PREDICTION OF THE FUTURE SITUATION OF THE RIVER NILE NAVIGATIONAL PATH

Nahla Sadek and Nasr Hekal

[1] Associate Professor, Nile Research Institute (NRI), Post Code 13621,
El Kanater El Khiaria, Greater Cairo, Egypt
[2] Researcher, Nile Research Institute (NRI), Post Code 13621,
El Kanater El Khiaria, Greater Cairo, Egypt
E-mail: nhekal@yahoo.com

ABSTRACT

To ensure the future operational efficiency of the newly developed navigational path between Cairo and Aswan, continuous field monitoring and maintenance works are a good practical but costly approach. However, numerical modeling can be used as a powerful approach in future prediction of navigational path bed changes. The riverbed areas prone to aggradation and degradation, which may influence navigability, can be identified. Moreover, the approximate time when such changes occur can be determined. This helps locate the areas where navigational bottlenecks may arise. Accordingly, the suitable effective measures to maintain such vulnerable areas can be taken at the right time. Using the second approach, the paper aims to evaluate the future situation of the proposed navigational path through reach (Assiut - Cairo) of the River Nile. It predicts the probable riverbed morphological changes that may prevail in the future due to the release of the emergency discharge of 350 Mm3/day through that reach. Also, a number of maximum, average, and minimum discharge hydrographs based on historical recorded data are used to predict the riverbed changes through the period between 2006 and 2017, which represents Egypt's future water budget plan. It is found that some cross sections along the study reach undergo navigational bottlenecks due to riverbed aggradation requiring maintenance works to keep the path navigable, while others experience degradation which is good for navigation.

Keywords: Path, Navigation, River Nile, Morphological Changes, Emergency Discharges.

1. INTRODUCTION

In Egypt, due to the continuous increasing population, the wide-ranging internal trade movements and the flourishing tourism along the country, road and railway transport means are no longer able to meet the increasing demands. Therefore, navigation through the River Nile has been recently considered as important as the other present transport means. It can relieve and absorb the daily pressure affecting them and can further increase the trade and tourism movement flexibility. In other words, it can contribute positively to solving the problem without the need of constructing new roads or railways.

On the other hand, Egypt's water resources, which are mostly (about 95 %) contributed by the River Nile, have recently become limited due to the increasing needs of the continuous overpopulation, the rising living standards of the individuals and the current sustainable water-related development projects. The annual water share allowed into the country is only about 55.5 billion cubic meters (bcm) of the total water of the River Nile Basin. This share is, unfortunately, fixed according to the 1959 international treaty with Sudan and therefore has to be used most wisely and rationally.

One way of water rationalization deemed effective by the Egyptian water policy experts is to cut down the additional discharges released downstream the High Aswan Dam (HAD) to serve the navigational purposes. Although the period of minimum discharge release coincides with the peak of the Egyptian tourist season where the number of normal river tourist vessels tends to multiply and needs more water to navigate safely, the experts still believe that safe navigation through the river can be available during such a period by deepening the navigational path to provide sufficient depths.

2. BACKGROUND

In cooperation with the Egyptian General River Transport Authority (EGRTA), the Nile Research Institute (NRI), embarked on a hydrographic survey of the River Nile between Cairo and Aswan for a distance of about 953 km. The aim of this survey was to develop a suitable navigational path serving the navigation movement along the river.

Using the collected hydrographic data, navigational contour maps have been developed with a proposed navigational path. This path is designed to be two-way and maneuverable and have a navigational draft of 2.30 m under the minimum water levels available along the river. Also, areas prone to navigational bottlenecks could be located. It has been proposed to dredge them to provide safe navigation through the river. However, the questions of how long the path will be navigable and what affects its operational efficiency searched for quenching answers.

3. OBJECTIVE

It is known that the variation of discharges released through rivers and the corresponding changes in water levels result in a sediment transport process which, in turn, causes riverbed morphological changes. Therefore, this paper basically intends to predict the future situation of the proposed navigational path through a certain reach of the River Nile and evaluate the riverbed morphological changes that may affect it due to the release of:

1. An emergency discharge of 350 Mm^3/day through the reach; and
2. A number of maximum, average, and minimum discharge hydrographs based on historical recorded data within the period between 2006 and 2017, which represents Egypt's water budget plan.

This may hopefully help locate the areas where navigational bottlenecks may arise. Accordingly, the suitable effective measures to maintain such vulnerable areas can be taken at the right time.

4. STUDY REACH DEFINITION

Reach (Assiut - Cairo) of the River Nile is taken as a case study where the bottleneck areas through it are focused to predict their future reactions. It is about 408.720 km long. It extends from just downstream Assiut Barrages at km (544.780) from Old Aswan Dam (OAD) far up in the south down to just upstream Delta Barrages at km (953.500) in the North as shown in Fig. 1. This reach was specifically chosen for the availability of the two sets of data required for model calibration purposes (hydrographic, hydrologic and sediment data).

5. THE NUMERICAL MODEL USED (GSTARS2.00)

5.1 Background

GSTARS2.00 stands for the Generalized Stream Tube model for Alluvial River Simulation. It is developed by Molinas and Yang (1985) for the U.S. Bureau of Reclamation. It is different from many of the 1-D alluvial river modeling computer programs, such as HEC-6 (U.S. Army Corps of Engineers, 1977, 1993) because it is able to simulate the flow conditions in a semi-two-dimensional manner and the change of channel geometry in a semi-three-dimensional manner. This task is performed using stream tubes within an essentially 1-D backwater model. The advantage of this approach is to reduce the intensive data and computational requirements of the more sophisticated truly 2-D and 3-D models. The model applies different sediment equations such as:

1. Meyer-Peter and Muller's;
2. Laursen's method;
3. Toffaleti's method;
4. Engelund and Hansen's method;
5. Ackers and White's 1973 method;
6. Yang's 1973 sand and 1984 gravel formulas;
7. Yang's 1979 sand and 1984 gravel formulas;
8. Parker's method;
9. Yang's 1996 modified method; and
10. Ackers and white's method with the revised 1990 coefficients.

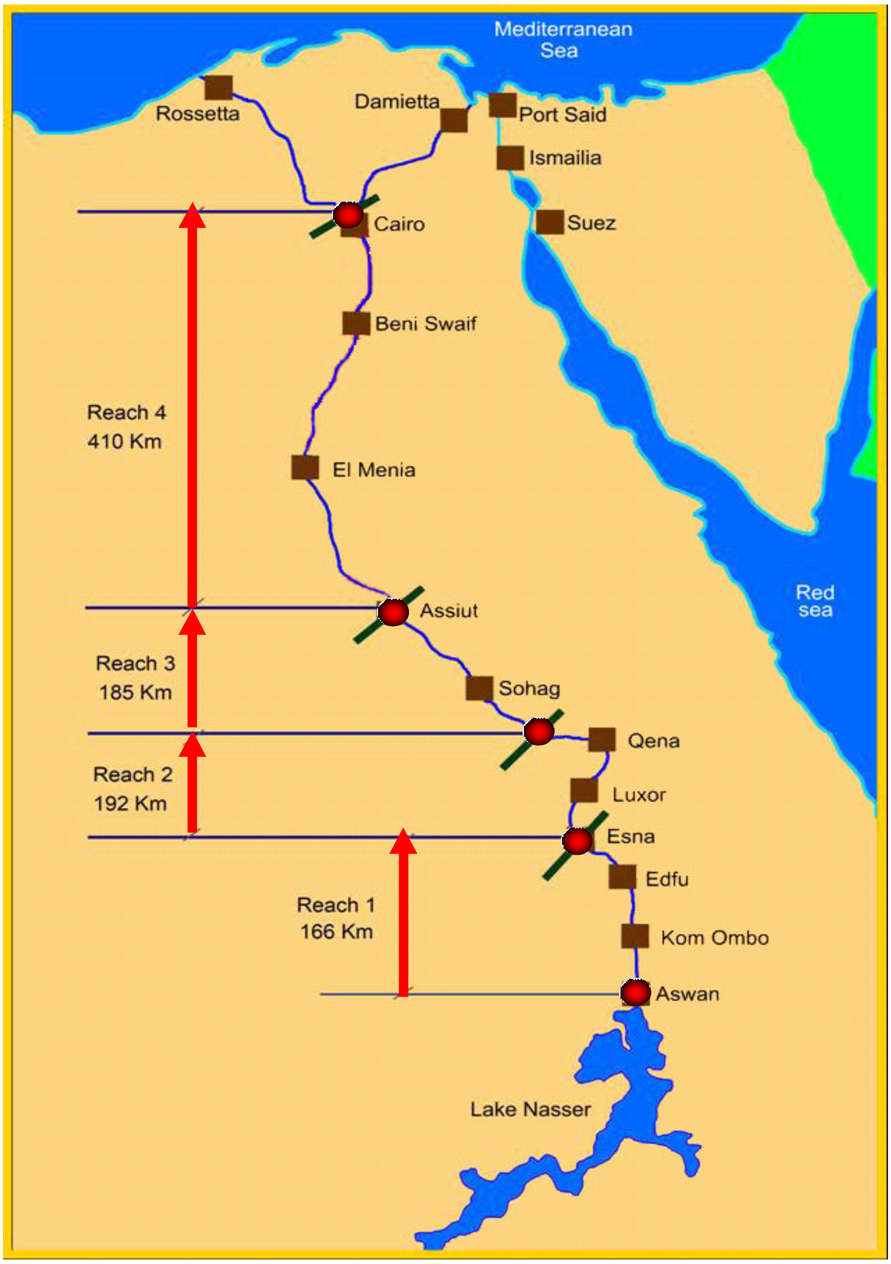

Fig. 1: The River Nile within the Egyptian Border

5.2 Model Theoretical Basics

5.2.1 Backwater Computations

For quasi-steady flow, discharge hydrographs are approximated by steps of constant discharge. For each step, the steady state equations are used for water surface profile computations. The model solves the energy equation based on the standard step method. For cases of change between sub-critical and super-critical flow conditions, the momentum equation is used instead. This allows for solving sub-critical, super-critical, or any combination of flow conditions, and also even for hydraulic jump cases.

5.2.2 Stream Tube Computations

In GSTARS 2.0, the stream tube concept is used to accomplish a semi-two-dimensional approximation of the simulated river reach under study. The water surface profile is computed first. Then, the channel reach is automatically divided into a selected number of stream tubes, which have the following characteristics:

- The total discharge is automatically divided equally among the number of tubes;
- The boundaries of the stream tubes are the channel boundaries and imaginary walls of the stream tubes themselves;
- The discharge along the stream tube is constant;
- There is no exchange of water or sediments through stream tubes boundaries.

Stream tubes locations are computed for each time step and may change with time steps. Sediment routing and bed sorting and armoring computations are carried for each stream tube apart. The exchange of sediment materials between stream tubes is allowed by the lateral variation of the stream tube boundaries from time step to another.

5.2.3 Sediment Routing Computations

The basis of the sediment routing computations in one-dimensional unsteady flow is the sediment continuity equation, which reads:

$$\frac{\partial Q_s}{\partial x} + \eta \frac{\partial A_d}{\partial t} + \frac{\partial A_s}{\partial t} - q_s = 0 \qquad (1)$$

Where η = volume of sediment in a unit bed layer volume; A_d = volume of bed sediment per unit length; A_s = volume of sediment suspension per unit length; Q_s = volumetric sediment discharge; and q_s = lateral sediment inflow.

5.2.4 Bed Sorting and Armoring

Sediment transport depends on the size fraction, which means the finer particles are eroded first. In some cases, the finer particles, which may be eroded by a certain flow condition, are all eroded leaving a layer of coarser particles, which can not be eroded by the current flow. In this case, no more erosion of this coarser layer could occur, which means that the bed is armored. This condition may change if the flow conditions are changed and flow erosion capacity is increased to be able to erode coarser particles. GSTARS 2.0 accounts for the bed composition in sediment routing procedures.

6. MODEL CALIBRATION

The model has been calibrated in two phases; the first was for the different water levels expected to take place in the study reach and the other for the sediment transport process.

Three sets of data were obtained; the hydrographic, hydrologic, and sediment data of the selected reach. The geometry of the reach was represented by 61 cross sections which were taken out from the survey maps of 1982 and those of 2005. The sections are spaced at an in-between average distance of 5 kilometers. As for the hydrologic data, the water levels recorded at twelve gauging stations spread along the reach and corresponding to discharges of 171 Mm^3/day and 350 Mm^3/day were obtained. As for the sediments, the grain size accumulation curves at such cross sections were deduced by analyzing the field data samples collected in 1982. The grain sizes required in the sediment equations (D_{50}, D_{90}, D_{35}) were computed.

6.1 Water Level Calibration

Using the different water levels corresponding to the maximum discharge expected to be released downstream Assiut Barrages which is equal to 171 Mm^3/day, the model was calibrated. Figure 2 shows the calibration results where the computed water surface profile and the measured one are plotted. It is found that there are no big differences between the two profiles.

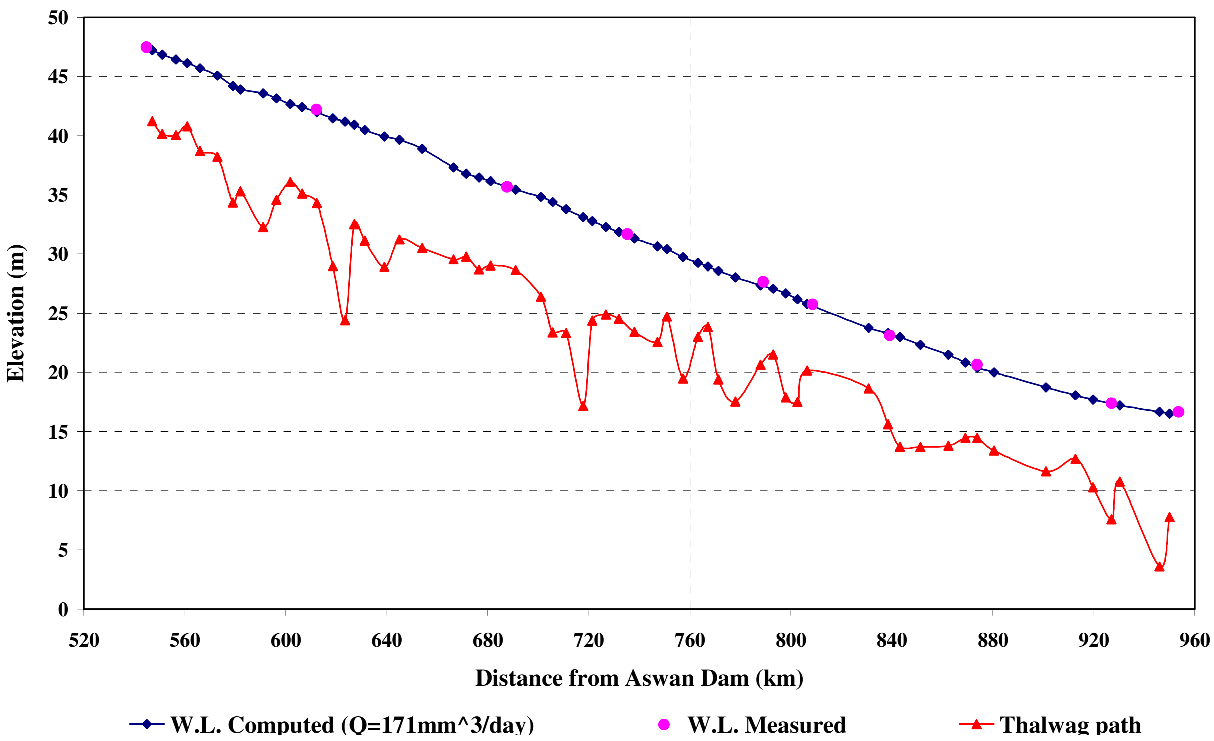

Fig. 2: Calibration Results for Discharge 170 Mm^3/day

It is worth mentioning that the discharge of 171 Mm^3/day has actually been released through reach (Assiut - Cairo) after the HAD construction, whereas the emergency discharge 350 Mm^3/day has never been released except during the annual floods that used to occur in the years before the HAD construction in 1964. Therefore, to calibrate the model for the emergency discharge of 350 Mm^3/day, the water surface profile was computed and then compared with that of 1964 as no other water surface profile corresponding to a discharge of 350 Mm^3/day is else recorded. Figure 3 shows the calibration result where there is a rise in the water levels computed because of the morphological changes that the reach cross sections had to experience due to the consequences of the dam construction such as control of discharge release, water level drop, and river contraction.

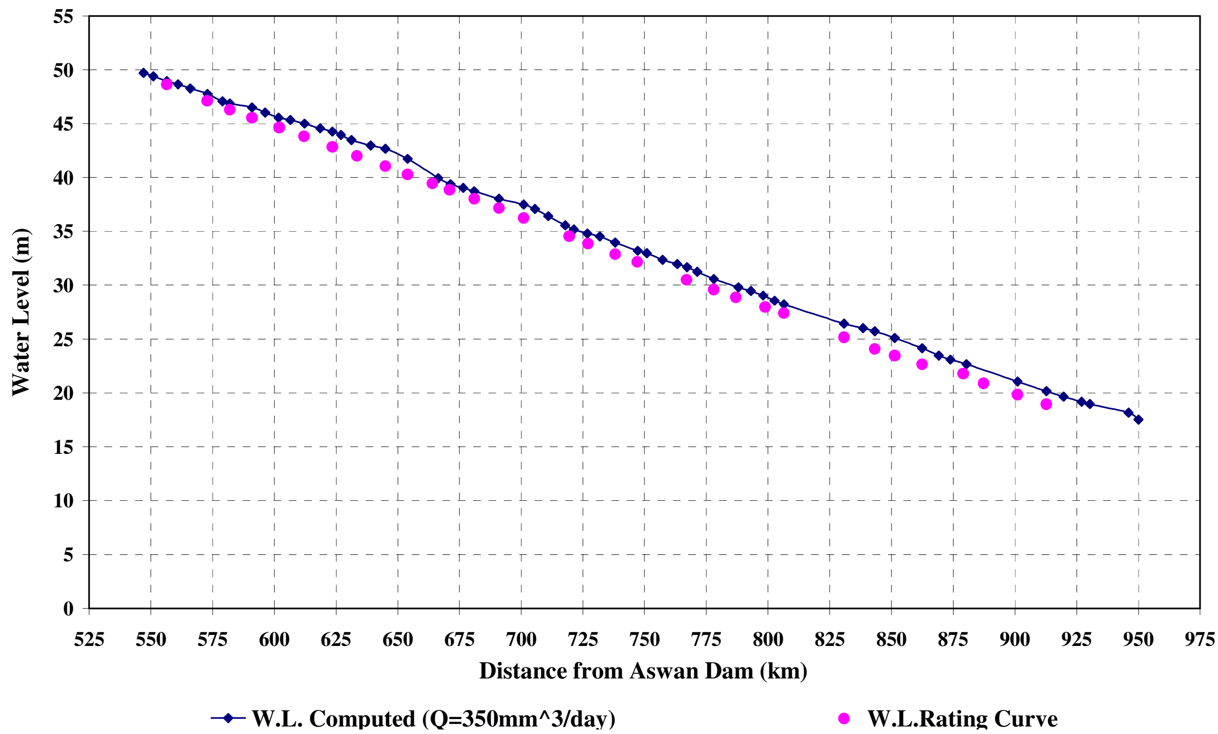

Fig. 3: Calibration Results for Discharge 350 Mm^3/day

6.2 Sediment Transport Calibration

The aim of this section is to determine the best sediment transport equation that can be used in the model. A number of cross sections representing the study reach were taken out from the hydrographic maps surveyed in 1982. Then, using these cross sections and the water levels corresponding to the actual discharges released in the reach from 1982 to 2005 in the model, a new set of cross sections for 2005 was deduced. These sections were compared with the actual cross sections practically surveyed in 2005. Applying the different sediment transport equations mentioned above in the model to deduce cross sections nearly similar to those of the 2005 hydrographic survey; (Ackers and White, 1973) equation was found to be the most suitable. Accordingly, the equation was chosen to be applied during the prediction process.

7. RESULTS AND ANALYSES

The navigational bottleneck areas along the study reach have been recognized and determined from the hydrographic survey maps of 2005 as shown in Table 1. These areas are considered the most vulnerable to riverbed changes. Therefore, the prediction of the future morphological changes expected to occur to the riverbed was focused at such areas in case of critical emergency discharges. Also, the changes at the different cross sections along the whole reach due to different maximum, average, minimum discharge hydrographs based on historical data were predicted through the period (2006 - 2017).

Table 1: Riverbed Future Changes at the Navigational bottleneck areas due to the release of emergency discharge (350 Mm^3/day) for 30 days

No	Location	Governorate	Distance downstream Aswan Reservoir (km)	Riverbed Changes (cm)	
				Degradation	Aggradation
1	Ezzbat Hassan Attia	Assiut	579	1 – 6	No Change
2	Beni Shakeer	Assiut	584	3 – 5	No Change
3	Nazlet El Awamer	Assiut	615	No Change	4 – 10
4	Geziret El Sheikh Temi	El Menia	656	No Change	12 – 17
5	Beni Hassan El Shrouk	El Menia	661	No Change	8 – 16
6	Beni Mohamed El Sharawy	El Menia	672	1 – 2	2 – 4
7	Sawada	El Menia	682	1 – 2	2 – 4
8	Al Berjaya	El Menia	693	1 – 2	2 – 4
9	Al Beho	El Menia	707	1 – 2	3 – 7
10	Matay	El Menia	725	1 – 3	1 – 3
11	Abo Aziz	El Menia	728	3 – 15	No Change
12	Beni Mazar	El Menia	736	No Change	
13	Gezerit Sharona	El Menia	751		
14	Awlad El Sheikh	El Menia	758		
15	Zawiat Al Jodama	El Menia	763	No Change	3 – 12
16	Ezbet Mahmoud Ewais	Beni Swafe	793	1 – 5	No Change
17	Al Dawya	Beni Swafe	806	1 – 3	No Change
18	Beni Swafe Bridge	Beni Swafe	808	1 – 3	No Change
19	El Alalma	Beni Swafe	818	No Change	2
20	Korimat	Giza	838	2 – 7	No Change
21	Sool	Giza	848	3 – 6	2
22	El Atf	Giza	883	No Change	No Change

7.1 Riverbed Changes Prediction due to the Release of Emergency Discharges

Using the emergency discharge of 350 Mm^3/day for a period of 30 days into the model, the morphological changes (aggradation/degradation) at the different cross sections through the study reach could be predicted. It is worth mentioning that the emergency discharge was applied for 15 days and the results were not so pronounced as those of the 30-day period.

Comparing the deduced cross sections obtained by the model with those of 2005, some riverbed changes were found at the different cross sections of the navigational bottleneck areas. Table 1 shows the amount of such changes. From the table, it can be found that the thickest aggradation was about 17 cm and occurred at Geziret El Sheikh Temi, 656 km downstream Aswan Dam, while the thickest degradation reached about 15 cm at Abo Aziz, 728 km downstream Aswan Dam.

7.2 Riverbed Changes Prediction due to the Release of the Historical Discharge Hydrographs through the period (2006 – 2017)

7.2.1 Proposed Discharges for Release till 2017

Table 2 shows the maximum, average, and minimum discharges expected to be released through the study reach during the future period till the year 2017. These values are based on the historical recorded data between 1995 and 2005 where they included successive high and low discharges. Such data were specifically chosen to represent the most critical situation that can affect the navigational path.

Table 2: Max., Average, and Min. Monthly Discharges from 1995 to 2005

Discharge (Mm^3/day)	Jan	Feb	March	April	May	June	July	Aug	Sept	Oct	Nov	Dec
Max	93	108	115	131	153	176	169	160	182	167	147	107
Average	64	77	92	105	130	168	164	150	119	97	92	65
Min	40	67	74	87	103	160	151	138	94	67	74	52

The table shows that the maximum monthly discharge ranges between a low value of 93 Mm^3/day in January and a high one of 182 Mm^3/day in September. Also, the minimum monthly discharge was found to range between a low value of 40 Mm^3/day in January and a high one of 160 Mm^3/day in June. As for the intermediate discharge, it ranges between a low value of 64 Mm^3/day in January and a high one of 168 Mm^3/day in June.

7.2.2 Predicted Future Riverbed Morphological Changes

Fig. 4 shows a comparison between the current lowest riverbed levels and the future deduced ones through the study reach in case of the release of the proposed discharges till 2017. It is found that the riverbed levels are expected to drop with a value ranging between 0.50 m and 2.10 m at some of the x-sections lying downstream Assiut Barrages from km 546 to km 578 downstream Aswan Dam. In the mean time, other x-sections will experience a rise in bed levels ranging between 0.10 m and 3.00 m. Also, Figs 5 – 6 show some x-sections that will undergo riverbed morphological changes.

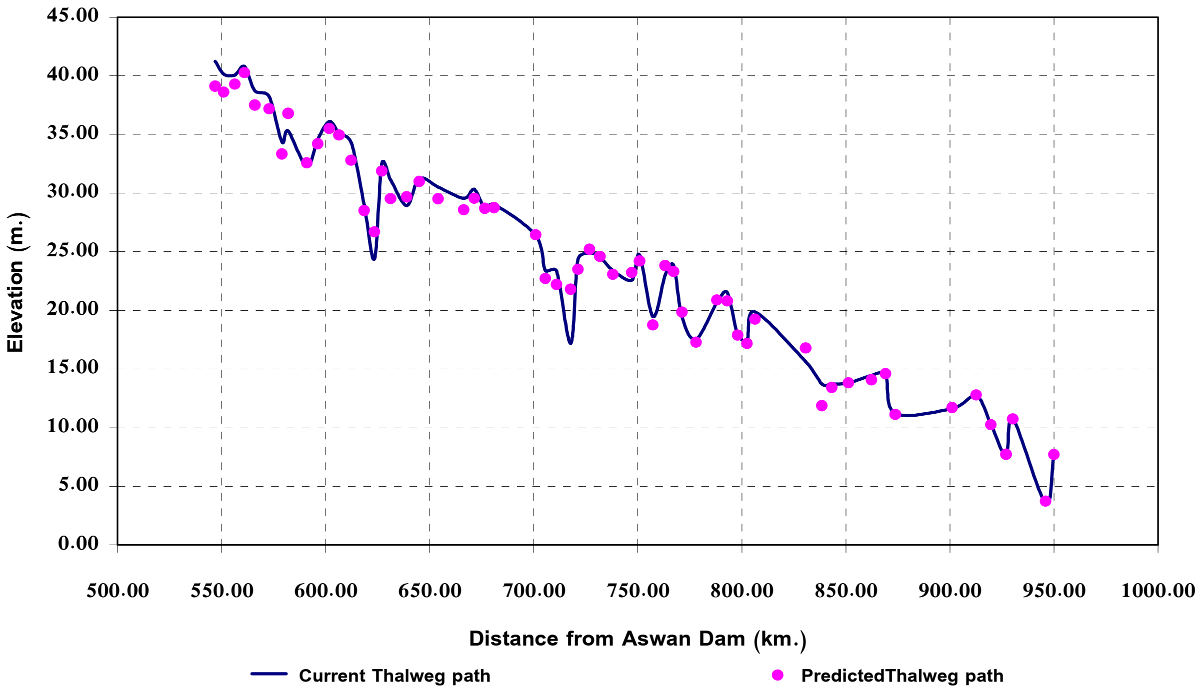

Fig. 4: Lowest riverbed level for the current and future situation

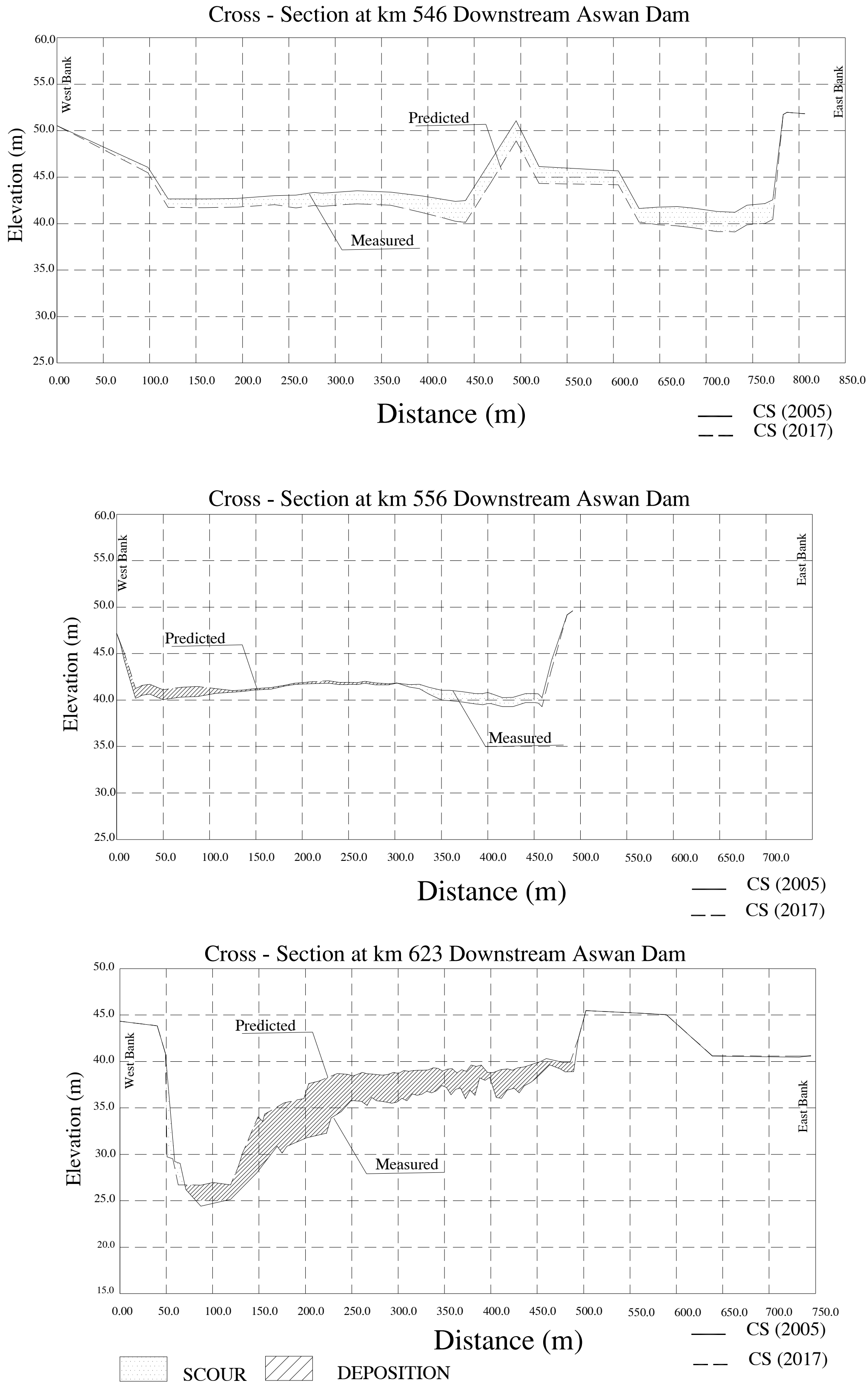

Fig. 5: Critical x-sections from km 546 to km 623 DS Aswan Dam prone to future riverbed changes

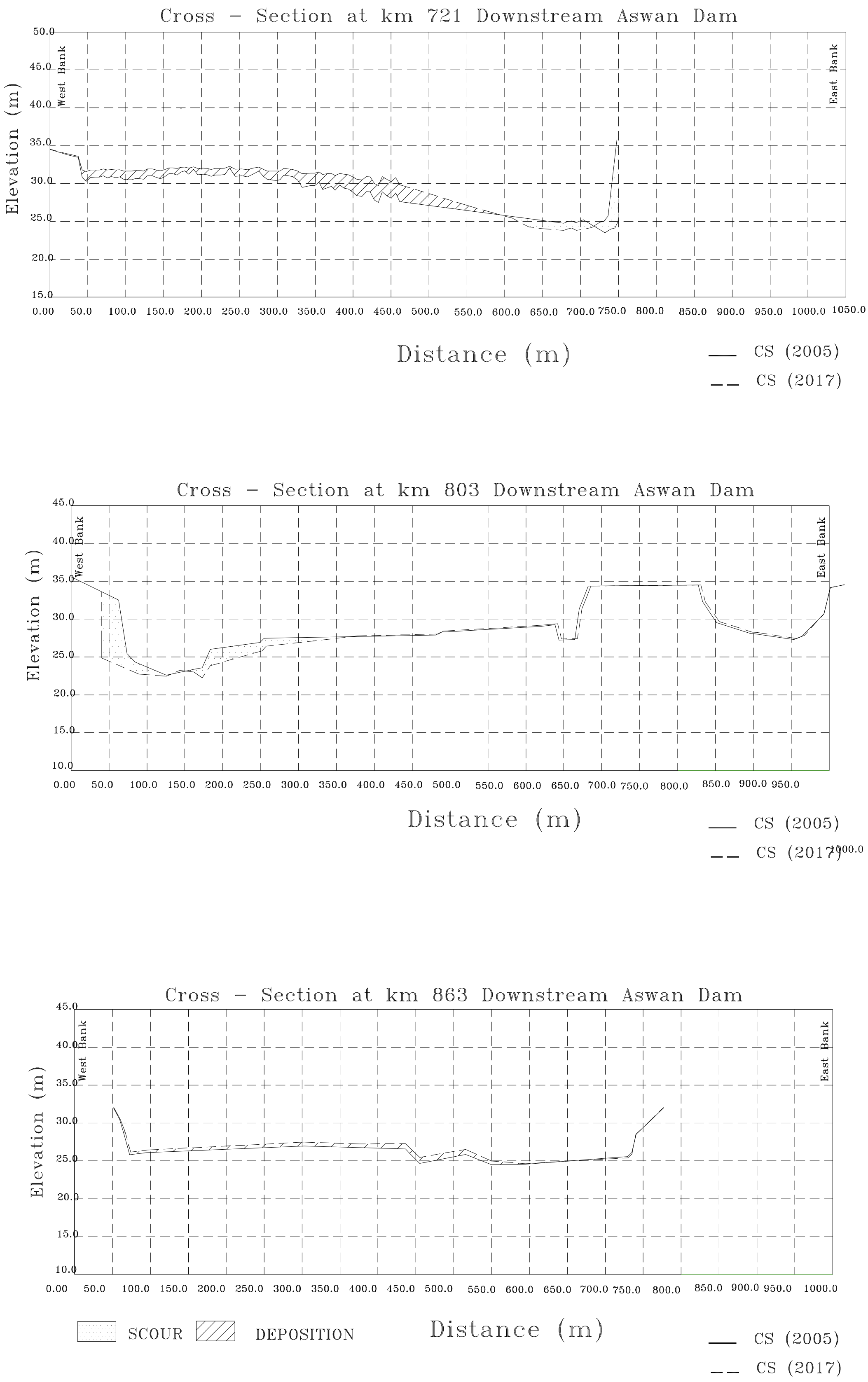

Fig. 6: Critical x-sections from km 721 to km 863 DS Aswan Dam prone to future riverbed changes

8. CONCLUSIONS

From the above analysis of the results, the future situation of the navigational path through Reach (Assiut – Cairo) of the River Nile could be predicted and it can be concluded that:

1. The riverbed of the reach would have pronounced changes (aggradation & degradation) at the different cross sections of the navigational bottleneck areas in case the emergency discharge of 350 Mm^3/day were released for 30 days. The expected thickest aggradation would be about 17 cm and occur at Geziret El Sheikh Temi, 656 km downstream Aswan Dam, while the thickest degradation would reach about 15 cm at Abo Aziz, 728 km downstream Aswan Dam;
2. If successive different high, average and low discharges are released through the reach for the period between 2006 and 2017 on a continuous basis, the riverbed at different cross sections are expected to undergo severe morphological changes. The riverbed levels will drop with a value ranging between 0.50 m and 2.10 m at some of the cross sections lying downstream Assiut Barrages from km 546 to km 578 downstream Aswan Dam. In the mean time, other cross sections may experience a rise in bed levels ranging between 0.10 m and 3.00 m. This means that the expected aggradation will certainly reduce the path navigability at such cross sections. This will help take the necessary precautions to maintain such areas and keep the path navigable for longer times;
3. Numerical modeling can be a helping and indirect tool for keeping the river navigability. Also, it can help reduce the maintenance works in the long run.

RECOMMENDATIONS

It is recommended to:

- Study the effect of the river vessel movement on the navigational path, particularly during the period of minimum discharge release. This is because the vessel bottom will be closer to the riverbed and may cause severe morphological changes; and
- Re-channelize the main waterway of the river, particularly upstream the navigational bottleneck areas so that the water currents can not be dispersed around. This kind of dispersion might cause scour at the riverbed areas near the river banks and carry the sediments into the navigational channel causing aggradation.

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