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Flood Risk Management and Assessment of Its Impact on Nile River Zone

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Abstract: ***Egypt is one of the countries that will face significant challenges in the coming years, especially with dam projects, climate changes, and sea-level rise. These challenges may lead to water shortage or lead to excess inflow water according to the operation rules for these dams. As a result, many considerations must be made in order to face these challenges. One of them, which is the focus of this research, is studying the impact of the extra discharge that can be released downstream of the High Aswan Dam to manage disaster considering the dam operation restrictions. Two-dimensional mathematical model (Delft3D) is used to predict the water surface profile associated with high discharge, which is about 350 m.m3/day under different scenarios of Barrage operation rules in the study area. The Great Cairo Region, where significant projects such as tourism, water, and power plants have been chosen to carry out this study, is the most critical and active area. For each scenario, the predicted water level and its impact on human properties and habitations is analyzed. In addition, many other side effects on the river behavior, such as aggradations, degradation, bank erosion and inundation are evaluated. An application was developed using the Python programming language and GIS to store predicted water levels and assess the database for the river's vulnerable facilities. Finally, the study will propose a strategy for managing and mitigating flood hazards.***

Keywords: Bank erosion, Flood Risk, Floodplain, Land inundation, GIS.

I. INTRODUCTION

Rivers are dynamic systems that are continuously changing due to hydraulic and sediment transport processes. Over time, the river responds to changing environmental conditions by modifying its cross-sectional shape, increasing or decreasing its local sediment carrying capacity, which is observed as patterns of erosion and deposition. The Nile River in Egypt mainly consists of a long single channel, which is followed by two branches that form the Delta. The most significant challenges that Egypt may face in the coming years are dam projects, climate change, and sea level rise. These challenges may result in water shortage or lead to an excess of inflow water according to their operation rules for these dams. Historically, the Ministry of Water Resources and Irrigation (MWRI) has been in charge of determining the management lines (ML) along the river. As shown in Figure (1), these lines are referred to as Terraces lines (TL), Channel lines (CL), and Floodplain lines (FP) [1]. The morphological lines that determined the active channel to convey the needed discharges over the year are known as the channel line (CL). This line is not stable throughout the year because it is dependent on the amount of water available [2]. The terraces Lines characterize the border channel on the river banks and can be defined the contour lines of high ground near the river bank. They separate between flat and steep slopes in cross sections. The area between these lines includes flood plain. These are typically low-lying areas between the terrace line and the outside active channel line [3]. With MWRI approval, it can also be used for temporary activities like parks, recreation, activities, fish farming, seasonal agriculture, and ferryboats. Over time, the management of lines changes is proceeded according to a number of factors [4]. First, changes in water levels according to the operation rules of Delta Barrage, that cause morphological and hydrological changes at the river. Furthermore, the encroachment on the river, which is regarded as one of the primary causes of their transition. Moreover, dredging works in front of water and power stations, as well as along the navigational path, to improve their efficiency [5].

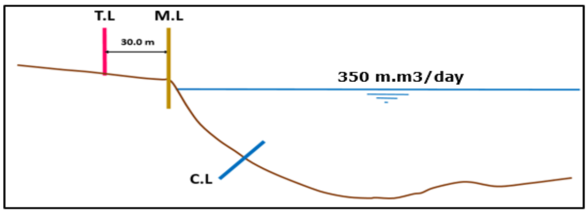

Figure 1: Description of the management lines

This study focuses on the great Cairo region as a critical pilot area, which extends downstream of Aswan Dam from km 900 to km 954. This area has been subjected to numerous human interventions [6]. Depending on the Delta Barrage's operation rules, different scenarios will be used, such as partial or complete gate opening. To predict their effects on the ML, two-dimensional mathematical models (Delft3D) will be used. As a result, propose the location of overtopping banks' protection works [7]. Finally, it will propose ML development strategy. The Management Lines application will be developed using GIS to present the ML during the study period, as well as creating a geo-database for human encroachments. This application could support decision-makers plan the location of bank protection works as well as identify human encroachments [8].

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II. METHODOLOGY

To satisfy the objective of the study the following activities will be carried out as figure (2).

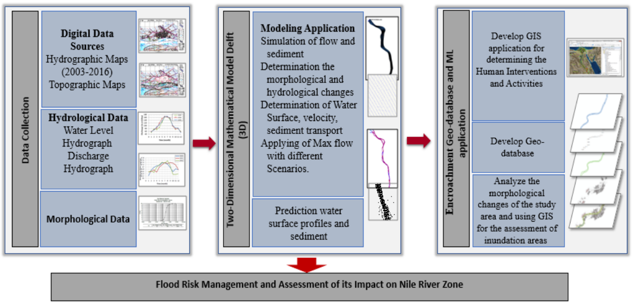

Figure 2: Research Methodology

III. STUDY AREA DESCRIPTION

The Nile River is divided into four reaches segregated by four barrages. The fourth reach is the longest, stretching 408.75 km between the Assiut and Delta barrages. This study focuses on the great Cairo region, which stretches from km 900 to km 954 downstream of the Aswan Dam, as depicted in figure (3). It is characterized by a variety of characteristics that influence the stability of the river morphology. To obtain more accurate results, recently surveyed maps from the year 2016 as well as recent data for water levels and discharges were used. GIS will be used as a preprocessor for model input, as well as to present and store all of the following data.

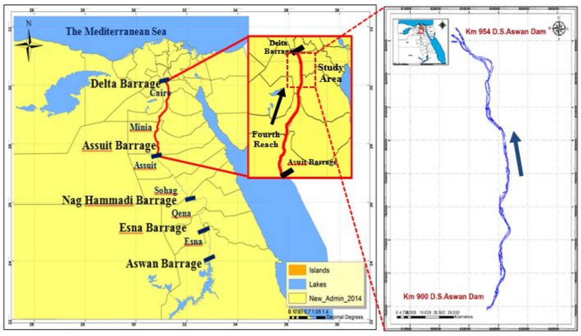

Figure 3: Location of Study Area

IV. DATA COLLECTION

A. Bathymetric data

Bathymetric data were collected along a 54-kilometer study area from the river's two banks between 2003 and 2016.

B. Flow Velocity Distribution Measurements

The velocity distribution measurements were collected at the same time of survey, using a "Valeport" flow current meter. The cross sections were carefully chosen to cover the entire length of the study area. The mean velocity was computed at each vertical, and the three mean velocities at the three verticals were averaged to give the overall average flow velocity of the entire cross section.

C. Bed material sampling

The material of the study area's bed consists of sand and silt. The fine sand ranges between 95.44% and 99.07% of the bed material sample on the other hand; the percentage of silt ranges between 0.18 % and 4.43% of the bed material sample.

D. Hydrological Data

Flow discharges and the corresponding water stages are essential data for simulating the hydrological characteristics of the study area and, and as a result, studying their effect on the management lines. During the study period, water levels upstream of the delta barrage and water discharges downstream of the Assuit barrage to Delta Barrage were collected and analyzed. The maximum and minimum discharges were found to be 175 and 60 million m3/day, respectively, while the water level ranged between 16 and 17.5 m at the upstream of delta barrage.

V. NUMERICAL MODEL

To simulate the river flow of the study area, the Delft3D model was applied to simulate the velocity flow, by a set of mathematical equations based on the conservation of mass, momentum, etc. Delft3D is a hydrodynamic model that can be used to simulate water flows, sediment transports, morphology, water quality, and particle tracking. This model can be used with good accuracy in the field of hydrodynamics (Carlos, Roberto 2005). Delft3D -flow is the hydrodynamic module of Delft3D, which consists of several modules. Delft3D-FLOW solves the Navier Stokes equations for an incompressible fluid, under the shallow water and the Boussinesq assumptions. The set of partial differential equations in combination with an appropriate set of initial and boundary conditions is solved on a finite difference grid (Deltares 2014).

A. Model preparation and Grid generation

Delft 3D Model generated a grid network automatically, then interpolated the bathymetric data into the mesh. The grid stretched for 60 km along the shoreline. A fine grid of (100m*160m) was used in the model as shown in figure (4).

The initial water levels are defined as the initial boundary condition. The boundary conditions formed by the inflow boundary are known as the inflow discharge to the study area and are defined as the discharge downstream gauge station Assuit. The upstream delta barrage water level is used to define the outflow boundary.

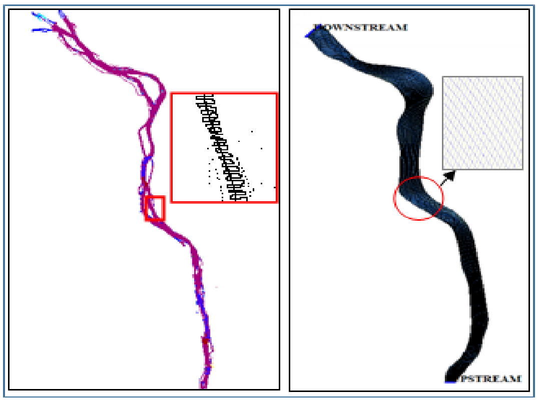

Figure 4: Study Reach Grid Elements and Bathymetry data

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B. Model Calibration

The model's calibration and verification depends on the amount and quality of topographic and hydraulic data collected, such as velocity distributions, water-surface elevation, flow rates, and bed roughness. The model was calibrated using the river discharge 80 (M.m3/s) at downstream Assuit Barrage, which corresponds to the water level 16.85m at upstream Delta Barrage. The model was calibrated, and it was found that there is a reasonable agreement between computed and measured values of flow velocity distributions and morphological changes at the selected cross sections. The calibration process was carried out by adjusting roughness coefficients at various locations along the modelled study area in order to achieve the best agreement between measured and resulted model values. Figure (5) shows velocity calibration and a comparison of calculated and measured velocities for different cross sections along the study area, with the root mean square error (RMSE) used to quantify the model performance. Figure (6) depicts the bed level calibration as well as the comparison of calculated and measured cross sections along the study area. To quantify the model performance for the calculated and measured bed level values, the root mean square error (RMSE) was calculated (to be 0.9153).

VI. MODEL IMPLEMENTATION

A. Predicted Water Surface Profile and studying effect of the changes in water levels in accordance with the Delta Barrage operation rules

Two scenarios were simulated using the model. These scenarios represent the maximum discharge in the future of 350 Mm3/day for a period of 30 days, with the reserved level are about 17.5 m and 16.5 m upstream Delta Barrage, respectively. The average water elevation slope was found to be about 6.8 cm/km along the 50 km length of the study area, as shown Figure (7). According to the model results, the effect of changing water levels in accordance with the Delta Barrage operation rules on the study area ranges from 0.2 m to 1 m. Consequently, morphological changes (deposition and erosion) may occur as a result of hydrological changes. Then there may be a transition in management lines, which will be explained in the next sections.

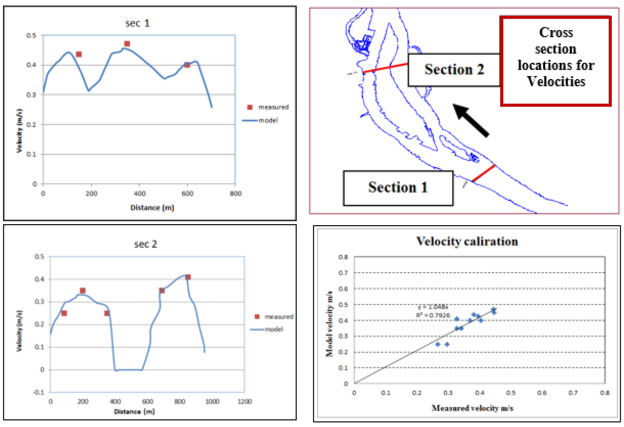

Figure 5: The velocity calibration

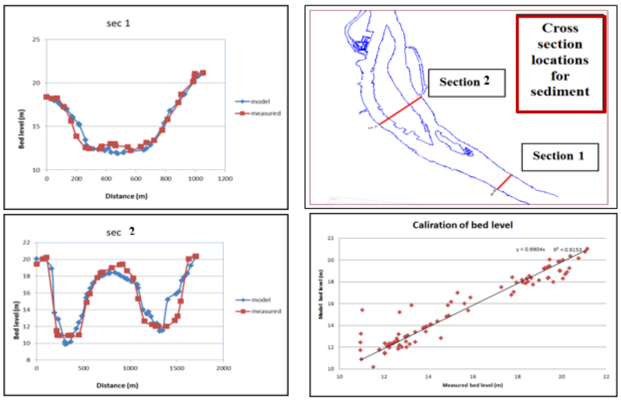

Figure 6: The bed level calibration

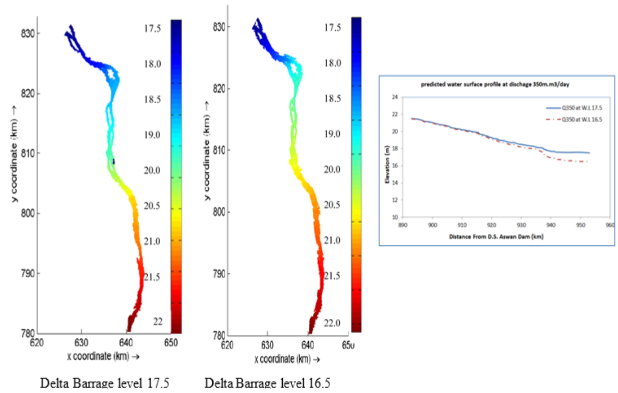

Figure 7: the predicted water surface profile corresponding to discharge 350 m.m3/day along the study reach

B. Assessment of Nile River Human Interventions and Activities through Developed Application of GIS

Encroachments on the river were thought to be one of the main causes of Management Lines transition. GIS was used in this section to evaluate and study the encroachments along the study reach. GIS refers to a group of computer systems that can assemble, store, manipulate, and display geographically referenced data [8]. The authors created a geo-database for the encroachment along the study reach as well as an ML application.

C. GIS Application

Geo-database is the spatial data storage format for ArcGIS, which differs from shape files and coverage in design and functionality. The geo-database is essential for decision makers and river managers because it provides valuable information within the scope of river study reach. Such information can be used to develop management plans and planning processes in order to preserve RML. The methodology for determining river encroachments using GIS can be shown in figure (8). In this part, Buffer analysis is one of the most important tools in the proximity process. It is used to identify areas surrounding geographic features. The process involves generating buffer zone between the Nile river Shore Line and the 350 Line.

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The attribute table of resulted encroachments layer contains all the data that could assist decision makers in determining the number, locations, and names of these encroachments, as shown in figure (9).

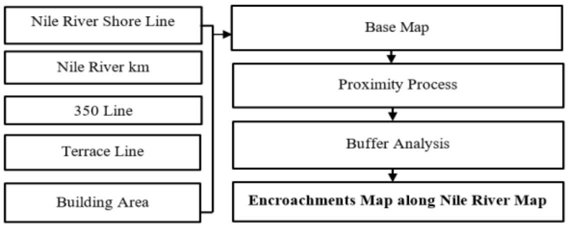

Figure 8: Methodology of using GIS for determining encroachments

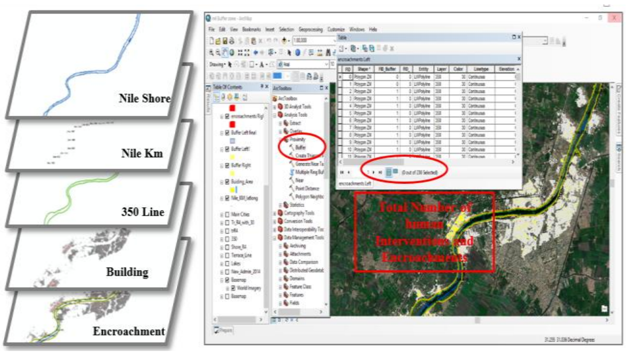

Figure 9: Encroachments Analysis and geo-database

Figure (10) show the classification of encroachments along El Dahab region. It can be noted that 31% were classified as urban areas, 11% as plantation, 19% as signboards, and 39% and for berths.

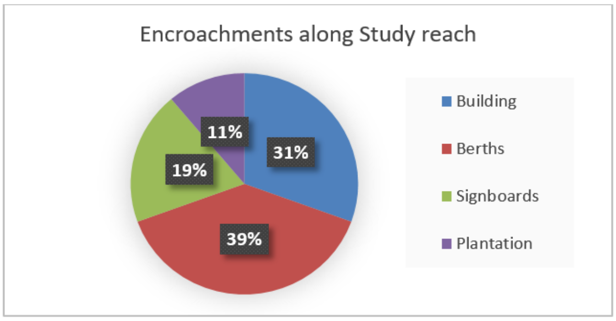

Figure 10: Encroachments classification

D. Assessment of inundation areas through GIS

Figure (11) Shows flood hazardous and expected inundation areas and encroachments computed and analyzed for the first scenario, where the water level upstream Delta Barrage is 16.5 m. According to this scenario, 192 buildings in the El Dahab Island region will be submerged.

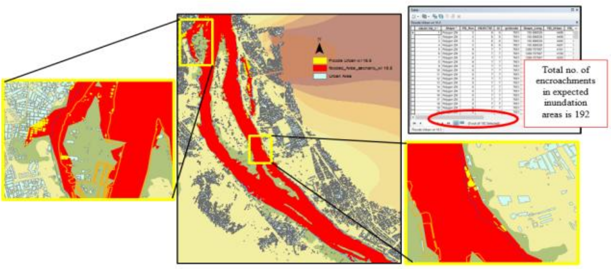

Figure 11: Computing and analyzing flood hazardous and expected inundation areas and Encroachments for first scenarios WL 16.5 m

E. Developed Management Lines application

An application has been developed with the intention of presenting ML and the encroachments along study reach. This application is characterized by friendly user interface and a database that allows the editing, searching, and storing all maps and the ML scanned files. During critical max-water periods, the program facilitates decision-making on encroachments activities. This developed application has three main components: (i) data base (ii) data management, (iii) data analysis, as shown in figure (12).

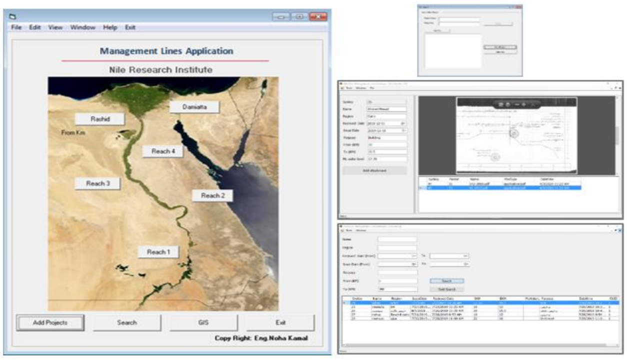

Figure 12: ML application, developed by Authors

F. Morphological Changes Analysis and Evaluation for the Study Area

The predicted morphological changes for the future period until 2025 are presented in this section. Figure 11 shows that this part of the analysis focuses on the critical pilot area, which has a length of 4 km. This region was selected to predict changes in management lines and, as a result, land uses between these lines. It is a critical area which exposed to significant changes, as it distinguishes between two recognized islands. These are the islands of El Dahab and Dar el Salam. El Dahab Island has a large area and a natural reserve, whereas Dar el Salam Island is in the inner curve, where deposition region is. In addition, there is a water pump station near the island of Dar el Salam. The location of the pump station shall be subject to sedimentation. Morphological changes are predicted for the future period up to 2025 for this region. Figures (13 and 14) illustrate the changes in velocity between the initial and predicted cases. For the initial case, the velocity distribution was between 0.1 to 0.5 m/sec along the water course. The predicted velocity distribution grew from 0.2 to 0.7 m/sec. In general, the velocity increased after running the model for nine years, causing morphological changes in many areas and affecting the size of the island. Figure (15) shows a major change in bed level that may occur at the end of the predicted years, as the example shown in figure (15) with cross sections 1 and 2. Based on the results, it is possible to conclude that deposition occurs far more frequently than erosion, especially in Dar El Salam Island region. Figure (15) shows that almost the same areas of deposition and scour appear, but the quantities of deposition have increased. El Dahab Island will be elongated to the south and north part, and this island may be exposed to significantly more sedimentation until it is attached to Dar Elsalam Island, and a new island will appear behind El-Salam Island.

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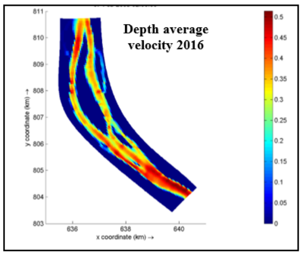

Figure 13: The initial velocity of study area at 2016

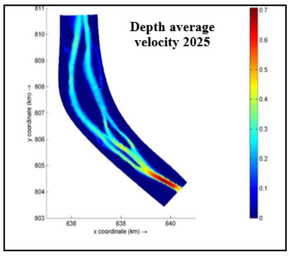

Figure 14: The predicted velocity of study area at year 2025

G. Evaluate the dredging works in the front of water and power stations and along the navigation path to improve their efficiency

In this part, the authors developed a geo-database for berths, water and power stations along the Nile River, as shown in figure (16). It can be noted that many water intakes already exist along the study area, especially in the vicinity of islands of Warrak, El-Dahab and Dar El-salam. These water stations frequently aid in sediment deposition to occur around their intakes. Based on this, it could explain the significant sedimentation along the study reach and, consequently the dredging works required to increase their efficiencies. On the other hand, this sedimentation is expected to cause navigation problems along the NRI-designed navigation path.

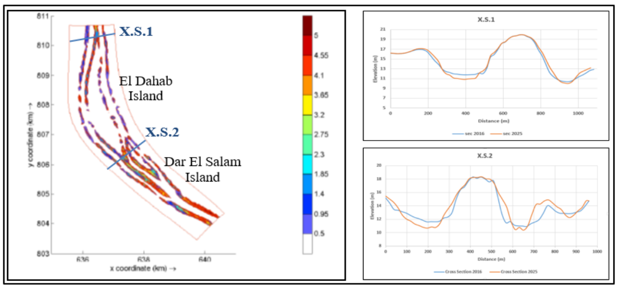

Figure 15: The predicted Morphological changes during period (2016-2025) with two cross sections

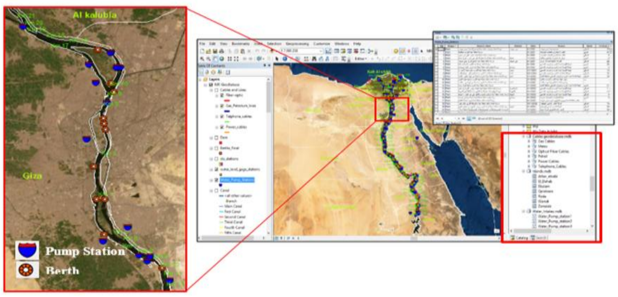

Figure 16: Devloped Geo-database for berths, and water pump stations along Nile River

VII. ANALYSIS AND EVALUATION OF THE EFFECT OF THE PREDICTED WATER SURFACE PROFILES ON BANKS VULNERABILITY TO OVERTOPPING

Management lines are subject to change due to some factors related to river process such as maximum discharge, erosion, and deposition. Therefore, they need to be updated and checked. Any development in the area between these lines is prohibited, unless it is absolutely necessary. Pump intakes, ferry landing facilities, bridge abutments and piers, roadway encroachments, and pipeline crossings under the river or tunnel are all included. In this section of paper, flood lines were aligned based on river morphology changes and water levels predicted in a 4 km reach. This approach can be used to determine the flood hazardous and expected inundation areas, and thus can be used as an early warning for people to evacuate the areas subject to inundation, as shown in figure (17) with two water levels 16.5 and 17.5 m in the two scenarios of gate position. According to the predicted morphological changes, there are significant changes in the predicted water level, which affects banks and management lines. In order to finalize new management lines, they should be verified and the situation on the field should be defined Figure (17) shows the predicted management line in year 2025, where sedimentation increase significantly and the area of flood plain decrease. Furthermore, predicted morphological changes had an impact on the shore line. With the ministry's approval, these new areas can be used for temporary activities such as parks and recreation activities, seasonal agriculture, temporary farm building, fish farming, temporary storage without solid walls, wildlife refuges, access to water, ferry facilities, and borrow pits (gravel/sand) (Mercer et al., 1990 and working paper 720-1, 1991). On demand, these lands may be returned to MWRI.

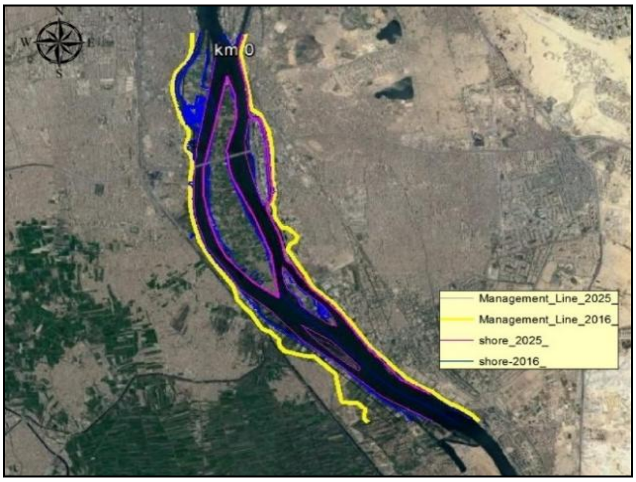

Figure 17: Effect of predicted water level 17.5 m on the lower banks

The types of ML were classified by determining the corresponding water levels of future discharges, which were derived from rating curves between the water levels and discharges. According to high discharges (350 mm^3/day) and different scenarios for operating gate barrage, the usage of flood plain areas can be determined after determining the management line and prohibition zone on both sides of these lines, which is 30 meters measured from the location of the refinement line.

ML are illustrated in the study area based on a cross-section at km 6.600 upstream Roda gauge station. Figure (18) shows the cross section in 2016 and the predicted cross section in 2025. When the two cross sections are compared, the ML shifts due to morphological change can be noted.

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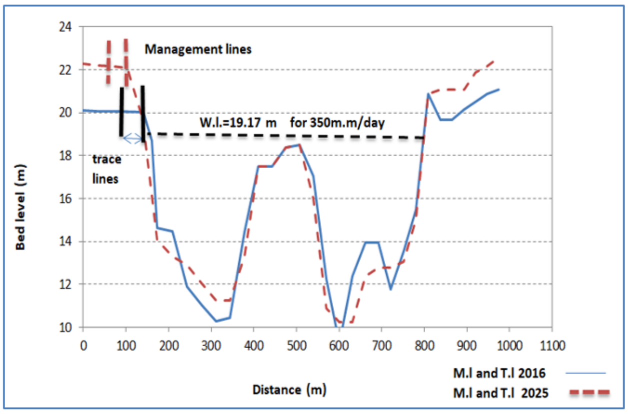

Figure 18: Predicted cross section and new ML at km 6.600 upstream El Roda

VIII. CONCLUSION AND RECOMMENDATIONS

This research is an integrated study that evaluates the factors affecting the change in management lines along the study reach, then determines and predicts the new ML. It can be concluded that, over time, the management lines changes due to a number of factors. First, changes in water levels according to Delta Barrage operation rules cause morphological and hydrological changes. Furthermore, encroachments on the river are regarded as one of the main causes of their transition. In addition, dredging works in the front of the water and power stations, as well as along navigational path, are being carried out to improve their efficiency.

Delft3D hydrodynamic model was used to predict new morphological changes and, as a result, to determine the new ML from 2016 to 2025. Furthermore, the developed application, which was linked to GIS, was a valuable tool for assisting in the determination of ML.

It can be concluded that the new ML concept should be verified throughout the Nile based on the results of the model, which is supported by a developed application and geo-database. In addition, field data collection and analysis are required to clarify the risks associated with using floodplain areas. Furthermore, it is necessary to design the necessary bank erosion protection works and to propose the optimum use of flood plains. It is recommended that remote sensing be used to determine management lines along the Nile River.

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