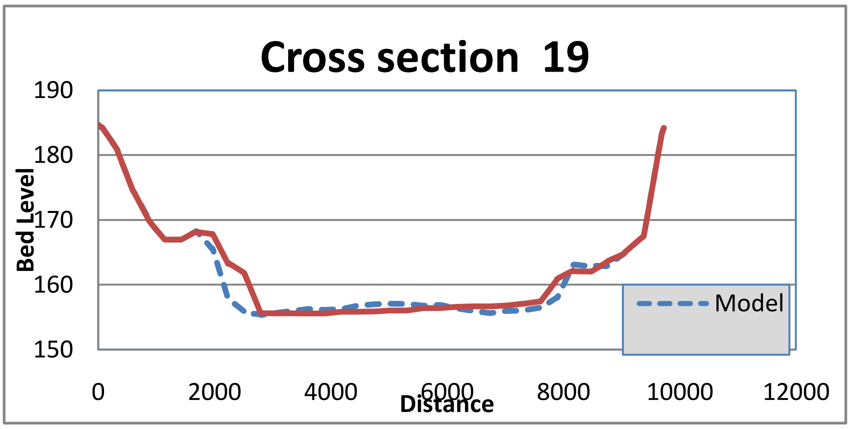
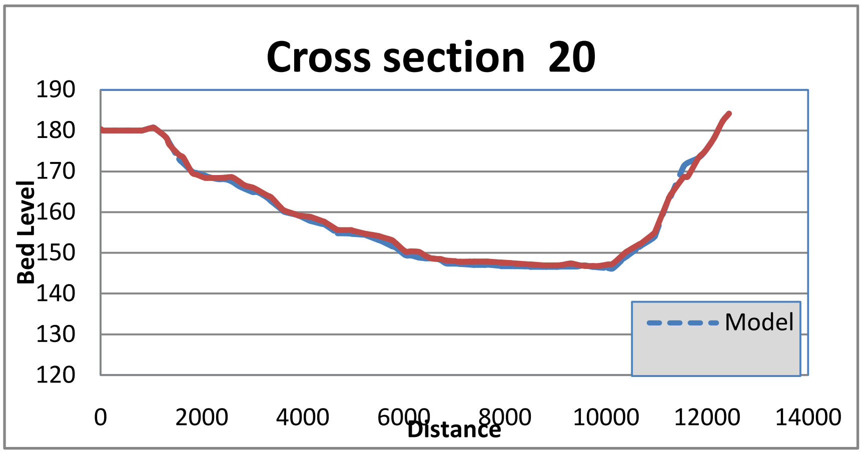


Figure 14: Comparison of Measured and Predicted Bed Level at Cross Section 19 for Year 2010 and 2012



Figuer 15 : Comparison of Measured and Predicted Bed Level at Cross Section 20 for Year 2010 and 2012

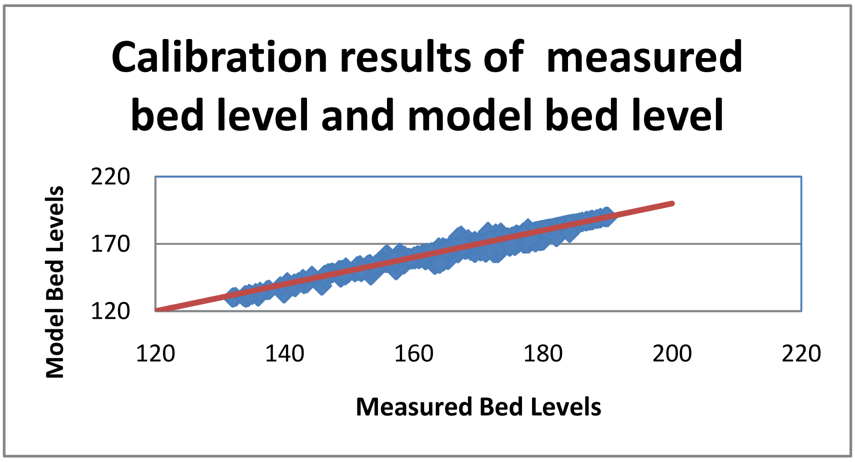


Figure 16: Bed Level Calibration along Study Area

A good agreement between the measured and predicted cross-sections was evident although some slight differences are observed at several cross sections but can be neglected. The error in general is very small compared to channel depth and also the Fig. (15) shows a good comparison between measured and model results this figure represents a comparison between measured bed level and model bed level for the twenty cross sections along reservoir.

Predicting the Sedimentations

The last step in model application is cross section prediction. This part is very important for any future studies. The model was applied to predict bathymetric change of AHDR from 2010 to 2025. A time series of 16 major floods similar to the flood years (2002–2006) "which represent an average flood" was simulated by repeating the same time series for years 2002 to 2006 as an assumption to predict future changes. Fig. (18) shows the contour map of predicted depths at 2012, 2018, 2021 and 2025 for the marked area which appear at Fig. (17). Also The longitudinal bed profile of AHDR was predicted for 2025 as shown in Fig. (19). The prediction indicated that the bed level will change with depositions ranging from15.6 m to 1.0m and erosion ranging from1.75m to 0.09m as shown in Fig. (19).

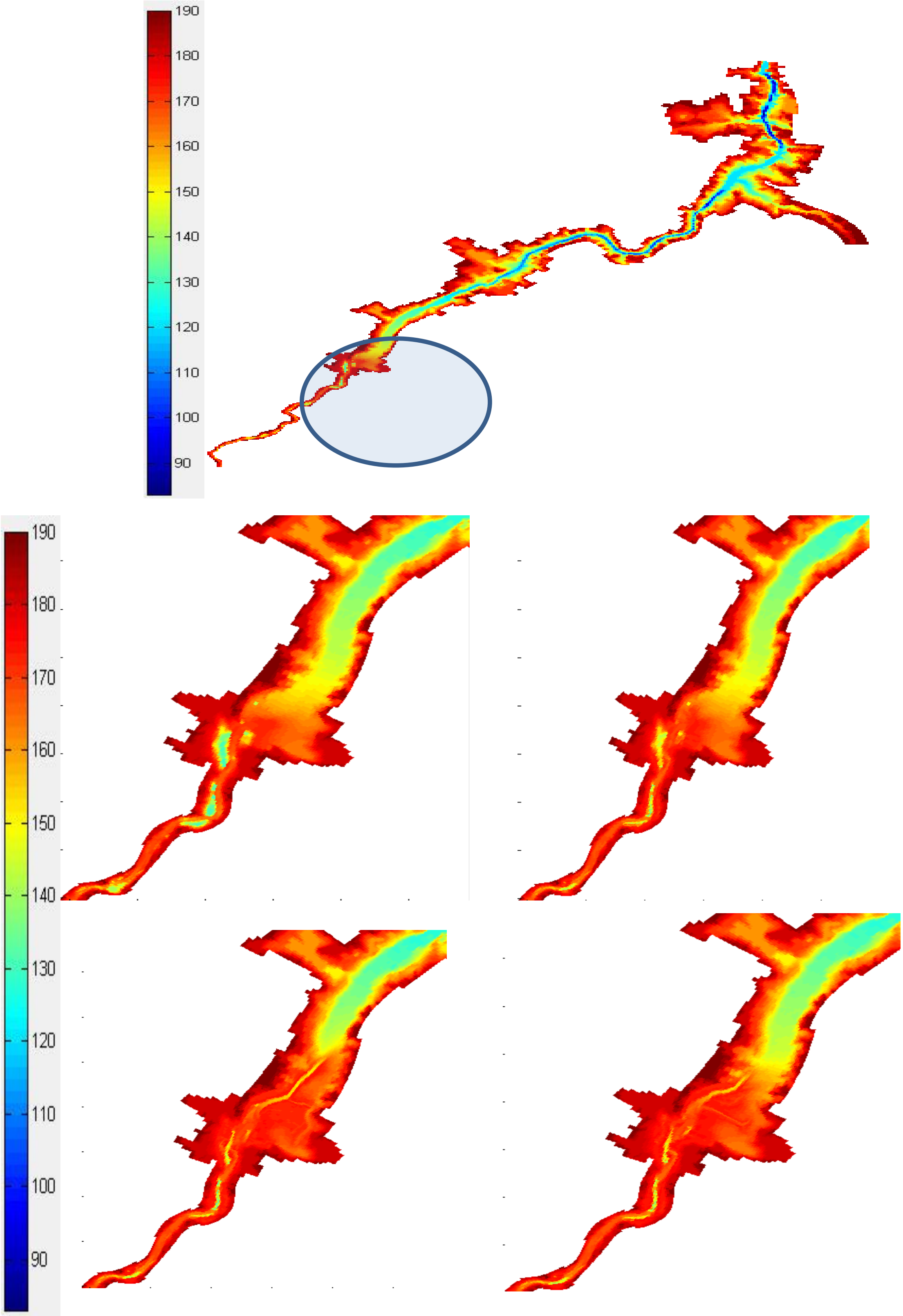


Figure 17 : Colored Contour Map of Reservoir Bed Levels at Year 2010, 2015, 2020 and 2025

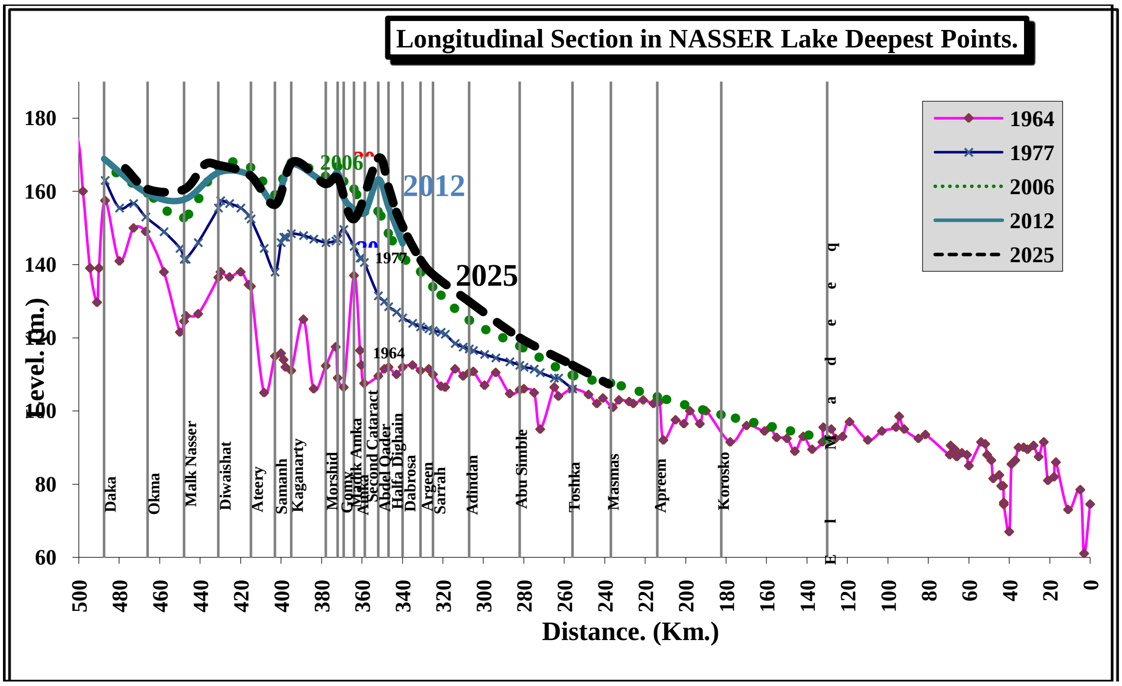


Figure 18: Longitudinal Profile of Deepest Point along the Middle of Reservoir at Year 2012 and 2025

Conclusion

Based on the above, the following conclusions are given:

- The implemented hydrodynamic and sediment transport model (Delft3D) could be used to predict sediment transport, channel change and delta migration.
- The modeling approach proved to be a useful tool to monitor future water flow and sediment deposition in the reservoir. This approach is very important for the operation plans and maintenance of the AHDR.
- Life span of the reservoir can be calculated using this approach by applying the model for very long period till the reservoir full of sediment

Recommendations

The following are also recommendations for future researches:

- Increase quality control on collected data; especially for velocity distribution and bed load.
- Different scenarios could be developed based on the future climate predictions for the reservoir area, and based on changes in suspended sediment concentration and sediment delivery to the main stream.
- Future upstream projects should be studied for its effects on the amount of water discharge and sediment deposition in the AHDR.

References

[1]. EL-Sersawy H and Farid MS. (2005). “Overview of Sediment Transport Evaluation and Monitoring in the Nile Basin. In”. Ninth International Water Technology Conference (NIWTC), Sharm El-Sheikh, Egypt. [As reported in Amary W. Study the Sedimentation inside High Aswan Dam Reservoir, M.Sc. Thesis, Faculty of Engineering, Cairo University; 2008].

[2]. Hurst HE. (1965). "The Nile: a general account of the river and the utilization of its waters". London (UK): Constable Company LTD, pp. 237–279.

[3]. Shalash S. (1980). "Effect of Sedimentation on Storage Capacity of High Aswan Dam Lake". Report No. (56), Qanater, Egypt. pp. 52-60.

[4]. Mohamed El-Moattassem, Tarek M. Abdel-Aziz and Hossam El-Din Mohamed EL-Sersawy (2005). "Modeling of Sedimentation Process in Aswan High Dam Reservoir". Ninth International Water Technology Conference, Sharm El Sheikh, Egypt.

[5]. Abdel Aziz T. (1997). "Prediction of Bed Profile in the Longitudinal and Transverse Direction in Aswan High Dam Reservoir". Ph.D. Thesis, Cairo University, Cairo, Egypt.

[6]. El-Manadely M.S. (1991). "Simulation of Sediment Transport in the Aswan High Dam Lake". Ph.D. Dissertation, Irrigation and Hydraulic Department, Cairo University, Egypt.

[7]. Abu EL-Atta A. (1978). "Egypt and the Nile after the Construction of the High Aswan Dam". Report, WRC, Ministry of Public Works and Water Resources, EL-Qanater, Egypt.

[8]. Makary AZ. (1982). "Sedimentation in the High Aswan Dam Reservoir". Ph.D. Thesis, Faculty of Engineering, Ain Shams University.
[9]. Dahab AH. (1983). "Lake Nasser Area Between Abu-Simble and Dall Cataract". Ph.D. Thesis, Faculty of Arts, Ain Shams University.
[10]. Abdel-Aziz TM. (1991). "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.
[11]. NRI. Annual Report, Nile Research Institute, Qanater, Egypt; 2012.
[12]. EL-Moattassem M and Abdel-Aziz TM (1988). "A Study of the Characteristics of Sediment Transport in Aswan High Dam Reservoir". Reportno. 117, Cairo, Egypt.