SILTATION IN IBRAHYMIA CANAL (UPPER EGYPT)

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ABSTRACT

This paper investigates siltation problems in a 60 kilometer reach of Ibrahymia Canal in Upper Egypt. Compilation of field data and historical records indicated that the canal was influenced by human intervention and siltation which reduced the conveyance capacity of the canal. Flow rate and stage data along with the application of a one-dimensional numerical model had been used to analyze the hydraulic characteristics along the canal. In order to improve the flow capacity at the downstream end of the study reach, a two-dimensional numerical model was applied to simulate the present status upstream Dirot Barrages on Ibrahymia Canal. A proposed modification was tested by the two-dimensional model in order to reduce siltation at the upstream end of Dirot Barrages, and to improve the flow efficiency at its downstream end.

Keywords: Canals, Ibrahymia, Siltation, Barrages, Dirot

1. INTRODUCTION

Sediment transport in irrigation canals is an important issue to be considered in the design and operation of irrigation systems. Irrigation canals are generally designed based on the assumption of steady uniform flow of water and sediments. However, the flow is predominantly non-uniform, due to time-dependent discharges and variation of water levels at regulation and division points. Therefore, a strong relationship exists between the sediment transport and flow conditions. The transport of sediment is greatly influenced by the sustainability of an irrigation system. Erosion and deposition increase maintenance costs. Understanding the behavior and transport of sediment allows efficient planning and reliable water delivery schedules, ensures the controlled deposition of sediments, and make maintenance activities more manageable.

As reported by Chow [1] three methods are used to design stable canals; these are; regime method, tractive force method, and rational method.

Siltation and design of alluvial channels were addressed by several researchers and development organizations for its impact on national development. According to FAO [2], the objective of a canal design is to select a bottom slope and geometric dimensions of the cross section such that during a certain period, the sediment flowing into an irrigation canal is equal to the sediment flowing out of the canal. Changes in equilibrium conditions for sediment transport result in periods of deposition or erosion.

Ranga Raju et al. [3] considered three categories for the design phase of irrigation canals. These are; 1) rigid boundary canals, the designed velocity is relatively high, 2) loose boundary canals carrying clean water, the velocity is not large, and 3) loose boundary canal carrying water and sediment, the designed canal should be capable on transporting water and sediment. In fact, it is difficult to maintain flow velocity that will prevent deposition throughout the year. However, irrigation canals require that the total sediment inflow during a certain time period is equal to the total sediment outflow.

Chang [4] mentioned that because of the sediment problems, the geometry and the slope of the canal must be interrelated in order to maintain sediment equilibrium. Dahmen [5] pointed out that the irrigation network should be designed and operated in such a way that: The needed flow passes at the design water level; No erosion of the canal bottom and banks occurs; No deposition of sediment in the canal takes place.

Ibrahymia Canal in Egypt had a long history of siltation. The canal irrigates thousands of acres in the Upper Egypt and is considered the irrigation artily in the western bank of the Nile. As reported in Egyptian Irrigation [6], Sir Colin Scott-Moncrieff reported that the major cost of the canal operation comes from the removal of silt from the canal. Currently, the canal suffered from siltation at the upstream of Dirot Barrages. The presence along with man-induced interference caused deposition of silt upstream the barrages and influencing the barrages efficiency.

This paper focuses on siltation upstream Dirot Barrages. These barrages are located 60 kilometer from Ibrahymia Canal intake on the Nile River. A one-dimensional numerical model had been used to analyze the hydraulic characteristics along the canal and a two-dimensional finite element model was applied to investigate current hydraulic conditions at the upstream end of Dirot Barrages. A mitigation measures were proposed to improve the flow at the downstream end of Dirot Barrages.

2. LOCATION

The Ibrahymia Canal is an irrigation canal which was dug in 1873. It was designed primarily to provide perennial irrigation to the sugar estates in Middle Egypt. It supplied perennial irrigation to 580,000 acres (2,300 km^2) and flood irrigation to another 420,000 acres (1,700 km^2). The discharge of the canal varied between 30 and 80 cubic meters per second in summer and between 500 and 900 cubic meters per second in flood season. Having its head on the left bank of the Nile, opposite Assiut, it runs northwards for 60 kilometers and then divides in Dirot into two main branches; one branch is the Bahr Yousef Canal, while the other is the Ibrahymia Canal. This 350 kilometer long canal, which is undoubtedly one of the largest artificial canals in the world, was designed to take off from the Nile, Figure (1). This study focuses on Ibrahymia canal upstream Dirot Barrages.

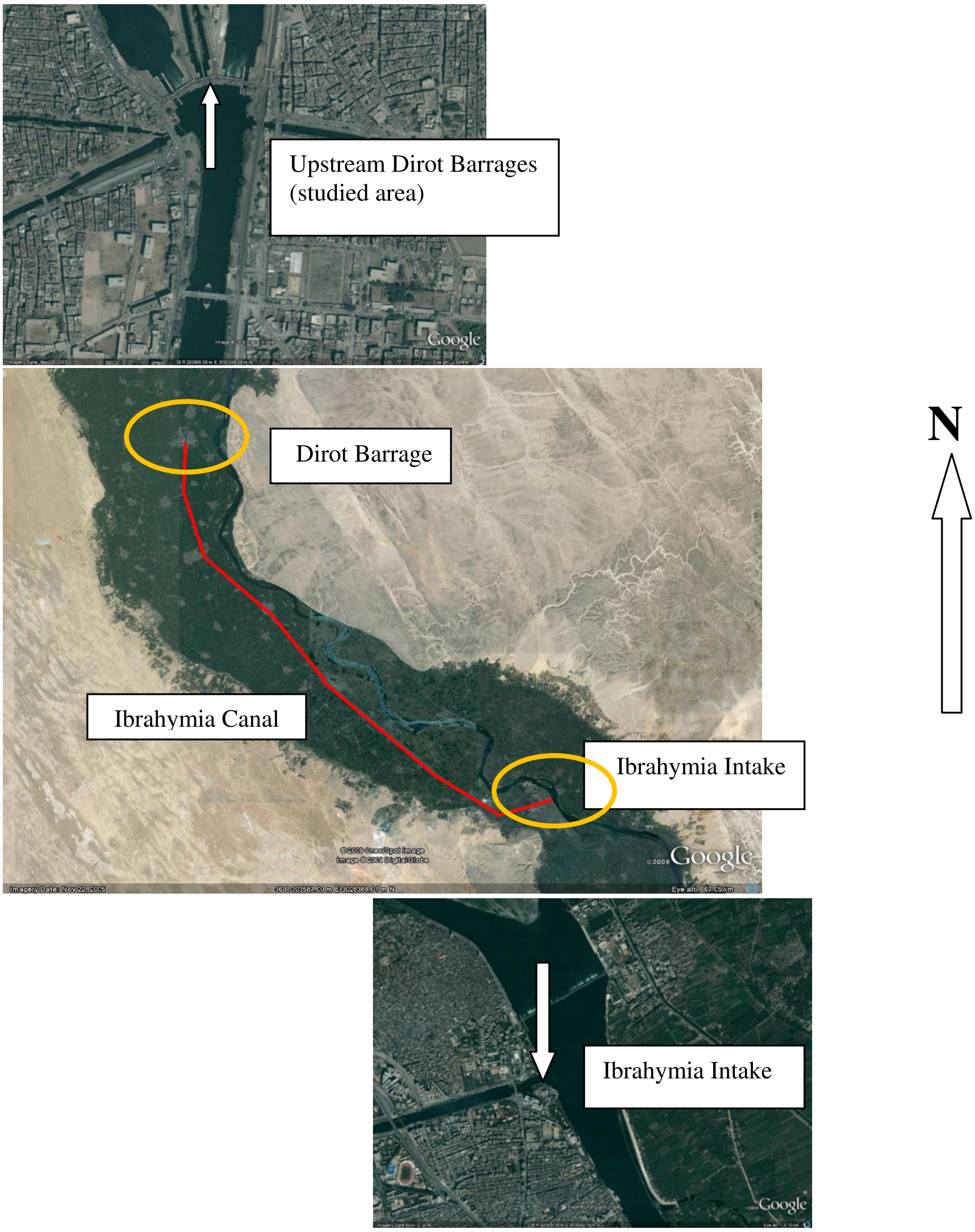

Figure (1): Layout of the study area

3. FIELD INVESTIGATION

Field investigation has been carried out to Ibrahymia canal and Dirot Barrages. This trip was conducted to observe, measure, and monitor the different factors affecting sediment transport along Ibrahymia canal upstream of Dirot Barrages. The investigation included, 1) visual observation and collection of notes on the status of the canal in terms of human-interference and canal maintenance, 2) survey of 13 cross sections along the canal with the aim to be able to estimate the change in canal capacity in carrying the flow, 3) measurements of current velocity and bed material characteristics at the middle of these cross sections. 4) hydrographic survey of canal bed upstream Dirot Barrages covered 750 meters upstream the barrages, and 5) extensive velocity measurements were taken at upstream of Dirot Barrages, where a heavy accumulation of sediment was observed. Figure (2) shows the location of the surveyed 13 cross sections along the 60 km downstream the Ibrahymia intake to Dirot Barrages. Figure (3) shows the layout of the sediment accumulation area and the 25 surveyed cross sections which covered about 750 meters upstream of Dirot Barrages.

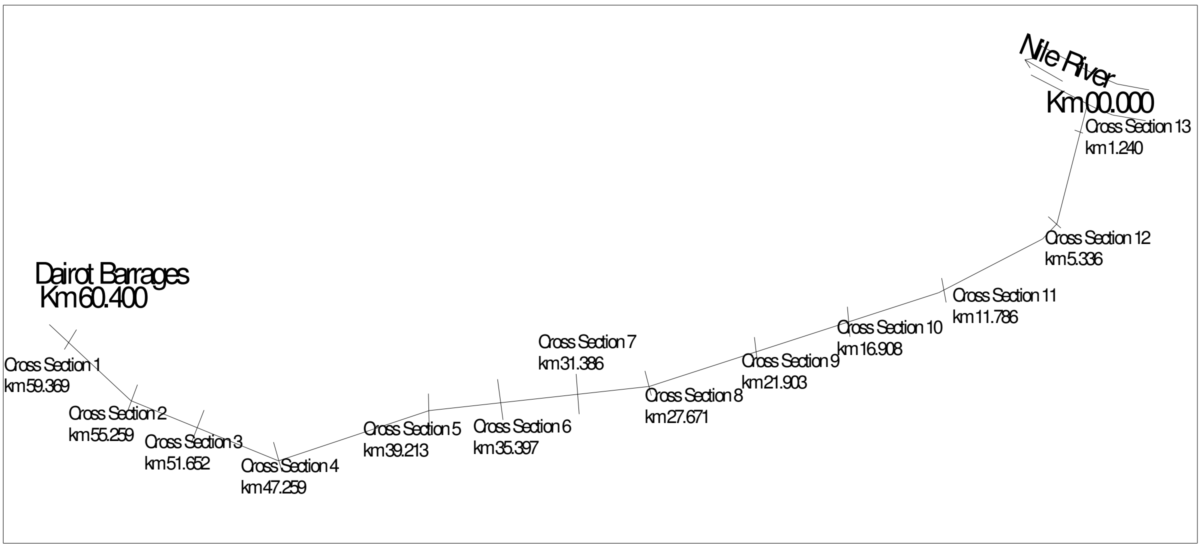

Figure (2) Location of cross sections along Ibrahymia Canal

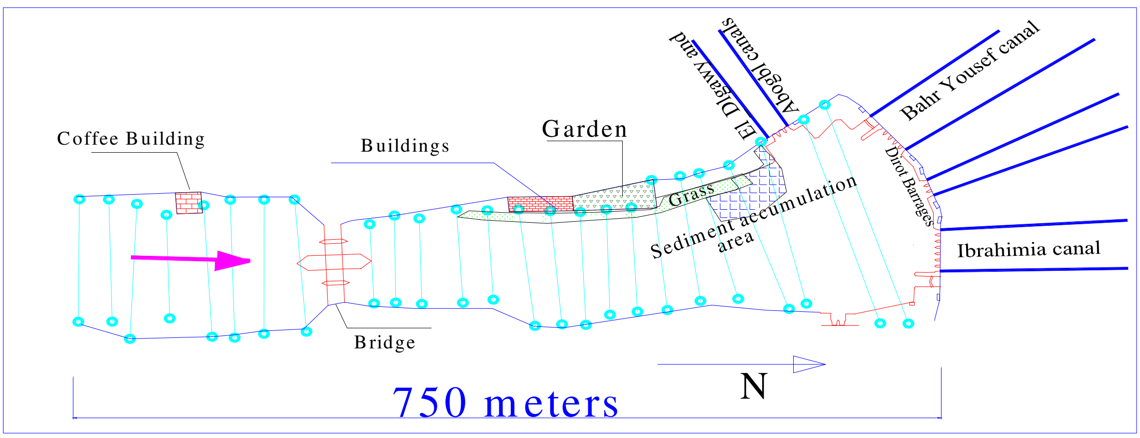

Figure (3): Layout of the sediment accumulation area

4. DATA USED

Two sets of data were used in investigating siltation problems upstream Dirot Barrages. The first set was obtained through field investigation, while the second set was obtained by compilation of historical data in office. Data were compiled from different sources to be suitable for usage as inputs and boundary conditions when applying the numerical model. Among these data were; 1) the originally designed cross sections of the canal and the bed slope, 2) the flow characteristics in the canal throughout the year, and 3) area which are being served by the canal.

Cross sections which were surveyed during the field campaign were compared to the originally designed cross sections. The differences between the original design and the current conditions are very obvious. These differences can be attributed to the accumulation of sediment in the canal, and lack of maintenance. Figure (4) shows one of these cross-sections upstream of Dirot Barrages.

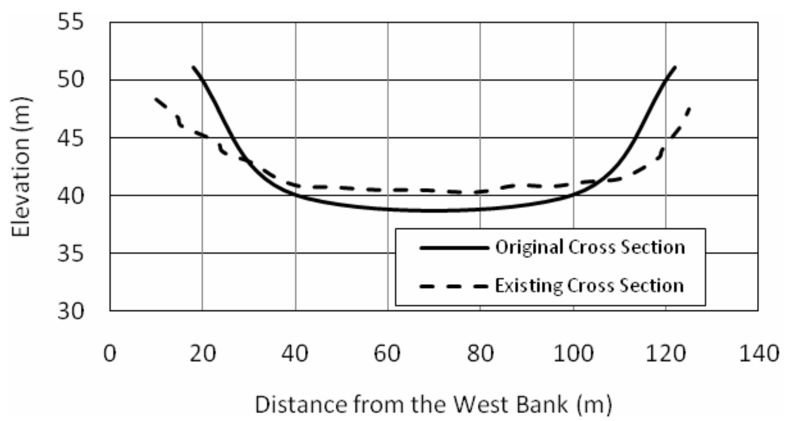

Figure (4): Cross-section 1 upstream Dirot Barrages

5. HYDROLOGY OF THE CANAL

Flow rate along Ibrahymia Canal is fairly constant throughout the years; however, the flow rate varied significantly within a single year. Figure 5, shows flow rate released from Ibrahymia Barrages on Ibrahymia Canal, and flow rate released from Dirot Barrages and Bahr Youssef Barrages at the downstream end of the sixty kilometer reach of Ibrahymia Canal in year 2005. The maximum flow rate took place during the period from June to September.

A one year flow stage presenting flow stage upstream and downstream Ibrahymia Barrages indicated head difference less than 15 centimeters during the month of December and a maximum head difference of 1.6 meter during the month of May as in Figure 6. The head difference is small most of the year, that is, gates are fully open most of the year in order to increase the flow capacity of the canal in order to fulfill the required flow depth needed at the upstream of Dirot and Bahr Youssef Barrages.

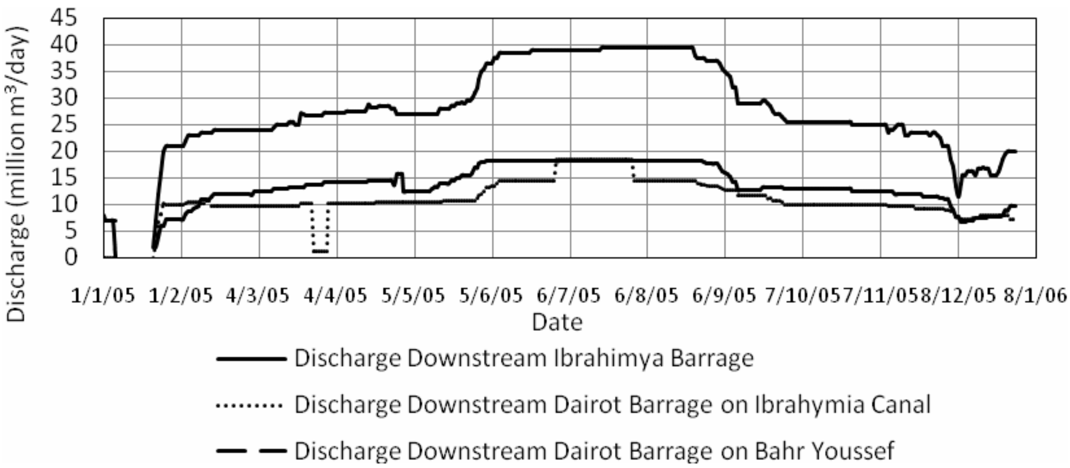

Figure (5): Flow rate downstream main Barrages on Ibrahymia Canal

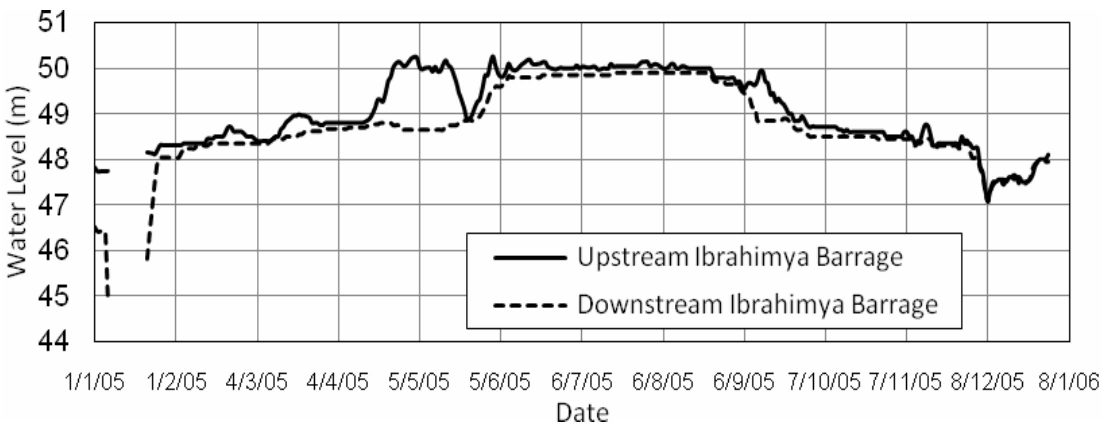

Figure (6): The head difference at Dirot Barrages

At the downstream end of the study reach of Ibrahymia Canal, the flow stage at the upstream of Dirot and Bahr Youssef Barrages is nearly constant. This constant flow stage is required to maintain constant flow throughout Dirot and Bahr Youssef Barrages as shown in Figure 7.

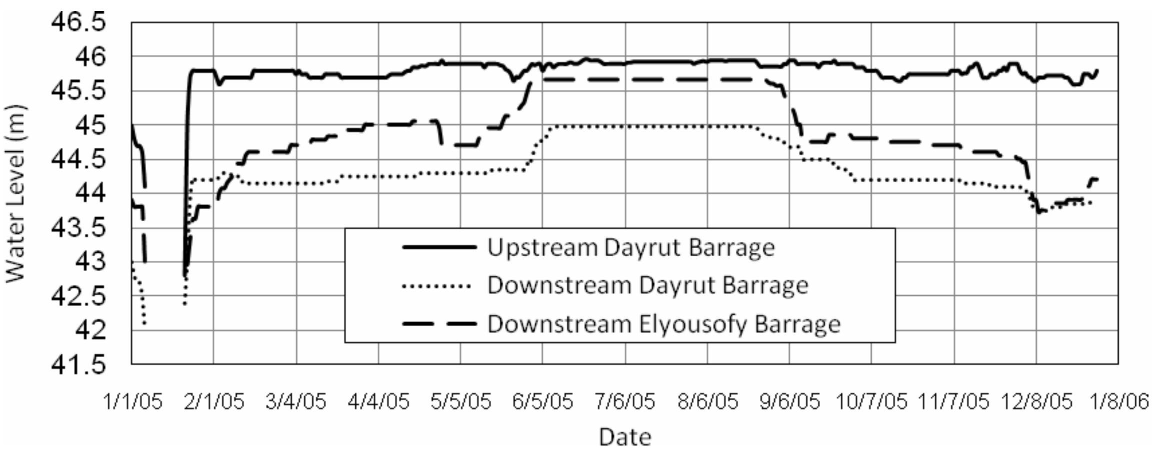

Figure (7): Water levels at Dirot Barrages

6. ANALYSIS OF CHANNEL GEOMETRY

A one-dimensional numerical model was used in order to investigate the effect of change in channel geometry on hydraulic characteristics of Ibrahymia Canal. The model was developed by the Hydrological Engineering Center of United States Corps of Engineer (HEC-RAS version 4.0). It allows the user to perform analysis of steady gradually varied flow in natural or constructed channel. Water surface profile is computed from one cross section to the next by solving the energy equation (Bernoulli's Equation) with an iterative process called standard step method. Considering a reach which has two cross sections, section (1) in the upstream and section (2) in the downstream, the energy equation is written as follows;

$$Z_2 + Y_2 + \frac{a_2 V_2^2}{2g} = Z_1 + Y_1 + \frac{a_1 V_1^2}{2g} + h_e \qquad (1)$$

Where:

Z_1, Z_2 are elevation of the main channel inverts at cross section (1) and (2),
Y_1, Y_2 are the depths of water at cross sections (1) and (2),
V_1, V_2 are the average velocities (total discharge/total flow area) at cross sections (1) and (2),
a_1, a_2 are velocities weighing coefficients at cross sections (1) and (2),
g is the gravitational acceleration, and
h_e is the energy loss between sections (1) and (2).

Surveyed cross sections during the field campaign were used as input in the numerical model. Maximum flow of 39.5 million m^3/day and its corresponding flow stage at the downstream end were the boundary conditions. Water surface profile was calibrated against actual data. The same model was applied using the originally designed cross sections under the same maximum flow as in previous step.

The output of the model in terms of the hydraulic characteristics of the channel was compared in the two cases (originally designed cross section and currently surveyed cross sections); Figure (8) shows the water surface profile in the two cases. The slope of the water surface profile was 6.86 centimeters/kilometer in the current case which was very close to the slope of the original cross section which is 6.76 centimeters/kilometer.

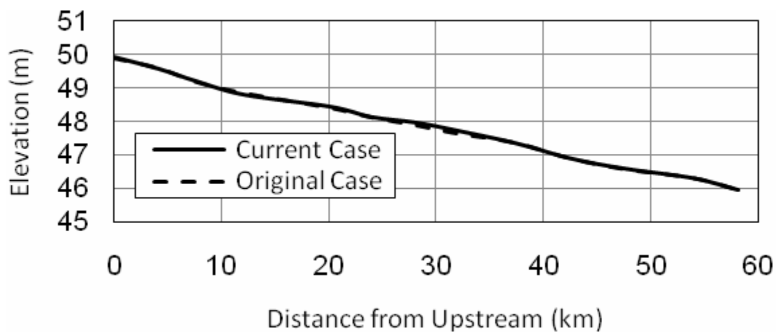

Figure (8): Water surface profile along the study reach

It was found that flow area corresponding to maximum flow increased significantly as in Figure (9). The increased flow area is due to the increased flow width as shown in Figure (10). Flow area had increased in order to fulfill the required flow stage at the upstream end of Dirot Barrages and Bahr Youssef Barrages since deposition took place along the canal.

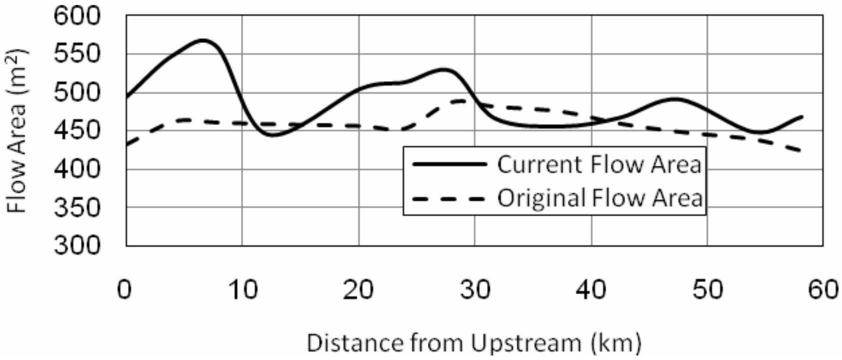

Figure (9): Flow area along Ibrahymia Canal

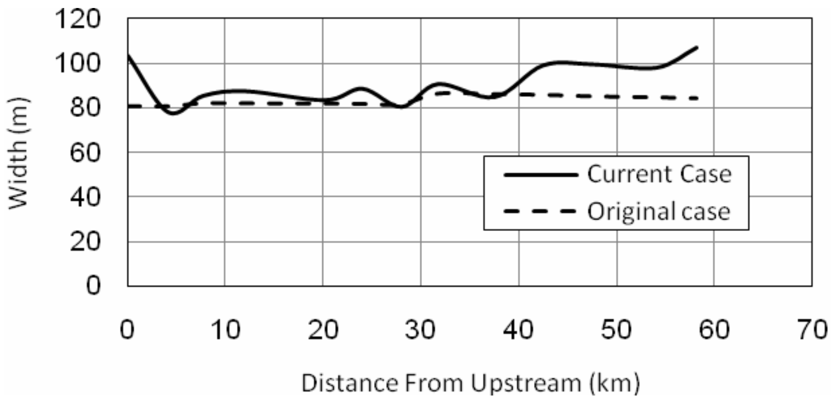

Figure (10): Flow width along Ibrahymia Canal

The output of the model showed that the current hydraulic radius is significantly distorted because of the changes in the flow width and area, Figure (11). These changes are attributed to the presence of silts on bed especially at the downstream of Ibrahymia Barrages and the upstream of Dirot and Bahr Youssef Barrages.

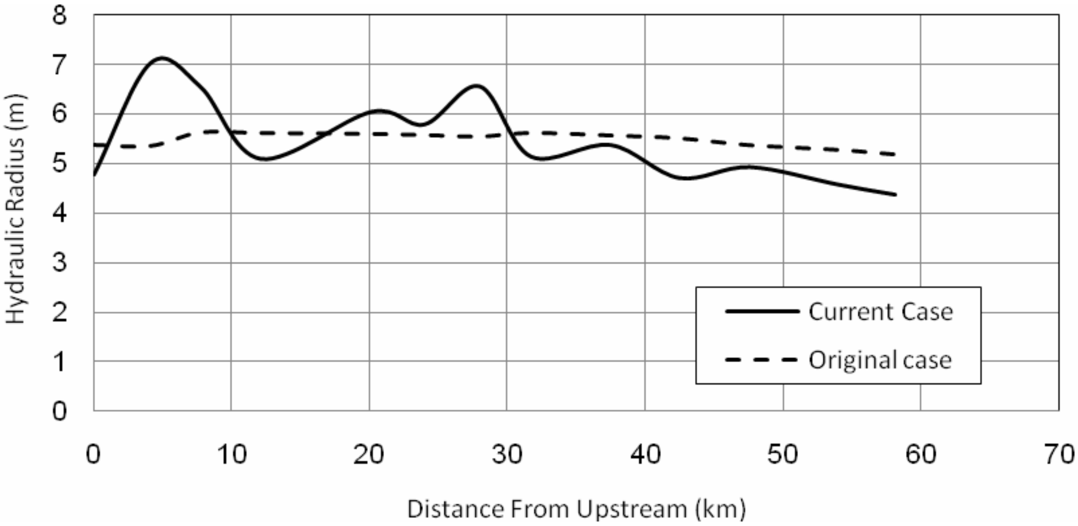

Figure (11): Hydraulic radius along Ibrahymia Canal

7. AGGRADATION AT THE UPASTREAM OF DIROT BARRAGES

7.1 Numerical Model (SMS)

The used module to carry hydraulics and sediment analysis in SMS is the Depth-averaged Flow and Sediment Transport model (FST2DH), it applies the finite element method to solve steady state or time-dependent systems of equations that describe two-dimensional depth averaged surface-water flow and transport of non cohesive sediment by surface waters. This model solves the depth-integrated equations of mass and momentum conservation in two horizontal directions. The vertically integrated momentum equation is written for flow in the x direction as:

$$\frac{\partial H}{\partial t}+\frac{\partial(HU)}{\partial x}+\frac{\partial(HV)}{\partial y}=q \qquad (2)$$

For flow in the *y* direction, the vertically integrated mass transport equation (continuity equation) is written as follows:

$$\frac{\partial}{\partial t}\overrightarrow{M_{column}}=\overrightarrow{M_{in}}-\overrightarrow{M_{out}}+\Sigma\vec{F} \qquad (3)$$

Where:

H = water depth,
U = horizontal velocity in the x direction,
V = horizontal velocity in the y direction,
q = unit source (inflow) or a unit sink (outflow) term,
t = time,
M = momentum force, and
F = external forces.

7.2 Mesh Generation

The first step in applying the model is to generate a mesh at which flow characteristics will be calculated at each node. In this paper, the mesh consisted of quad elements in which every element has 9 nodes. That is, flow was calculated at 9 nodes at each element.

A preliminary finite element mesh was developed, using the SMS 10.0 software (U.S. Department of Transportation 2007). A finite element mesh is defined as a network of triangular and quadrilateral elements constructed from nodes. In this study, the Map Module in SMS was used to define the study area boundaries and water features using hydrographic survey carried out during field investigation. Then, SMS model automatically generates a mesh or grid network from the map module and then interpolated the bathymetric data into the mesh. The mesh contains (2000) elements and (6240) nodes, (Figure 12). The mesh represents 1 kilometer length upstream Dirot barrages, (Figure 3). The built-in interpolate command in the mesh creator module of SMS was used to assign a depth for each individual node using the surveyed bed elevation in terms of (XYZ) data points.

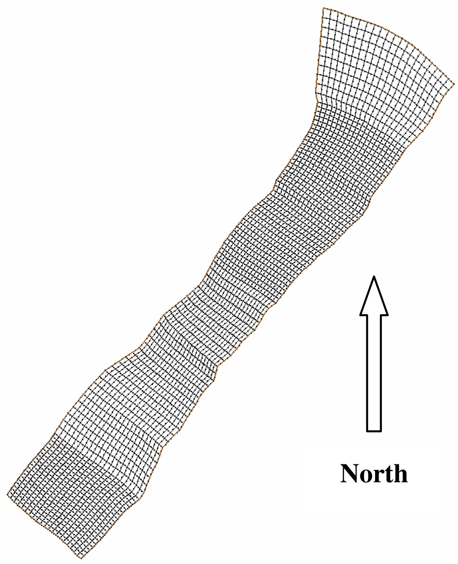

Figure (12): The designed mesh

7.3 Calibration

In order to test the model for its ability to simulate real situations, the model had been calibrated against real data collected from the field. During field campaign the measured flow discharge was 387 m^3/sec, at which the model was calibrated. The measured field velocities were used in calibrating the model by comparing them with velocities resulted from running the numerical model. Velocity measurements were carried out at five cross sections located as indicated in (Figure 13). These locations were spread out through the study reach in order to present the study area.

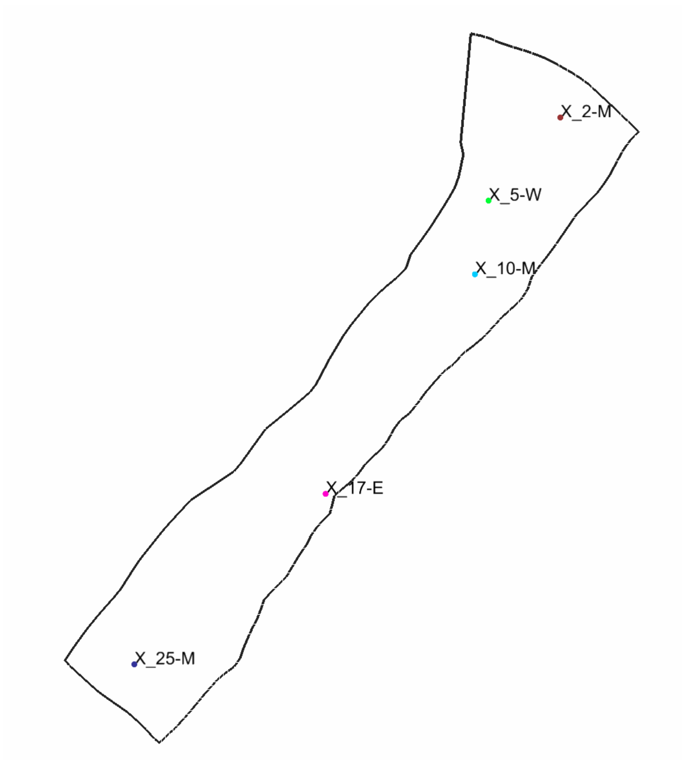

Figure (13): Locations of the observed velocity in the field

Comparing the observed velocity with the computed velocity from the model showed that the computed velocities overestimated the observed ones as shown in Figure (14). Therefore, the roughness Manning's coefficient of roughness had to be adjusted in order to make the computed velocity equal or near equal the observed velocity. In the mean time, Manning roughness coefficient should be a representative for the type of soil in the canal and the presence of any structures.

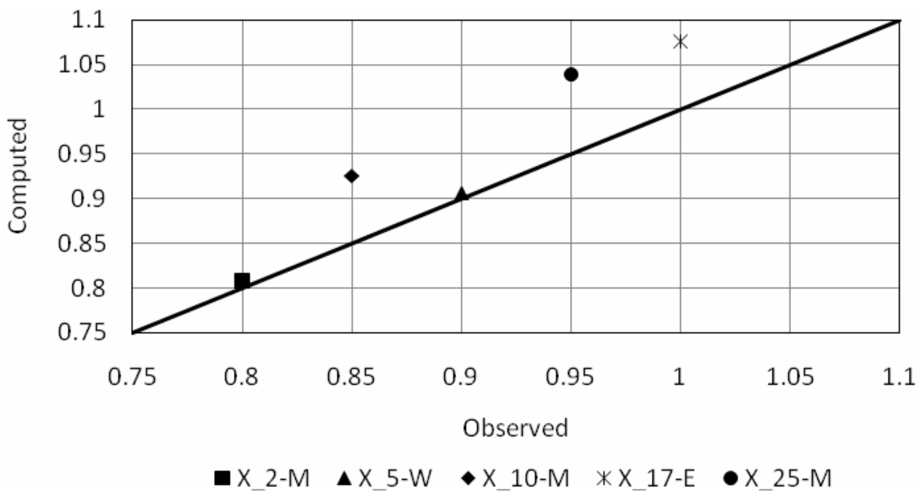

Figure (14): Computed versus observed velocity before adjusting Manning coefficient

Readjustment of the Manning coefficient showed that Manning roughness coefficient is in the range of 0.025 yielded computed velocity from the model in a very close range with the observed ones. In addition, bed material of the canal is medium sand has d_{50} ranges between 0.47 mm and 0.54 mm. The maximum deviation for the computed velocity from the observed velocity is 10% as shown in Figure (15).

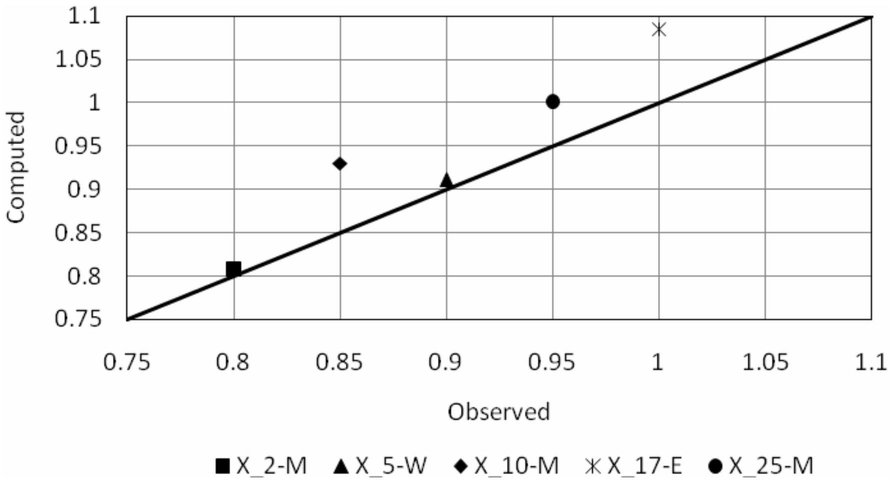

Figure (15): Computed versus observed velocity after adjusting Manning coefficient

8. PROPOSED MODIFICATIONS

In order to eliminate deposition problem upstream Dirot Barrages, it is necessary to re-align the canal banks in order to modify the flow velocity and reduce deposition in this area.

Modifications were carried out upstream of Dirot Barrages for a distance of 750 meters. These modifications include; alignment of the left and right banks of the canal, adjustment of the canal bed to match the originally designed cross sections of the canal, and removal of the present occupancy on canal sides bank, (Figure 16). The volume of dredging upstream Dirot Barrages was about 4500 m^3.

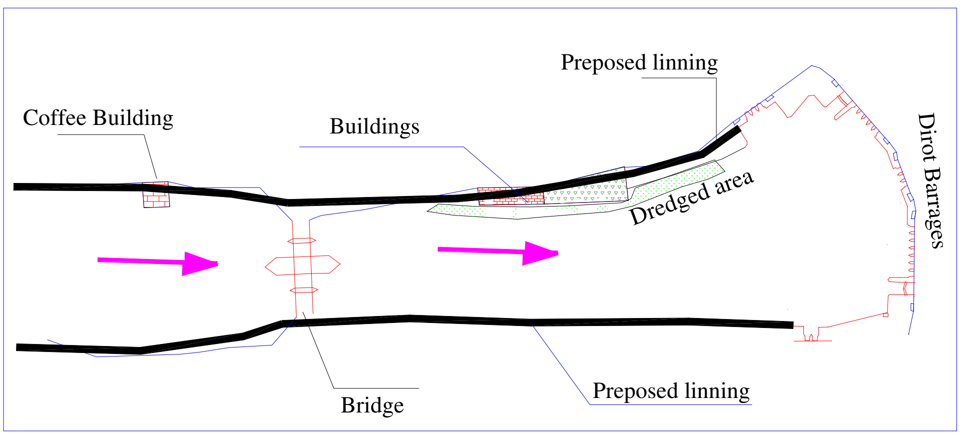

Figure (16): Canal modifications

According to the new alignment, a new mesh was generated in order to reflect the new conditions. After running the model, velocities at the upstream of distribution barrages were deducted and plotted as shown in Figure (17). The figure indicated a reduction in the velocity field by around 30%. Maximum velocity was reduced from 0.95 m/sec before modifications to 0.66 m/sec after modifications; thus, reducing bed particle mobility and deposition at the inlet of distribution barrages.

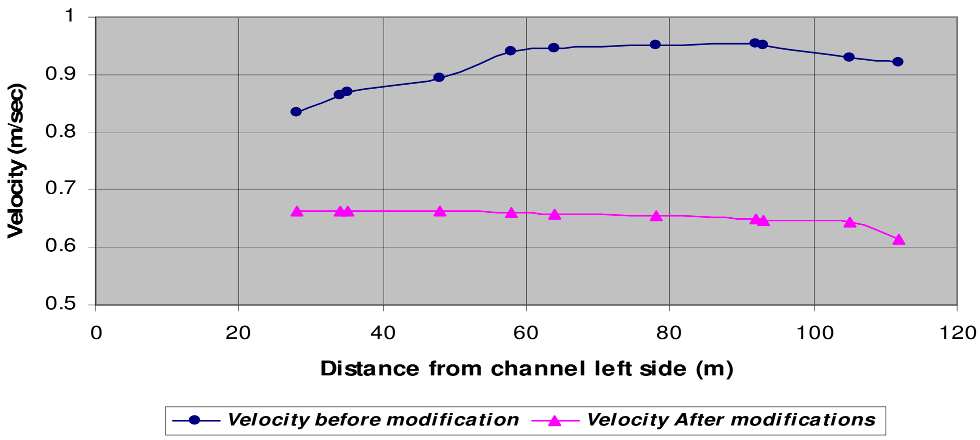

Figure (17): Computed flow velocity before and after modifications

9. SEDIMENTATION AT THE UPSTREAM END OF THE DISTRIBUTION BARRAGES

In order to investigate sediment transport in the study area, the same mathematical model was applied. This SMS (Surface-water Modeling System) has a module (FST2DH) which has the capabilities for sediment transport calculations. The model is a two-dimensional model intended for medium to coarse sand bed which is the case in this study. In carrying out the analysis, the following criteria were taken into consideration; 1) The Engelund-Hansen method for calculating the sediment transport was applied, 2) Grain size distribution curve for canal bed material was considered in the input, and 3) Maximum discharge of 387 m^3/sec. in the canal.

Two cases were considered in running the sediment transport module. The first case was the existing situation, while, the second case was after canal modifications.

Figure (18) shows the differences in bed elevations after running the program with the existing and modified situations. The program was run for two-month duration. Sediment transport in the reach was considered as balanced. That is, no sediment transport entering or leaving the reach.

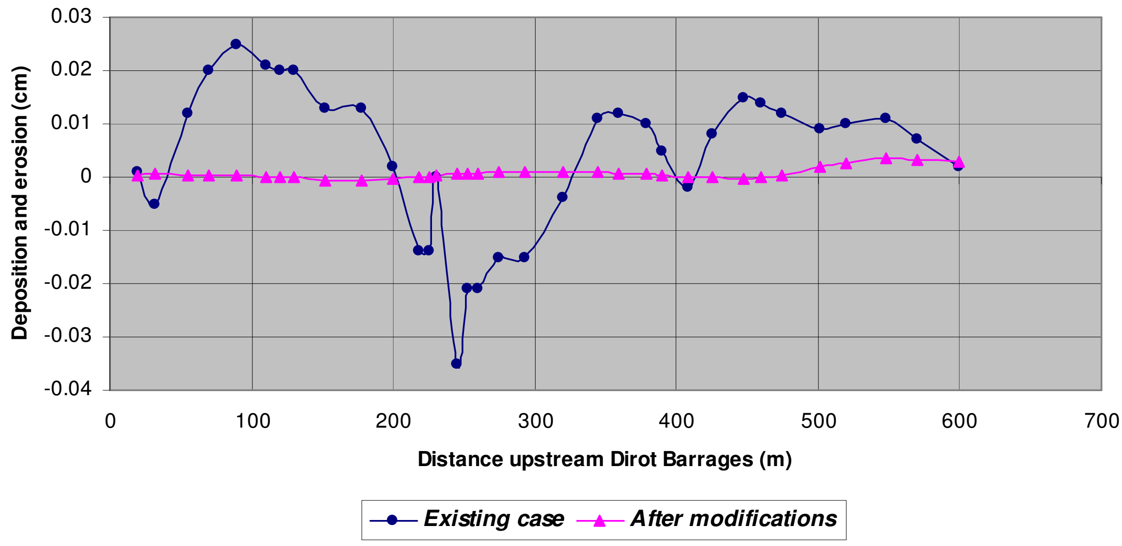

Figure (18): Changes in bed elevation before and after modifications

Figure (18) indicates deposition up to 2.5 cm at the end of the two-month period at a distance of 100 meters upstream Dirot Barrages. The distance between 50 meters and 200 meters is a deposition zone followed by erosion zone in the distance between 200 meters and 320 meters upstream Dirot Barrages. The maximum erosion is 3.5 centimeters at a distance 240 meters upstream Dirot Barrages. Accordingly, the expected deposited volume in this area is about 3000 m^3/year.

After running the sediment transport module under the same conditions for a period of two months, the results were encouraging in terms of reducing the sedimentation and erosion along the canal. Figure (18), shows these results which indicate a maximum deposition of 3.5 millimeters at 600 meters upstream Dirot Barrages. In the immediate upstream of Dirot Barrages erosion and sedimentation is very low.

It can be concluded that the proposed modifications will reduce the value of sediment transport. Hence, deposition will take place far upstream from the barrages and will not affect the flow from flowing to the barrages.

10. SUMMARY AND CONCLUSIONS

Historically, Ibrahymia canal underwent siltation problems since it was dug in 1873. The canal is the irrigation artily in the Upper Egypt. Recently, this problem came into the surface at the upstream of Dirot Barrages 60 kilometer from the canal intake. The siltation problem combined with human interference reduced the canal efficiency. Both field and historical data were used in order to investigate the problem and improve the conveyance capabilities of the canal. A two-dimensional numerical model was applied in order to characterize the flow in the canal. Analysis of the model results indicated deposition of silts at the upstream end of Dirot Canal under the current geometry of cross sections and current hydrological conditions. Since, human-interference on the canal is immense and resulted in the change in cross section geometry from the originally designed sections, modifications were proposed with respect to the geometry of cross sections and the terrace lines of the canal. It was proposed that the original cross sections to be maintained. The newly proposed measures were tested using the same two-dimensional model. The results of the model were very promising. The siltation was reduced significantly in the canal specially in the upstream end of Dirot Barrages. Thus, the conveyance capability of the canal shall be improved. It is strongly recommended to maintain the canal annually to eliminate the accumulation of silt.

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