

IMPACT OF FUTURE DISCHARGES ON DAMIETTA BRANCH MORPHOLOGY

Abdel-Azim M. Negm¹, Tarek M. Abdel-Aziz², Mohamed N. Salem³
and Wessam Yousef⁴

¹ Vice Dean and Professor of Hydraulics, Faculty of Engineering,
Zagazig University, Zagazig 44519, Egypt, [E-mail: amnegr85@yahoo.com](mailto:amnegr85@yahoo.com)

² Professor, Secretary General of Nile Research Institute,
National Water Research Center 13621, Qanater, Egypt, [E-mail: aziztm@hotmail.com](mailto:aziztm@hotmail.com)

³ Professor of Irrigation and Drainage Structures, Faculty of Engineering,
Zagazig University, Zagazig 44519, Egypt. [E-mail: mnsa30@yahoo.com](mailto:mnsa30@yahoo.com)

⁴ Civil Engineer, Ministry of Housing, Utilities, and Urban Development, Egypt.

ABSTRACT

Damietta Branch is very important for navigation and irrigation in Egypt. The hydraulic characteristic changes and morphological changes such as scour, deposition, bank erosion, beside the encroachment by people on the floodplain during the last three decades reduced its capacity to convey high discharges. This research work aims at preparing this branch to pass future releases more than the maximum current release. Comparisons between cross sections in many years under scenario of increasing the discharge from 60 to 80 million m³/day are carried out. Two-dimensional hydrodynamic mathematical model (CCHE) package is used to study the morphological changes in Damietta Branch and to predict the effect of high flows on water velocities and geometrical changes in different cross sections. Also the side effects on the navigational channel and over topping problems have been investigated. Consequently different solutions were suggested to increase the ability of Damietta Branch to convey high discharges.

1. INTRODUCTION

Damietta Branch is one of the two River Nile Branches (Damietta and Rosetta Branches). It is considered an important waterway through the river Nile. It extends from downstream Delta Barrages at km 26.5 behind EL-Roda Gauge station to the Mediterranean Sea with length about 245 km. It has an average width of about 280 m and average sinuosity about 1.3. The water level slope of Damietta branch from Delta Barrage to Zefta barrage (119.85 km from EL-Roda Gauge station) is about 5.5 cm/km in case of high flow and 3.8 cm/km in case of low flow. But the water level slope downstream Zefta Barrage is about 2.7 cm/km in case of high flow and 2.4 cm/km in case of low flow. Delta Barrage is replaced by a new Barrage on Damietta Branch in 1982 downstream the existing one, which is located at 253.7 Km from EL-Roda Gauge with five vents. The vent's width is 5.25 m and the pier's width is 1.5 m to prevent salt water intrusion. The maximum flow rate should not exceed 22 million

m³/day. This branch is morphologically unstable and comprises many local changes by hydraulic characteristic changes and morphological changes as scour, deposition and bank erosion. In addition to the encroachment by people on the floodplain during the last three decades has reduced river capacity to convey high discharges.

Some Scientists studied the nature of river bends along Damietta Branch which contains the three mentioned types of bends. They showed that there is non-uniform in bank erodability; Attia and El-Said (2004), [7]. Attia and Sadek (2005), [3] studied the capacity of the reach located downstream Zefta Barrage up to new Damietta Barrage to pass the expected future high release more than the maximum current releases to the Mediterranean Sea. One dimensional mathematical model was used to analyze and evaluate the effect of the predicted water level related to different high discharges on both banks.

Moustafa (2005), [2] discussed the Nile River morphology expected changes for the reach of Damietta Branch. He studied the difference between the meander morphologies at 1982 and 2001 such as: channel width, channel depth, meander wavelength because this reach is meandering and contains many bends and islands. He developed (GSTARS 2.0) model to predict the morphological changes. Then, he found that due to the increase of flow the average amount of degradation is 14.91m/km, and the amount of aggradations is 10.62 m/km.

Zaghloul (2006), [10] analyzed the morphological changes in the Delta Barrages area (Damietta and Rosetta Branch) to emphasize the aggradations in the 40 km upstream reach and showed the degradation in the downstream area which extends about 10 Km along the two branches. He used the hydrographic survey of the river bed in 1982 and 2002. It was found that there was a rising in the bed level upstream Delta Barrage of about 1.5 m in some places and increasing in its width and depth along the study reach.

Abdel-Naby (2006), [1] studied the effect of morphological changes on different parameters such as channel plan form, width, erosion and deposition near the embankments of the River Nile at the study area Kasr El-Nile, to protect water structures and river banks by applying a mathematical surface water Modeling System (SMS). This research showed that the rate of average velocity tends to be higher at the east side rather than the west side. The rate of deposition is higher and causes navigation problems.

Moussa and Aziz., (2007), [9] analyzed and make comparisons among many different formulae as equations of Ackers and White, Engelund and Hansen & Yang, to predict the amount of sediment discharges in the Nile River at Damietta Branch in the period from 1982 to 2001. He found that the equations of Ackers, White and Yang are similar results with a predicted percentage of 76.34%. The rate of error for the cross sections is small for Ackers and White equation than the other two equations.

The main purpose of this research is to study the meandering geometry for this branch from downstream Delta Barrage up to Zefta Barrage, and the reach capacity to pass

expected future discharge of 80 million m³/day rather than the maximum current releases of 60 million m³/day to the Mediterranean Sea. The (CCHE-2D) package is adopted for the morphological study. Consequently, proposing the location of protection works for the overtopping banks.

2. STUDY PLAN

The collected data e.g. (bed levels, velocities, discharges and suspended sediment concentration) was collected by the Nile Research Institute (NRI), National Water Research Center (NWRC) and Hydraulic Research Institute (HRI).

The considered reach is 90 km length starting at km (26.5) and ends at km (116.5) and contains 10 cross-sections; the following procedure is adopted in this paper:

1. Determine the hydrographic data through 460 cross-sections along the study area with spaced 200m apart.
2. Study the velocities and discharges which were passed during the last years.
3. Apply a mathematical model (CCHE-2D) to determine the velocities along the study area.
4. Analyze the effect of the predicted discharges and velocities by the model on the right and left banks which are exposed to overtopping.
5. Propose the suitable type of bank protection works.

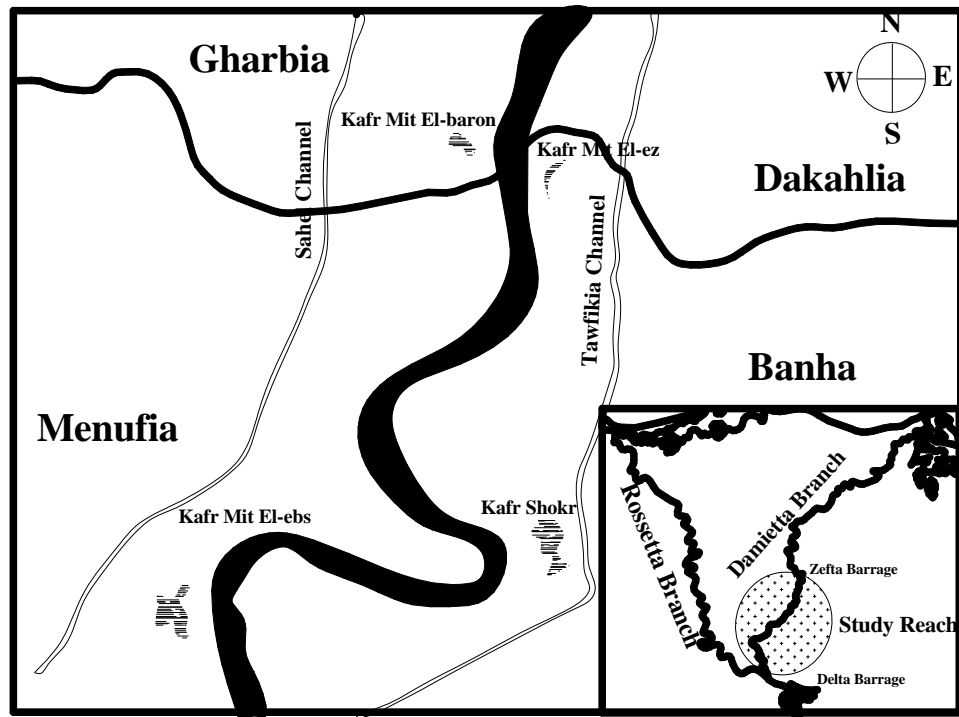


Fig. 1 The Damietta branch topography

3. FIELD DATA

The Nile Research Institute (NRI) and Hydraulic Research Institute (HRI) performed a complete hydrographic survey and collected the data of the water levels, corresponding passing discharges and suspended sediment concentration for Damietta Branch. The average velocities at ten sections were computed based on actual measurements of velocities at vertical line for each section. At each vertical location the velocity is measured at five depths along the specified locations (0.5 m under the surface water, 25%, 50%, 75% of the total depth and 0.75 m above the river bed) as shown in Fig.(2). Table 1 shows the computed average velocities at ten different sections. While the bed material samples collected at sections along the study reach from data by Nile Research Institute (NRI). The grain size distribution curves at cross sections are shown in Fig. (3).

Table 1 The average velocity along the study area

Cross Section	Distance behind EL- Roda Gauge (KM)	Date	average velocity (m/s)
1	31.50	14/12/2003	0.71
2	36.50	13/12/2003	0.77
3	56.50	10/12/2003	0.79
4	73.50	10/12/2003	0.69
5	86.50	10/12/2003	0.59
6	95.82	23/4/2003	0.52
7	97.26	24/4/2003	0.50
8	99.00	28/4/2003	0.50
9	100.6	20/12/2003	0.49
10	101.83	22/12/2003	0.41

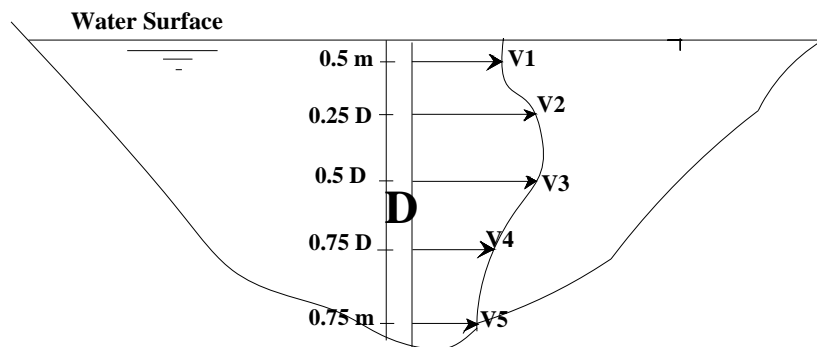


Fig. 2 Computation of the average velocity at any section

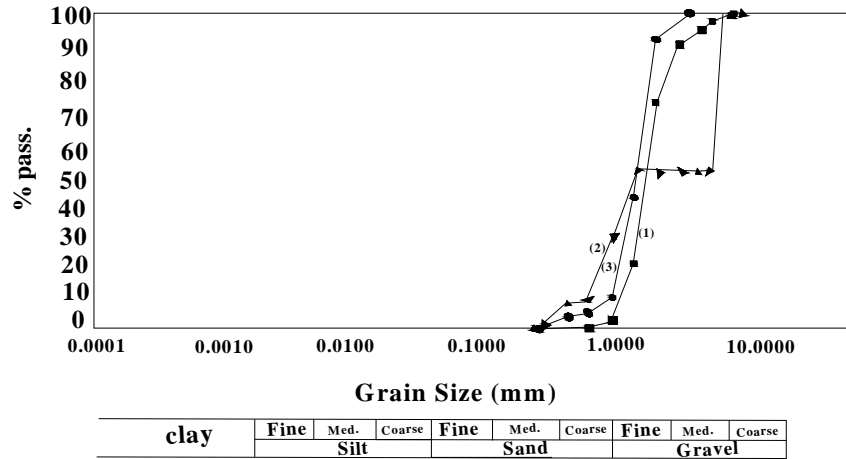


Fig. 3 Grain size distribution curves at Cross Section No. (6)

4. MATHEMATICAL MODEL

This study uses the 2-D Hydrodynamic Model (CCHE-2D), (2005), [6] which was based on the solution of Navier-Stokes equations for turbulent flow, and used the finite volume method for solving the sediment transport equation. The model is utilized to determine the cross sections as a result of passing discharges greater than the current one. This model was used successfully in some similar situations as Negm et al., (2010), [9] for calculating and predicting different hydraulic parameters such as average velocity, cross-sections at Lake Nasser.

The governing equations of (CCHE-2D) used for simulating the flow field are;

Continuity equation:

$$\frac{\partial z}{\partial t} + \frac{\partial (hu)}{\partial x} + \frac{\partial (hv)}{\partial y} = 0 \quad (1)$$

Momentum equations:

$$\frac{\partial u}{\partial t} + u \frac{\partial u}{\partial x} + v \frac{\partial u}{\partial y} = -g \frac{\partial z}{\partial x} + \frac{1}{h} \left[\frac{\partial (h\tau_{xx})}{\partial x} + \frac{\partial (h\tau_{xy})}{\partial y} \right] - \frac{\tau_{bx}}{\rho h} + f_{cor} v \quad (2)$$

$$\frac{\partial v}{\partial t} + u \frac{\partial v}{\partial x} + v \frac{\partial v}{\partial y} = -g \frac{\partial z}{\partial y} + \frac{1}{h} \left[\frac{\partial (h\tau_{yx})}{\partial x} + \frac{\partial (h\tau_{yy})}{\partial y} \right] - \frac{\tau_{by}}{\rho h} + f_{cor} u \quad (3)$$

Sediment transport equation:

$$\frac{\partial c_k}{\partial t} + U \frac{\partial c_k}{\partial x} + v \frac{\partial c_k}{\partial y} = \epsilon_s \left(\frac{\partial^2 c_k}{\partial x^2} + \frac{\partial^2 c_k}{\partial y^2} \right) + \frac{\alpha \omega_{sk}}{h} (C_{*k} - C_k) + S_c \quad (4)$$

Where u and v was the depth-integrated velocity component in the x and y directions; z is the water surface elevation; g is the gravitational acceleration; ρ is water density;

h is the local water depth; f_{cor} is the coriolis parameter; τ_{xx} , τ_{xy} , τ_{yx} and τ_{yy} are the depth integrated Reynolds stresses; τ_{bx} and τ_{by} are shear stresses on the bed surface; C_n is the concentration of n -th size class of sediment; S_c is the source term including the derivatives of ϵ_s and h ; z -direction being assigned as the vertical direction along the gravity; ω_{sk} is the settling velocity of the n -th size class of sediment; ϵ_s is the eddy diffusivity of sediment, $\epsilon_s = \nu_s / \sigma_s$; V_t is the eddy viscosity of flow; and σ_s is the turbulent prandtl-schmidt number (between 0.50 and 1.0); S_c is the source term including the derivatives of ϵ_s and h ; C_k is the depth averaged concentration and C^*k is the transport capacity of total load.

5. MODEL CALIBRATION

The required data for the program are geometric and hydrologic data. The hydrologic data is the flow discharges and average velocities along the study area. While the geometric data are composed of 90 cross-sections with spacing 1 km apart. These cross-sections were surveyed by HRI in 2000 as shown in Fig. (4) to Fig. (7). The comparison between measured and computed velocities at different cross sections as in Fig. (8) indicated the suitability of the model for the study purpose. The model simulates the velocities for the different predicted discharges to define the area which is exposed to overtopping as shown on the same Fig. (4) to Fig. (7) where the values (dashed line) are computed by the model.

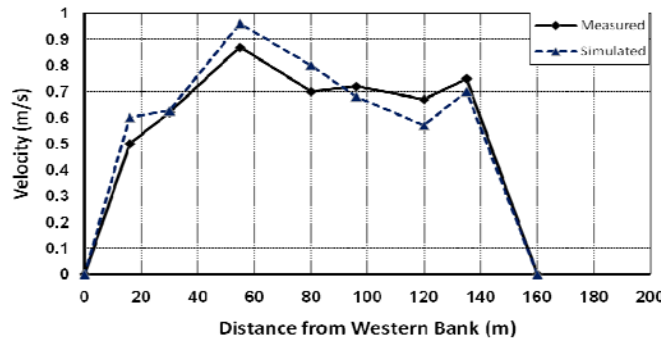


Fig. 4 Comparison between measured and simulated velocity at Sec. (2)

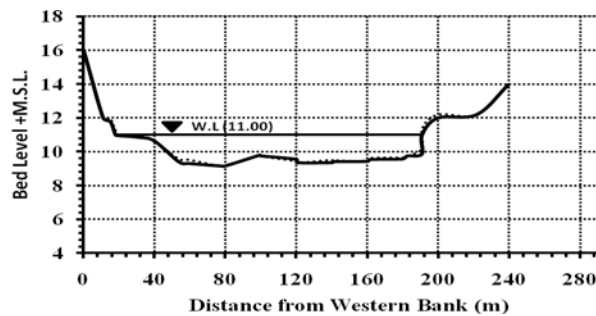


Fig. 5 Comparison between measured and simulated cross section No. (2)

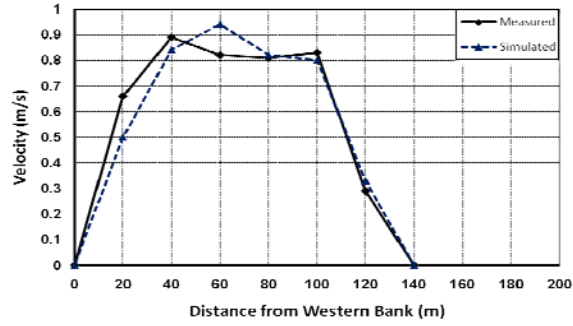


Fig.6 Comparison between measured and simulated velocity at Sec (3)

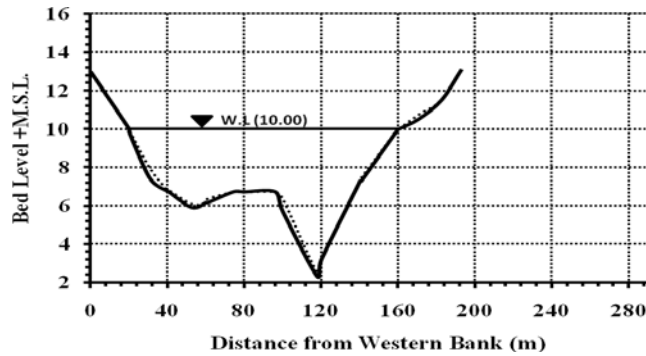


Fig. 7 Comparison between measured and simulated cross section No. (3)

Table 2 Values of statistical parameters for comparison between measured and predicted velocities

parameter	Symbol	Values	Ideal
Root Mean Square Error	RMSE	13.64%	0 %
Coefficient of Determination	R^2	82.76%	100 %

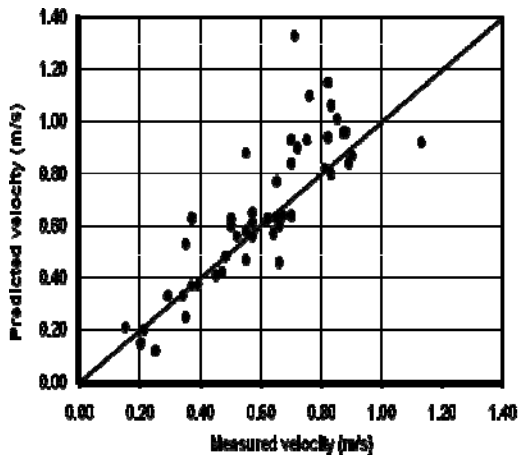


Fig. 8 Comparison between predicted and measured velocities

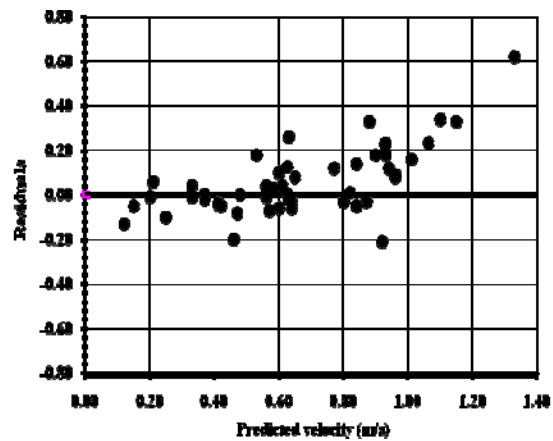


Fig. 9 Variations of residuals for different sections with predict velocities

6. MODEL VERIFICATION

The verification procedure was conducted by achieving, at first, the hydrodynamic simulation using the hydrodynamic module (e.g., the simulation stage). Since the velocity distribution along the studied reach was very close to that measured in the field as shown by Fig (8) and (9). Figure (9) presents the distribution of the residuals with the predicted values, indicating random distribution and uncorrelated residuals. But Table (2) provides the values of RMSE and the R^2 .

The bed levels were computed and compared to the field measurements at sections (2), and (3) as shown in Fig. (10) and Fig. (11) Respectively. It can be noticed that there is an acceptable agreement between the numerical model outputs (predicted) and the measured data for all cross sections as shown in Fig. (12).

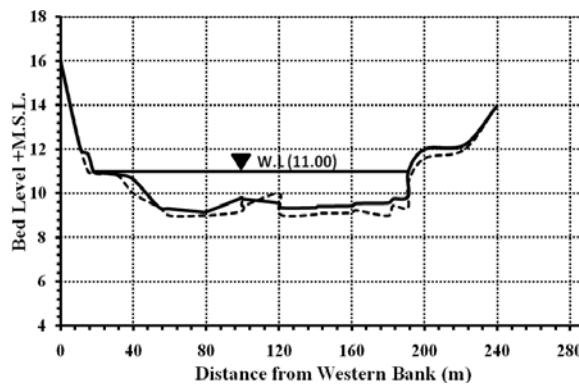


Fig.10 Measured and simulated cross section No. (2)

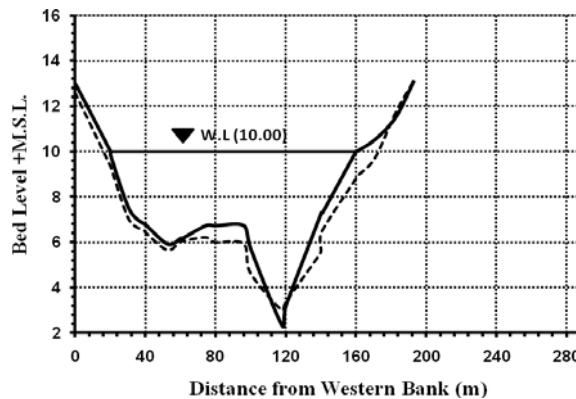


Fig.11 Measured and simulated cross section No. (3)

The residuals show a random distribution around the line of zero. It was found that the model is well verified and can be used as an accurate tool to predict the futures bed levels along the study area as shown in Fig. (13).

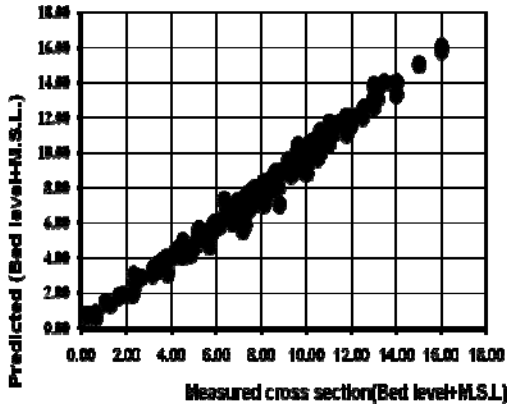


Fig.12 Comparison between predicted and measured values of bed level

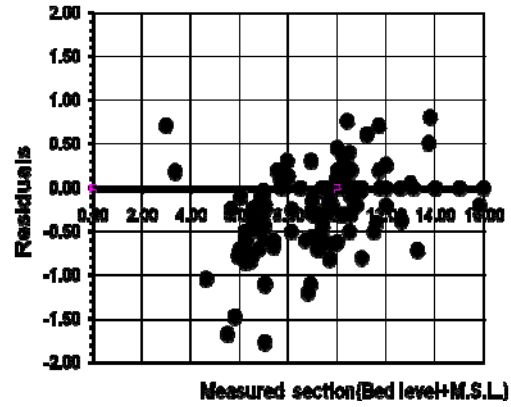


Fig. 13 Variations of residuals for different sections with predicted bed levels

The selected reach consists of many successive meandering curves where point bars and pools are the common bed forms and composed of a relatively homogeneous combination of fine sand and silt. The river free surface width is varied between a maximum width of a 365.07 m at km 101.83 downstream EL-Roda Gauge and minimum width of 244.6 m at km 95.82 downstream EL-Roda Gauge at 80 M.m³/day. Velocities sections are shown in Fig. (14).

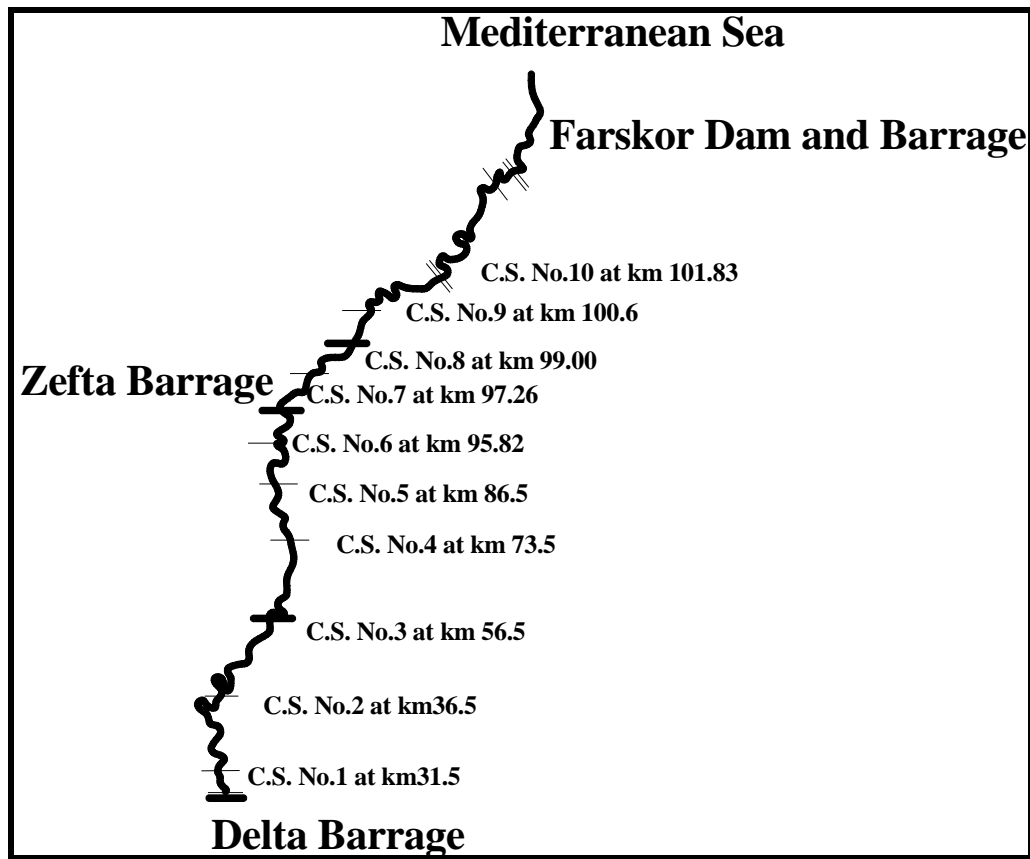


Fig.14 The measured cross sections along the study area

7. EFFECT OF VARIATIONS IN THE WATER WAY

Damietta Branch has become the focus of the erosion and sedimentation cases in recent years. Therefore, understanding the impacts of them as the shape of the river, its slope, width, depth, sinuosity and plan form provides a very good indication of the problem and helps in providing suggested solutions.

7.1 The Variation in Channel Width

The outer curve of the meandered reach is subjected to erosion and continuous deposition and sedimentation along the inner curve as shown in Fig. (15) and Table (3). Sec. (7) has more scour and deeper bed levels along the west side of the river which reached about (3.0) m above Mean Sea Level. While more deposition is taken place along the east side which consequently reached a level higher than the low water surface level. Consequently, lateral migration of curved river reaches cause several morphological problems that affect the navigation waterway. Then we must dredge about 3.2 m in the west side.

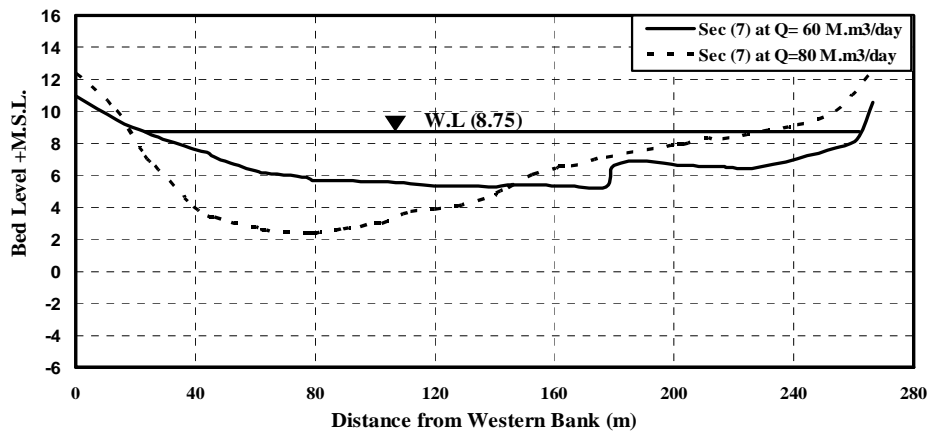


Fig. 15 Comparison of bed line at $Q = 60$ & $80 \text{ M.m}^3/\text{day}$ for cross-sec (7)

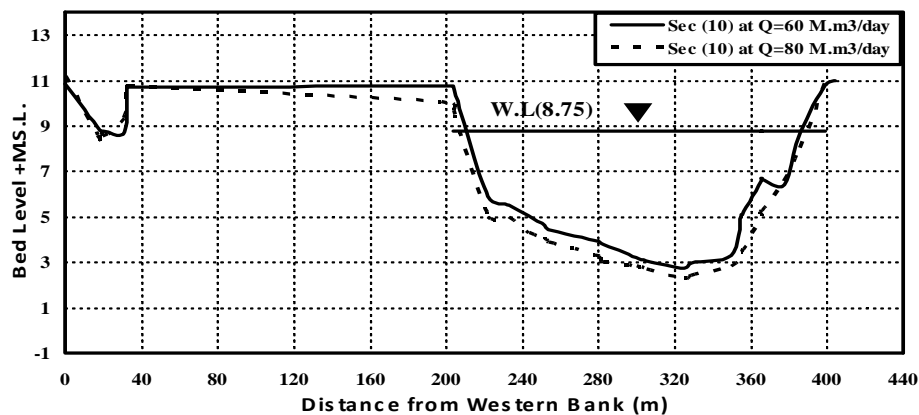


Fig. 16 Comparison of bed line at $Q = 60$ & $80 \text{ M.m}^3/\text{day}$ for cross-sec (10)

Cross section No. (10) has an island as shown in Fig. (16). This island makes reduction in the flow area. The width of the scour hole and low bed level zone located along the outer curve was enlarged due to the influence of the transverse velocity component of the helical flow currents and cause degradation in this cross section. The bed level near the east bank was lowered to about 2.41m above the Mean Sea Level and the channel is being narrowed along the downstream. We must dredge about 1.0 m in bottom of the cross section for preparing it to pass expected future discharges 80 M.m³/day. There are variations in the average top width for cross-sections at the study area. The reduction in width leads to acceleration of degradation as showed in sec. (7). Any increasing in degradation will result in instability of the bank and consequently failure may occur which in turn will lead to width increase. This means that the outer curve of the meandered reach is subjected to erosion while deposition will take place along the inner curve.

Table 3 The worked out cross section parameters

C.S. No.	Discharge (M.m ³ /day)				Direction	Diff. Area (m ²)	The Dredging Volume(m ³)
	C.S. Area (m ²)		Top Width (m)				
	Q=60	Q=80	Q=60	Q=80			
1	241.95	362.11	296	287.2	Shift to left	120.16	2192.92
2	227.33	266.49	173	169	Shift to left	39.16	293.7
3	501.04	863.05	140	155	Shift to right	362.01	4887.13
4	580.51	743.9	196.3	189	-----	163.39	2450.85
5	859.52	1076.9	282.79	275	-----	217.4	2424.01
6	763.06	749.4	198.53	170.44	Shift to left	-13.66	-71.03
7	581.34	750.18	241	238	Shift to left	168.84	337.68
8	779.63	824.75	220	218	-----	45.12	72.19
9	1171.6	1204.4	154	190	Shift to right	32.81	55.77
10	710.03	832.18	174.4	180	Shift to right	122.15	207.65
Total Volume (m³)							12921.90

7.2 The Variation of Average Depth

The change in the bed mean depth for different discharges may be used as an indication of either silting or scouring process, and the river meandering variation with time that took place within the study areas is shown in Table (4) and Fig. (17). At the outer curves of the study reach, this increasing of the average depth has taken place due to two factors; 1- The construction of spur dikes at the outer curve which increases the scour depth at the tip. 2- The continuing formation of the island towards the upstream direction as in sec (9) at Km 100.6 downstream EL-Roda Gauge, which constricts the effective channel width causing the channel to grow deeper.

Table 4 The average depth for cross sections

C.S. NO.	Discharge (M.m ³ /day)	
	Average Depth(m)	
	Q=60	Q=80
1	0.817	1.26
2	1.31	1.57
3	3.57	5.56
4	2.95	3.93
5	3.03	3.9
6	3.84	4.68
7	2.41	3.93
8	3.54	4.82
9	7.6	6.7
10	4.07	4.77

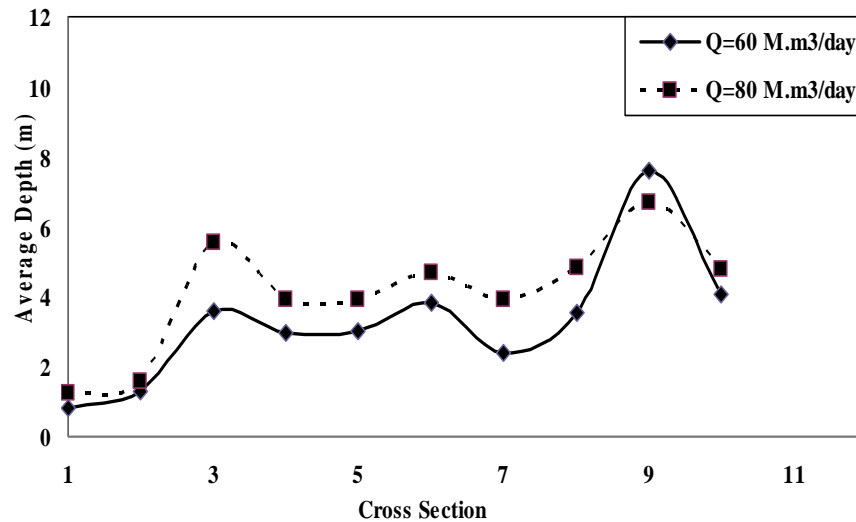


Fig. 17 The average depth at different discharges for the study area

7.3 The Variation in Thalweg Line Level

Studying the variation in the thalweg line profile along the study area by measuring the minimum bed levels as indicated in table (5). The worked out analysis illustrates that the average value of the minimum bed level is lowered from the range between (3.73m to 2.48m) to the range between (1.74m to 0.93m). These results appeared the morphological changes and the river meandering variation with time along the study area. The comparison between the deepest bed levels, corresponding to the previous and future discharges is shown in Fig. (18).

Table 5 The minimum bed level of cross sections at different discharges

C.S No.	Min. Bed Level (m)		Difference	Bed condition
	Q=60	Q=80		
1	9.12	7.75	-1.37	Scour
2	9.16	8.42	-0.74	Scour
3	2.30	3.30	1.00	Deposition
4	6.81	5.60	-1.21	Scour
5	6.98	6.01	-0.97	Scour
6	0.25	-0.72	-0.97	Scour
7	5.26	-1.15	-6.41	Scour
8	3.47	2.00	-1.47	Scour
9	-1.83	-1.96	-0.13	Scour
10	2.74	2.14	-0.60	Scour

It can be noticed that the average bed level decreases and scour is taken place along the curved meandering zones while the transition zones suffer low deposition. In table (5) the positive difference value means increase in the bed level (deposition), while the negative difference value means decrease in the bed level (scour). It can be concluded that the average bed level decreases and scour is taken place along the curved meandering zones while low deposition occurred in the transition zones.

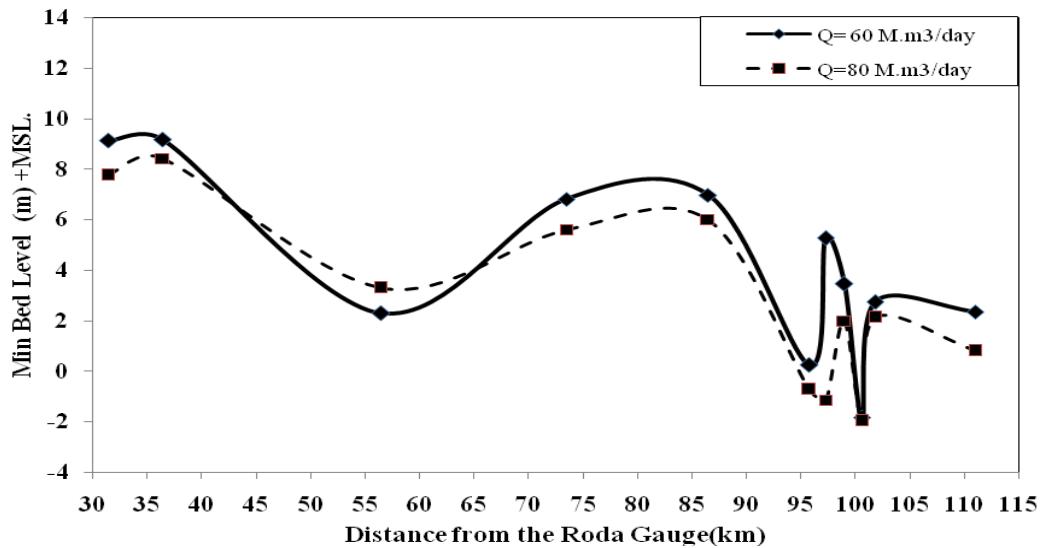


Fig. 18 The min bed level at different discharges for the study area

7.4 Scour and Depositions:

- In Sec. (1) the percentage of erosion was approximately 76.11 % from the West side to km 222.2 but the deposition was happened about 23.8 % at the East side.
- In Sec. (2) the percentage of erosion was about 57% from the West side to km

141.18 while the deposition was happened about 43% at the East side.

- In Sec. (3) & Sec. (4) the percentage of erosion was higher in the whole cross Section about 98.7 % and little aggradations.
- In Sec. (5) there was a gradual widening in the channel cross-section, the percentage of erosion was approximately about 79.3% but deposition happened 20.7%.
- In Sec. (6) more local scour was accomplished along the West side to km 90.42. Then, the percentage of erosion was about 67.3 %. While more deposition is taken place along the East side about 32.7 % due to the influence of the cross-section by the curvature in the clock wise direction.
- In Sec. (7) & Sec. (8) the streams tend to be channelized; so that this cross section has lateral migration degradation in the left bank about 80 % and very few aggradations in the right bank.
- In Sec. (9) & Sec. (10) were as the deposition zones (islands) increased in width and more local scour was obtained about 87% along the East side of the river, but aggradations is happened about 13 %.
- In Scenario at discharge = 80M.m³/day, it showed that the bed level at the outer curve is increased from 1.0m to 3.8m for safety, and the eroded volume is 12921.90 m³.
- The maximum erosion appeared in sections (3) & (4) and (10), while the maximum deposition showed in sections (2) & (6) as shown in Fig.19.

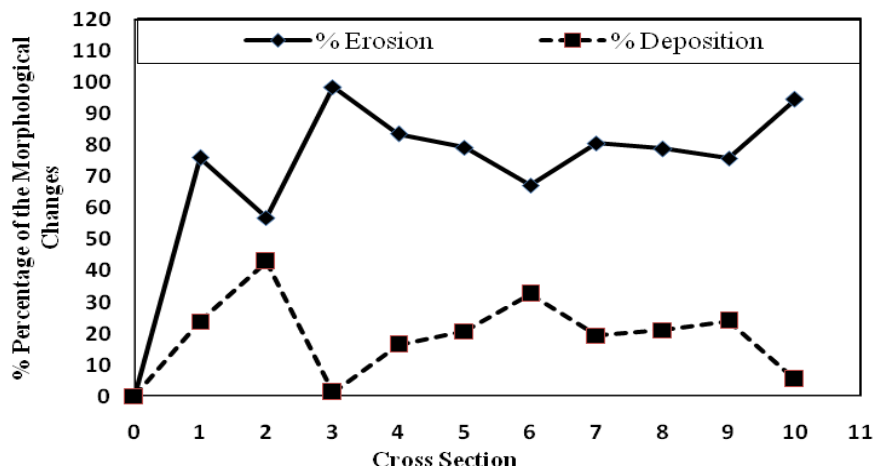


Fig. 19 The percentage of the morphological changes for the study area

8. CONCLUSIONS

The present study investigated the characteristics of the reach of Damietta Branch from km 26.5 to km 116.5 downstream EL-Roda Gauge with a total length of 90 km. The hydrodynamic model (CCHE-2D) based on the solution of Navier-Stokes equations for turbulent flow is used to simulate the domain. The increase of the current discharges from 60 Million m³/day to 80 Million m³/day was studied numerically and

the following conclusions are presented;

1. The maximum erosion appeared in sections (3) & (4) and (10), while the maximum deposition was shown in sections (2) & (6).
2. In the scenario of 80M.m³/day discharge, it showed that the bed level at the outer curve will increase from 1.0m to 3.8m, and the eroded volume will be 12921.90 m³.
3. There are width increase in sections (3), (9) and (10). On the other hand, there are decreases in the other sections.
4. The average value of the minimum bed level is lowered from 3.73 m over the Mean Sea Level to 0.93 m below the Mean Sea Level.
5. The results show that, there are an acceptable agreement between the hydrodynamic model results and the field measurements for the current flow.

9. RECOMMENDATIONS

Based on the results of the hydrodynamic model (CCHE-2D) in case of releasing discharge 80 million m³/day in Damietta Branch; it is recommended to:-

1. Dredge about 3.2 m in the west side for the whole study area to sustain safe navigation waterway.
2. Dredge about 1.0 m in bottom of all cross sections near the east bank to increase the ability of Damietta Branch to convey high discharges.

10. REFERENCES

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