

Morphology of the Nile River due to a Flow Rate over the Maximum Current: Case Study Damietta Branch

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Abstract Damietta branch is one of the two branches of the Nile River. It is the main source of water for water supply for both domestic and industrial activities, irrigation and navigation purposes in the Nile Delta region and its fringes, Egypt along with the Rosetta branch. Field investigations proved that scour, deposition, and bank erosion occurred along the course of the branch. Also, encroachment by people on the flood plain during the last three decades led to a reduction in its carrying water capacity. Therefore, this chapter aims at presenting the results of a numerical investigation on the effect of passing a higher future discharge more than the maximum current flowing discharge. Two-dimensional hydrodynamic mathematical model (CCHE2D) was used to simulate the morphological changes in Damietta branch due to an additional excess flow of 20 Mm³/day. Also, the CCHE2D was used to predict the effect of high flows on water velocities and geometrical changes at different cross sections. Comparisons between cross sections under the scenario of increasing the discharge from 60 to 80 million m³/day were carried out. Moreover, the side effects on the navigational channel and overtopping problems had been investigated. Consequently different solutions were suggested to increase the ability of Damietta branch to convey higher discharges.

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1 Introduction

Investigating the morphology of rivers is of great importance to maintain the river regime fixed as much as possible to create safe environment for activities such as navigation and sustainable stream. However, after the construction of dams across the river to store water for irrigation, water supply, flood control, generation of water power, navigation, or recreation, the sediment transport capacity to the downstream of the dam is reduced.

In case of Aswan High Dam on the River Nile in Egypt, the effect of the dam on the Nile River was summarized by Gaweesh and Gasser [1] in Table 1.

After constructing the dam, the water released from the dam reservoir is almost sediment free and hence it picks up sediment from the bed and banks of the stream causing degradation over long reaches of the stream. Also, passing higher discharge than the maximum designed ones may alter the river morphology. It may also lead to channel widening or change in the plan form of the river [2]. A recent study [3] focused on three river segments, separated at the confluences with two tributaries, Plum Creek and Long Pine Creek. With an overall temporal scope of 1988–2010 that includes a short interval preceding and a long interval following the Niobrara National Scenic River Designation Act of 1991. The study analyzed five separate time periods: 1988–1993, 1994–1999, 2000–2003, 2004–2006, and 2007–2010, each of which ended with a year in which aerial photography coverage was available. Changes in channel morphology were examined using aerial photographs from 1993, 1999, 2003, 2006, and 2010 to measure channel width, area of islands, and incipient flood-plain surfaces, and to compute the braided index. Channel metrics were computed for each photography year and summarized by river

Table 1 Effect of dam construction on the Nile River [1]

Items	Before AHD	After AHD
Discharge (Q) downstream dam	Reach to 800 million m ³ /day during the flood season	The maximum value of about 270 million m ³ /day at present
Water surface slope	5–10 cm/km depending on the flow discharges and upstream, downstream, water levels at the intermediate barrages	Decreased to a range 4.8–8.4 cm/km due to reduction in the discharges
Depth of water	As a consequence of the reduction that occurred in the discharge, the flow depth has been significantly reduced except for low flows within thalweg lines	
Velocity	The range of velocities is reduced depending upon the reduction that occurred in the flow discharge and depth	
Size of bed materials	Increased over time due to sorting of the bed material and clear water released from AHD	
Grain roughness	Enlarged as a result of increase that occurred in median diameter of the bed material	
Bed material discharge Qs	Reduced due to the limited discharges and because of trapping the sediment in the reservoir upstream of AHD	
Sinuosity	Increased in consistence with reduced discharges, increased channel roughness at low flows and relatively mild channel slopes	

segment. Additionally, at fixed-location cross sections, photography analysis identified localized geomorphic change to infer processes. Accuracy of geomorphic feature classification was estimated and the root-mean-square difference (RMSD) between aerial photographs was calculated to determine associated errors in channel metric calculations. The horizontal accuracy of boundaries delineated in the classification was estimated as 5 m for boundaries based on 1993 aerial photography and 4 m for all other aerial photography. The RMSD between aerial photography years ranged from 3.04 to 4.16 m.

In Egypt, on the other hand, several investigations were conducted to deal with the effect of Nile river extra discharges on river morphology and bank erosion [4–14]. It was concluded that there was non-uniform erodability of the bank [15]. The meander morphologies of Damietta Branch were investigated by Moustafa [16] at 1982 and 2001 using GSTARS2 model. The investigated parameters include channel width, channel depth, and meander wave length. The reach has features such as meandering, bends, and islands. It was concluded that due to the increase of flow, the average rate of degradation was 14.91 cm/km while the average rate of aggradations was 10.62 cm/km. Also, the morphological changes were studied by Abdel-Naby [17] to investigate its effect on different parameters such as channel plan form, width, erosion, and deposition near the embankments of the River Nile at the area of Kasr El-Nile. The purpose of the investigation was to suggest measures to protect the water structures and river banks. The Surface water Modeling System (SMS) was used during the modeling processes. It was concluded that the rate of average velocity tends to be higher at the East side rather than the West side. The rate of deposition was high and caused navigation problems. For the reach from

Sohag to El-Minia, Ahmed and Fawzi [18] dealt with meandering and bank erosion of the River Nile and its environmental impacts. The analysis of Landsat imagery revealed the migration of river course with time and space. Some islands disappeared completely in the study area whereas new islands appeared. The lateral erosion on the river banks led to a decrease in agricultural lands bordering the river banks and a decrease in the areas of the river islands which in turn reduced the agricultural production. Protection methods were recommended to protect the river bank from further movement and erosion. River control was recommended to weaken the secondary currents created by the river bends. It was recommended to regularly monitor the river banks and islands and measure the rates of erosion and deposition. Sand bars and subsurface islands should be monitored and identified with flash lights to mitigate navigation problems. Also, the fourth reach of the Nile River located between Assiut Barrage (km 544,500 downstream the Aswan Dam) and the Delta Barrage (km 954,500) was studied by Mostafa [19]. The morphological changes were analyzed with respect to the future expected low and high flows on potable water and power plant stations and navigation problems. Scenarios were considered to study the effects of high flows to locate the areas that will be inundated and to predict the morphological changes. The GSTARS3 model and others were used to simulate the water surface profile and the sediment transport. It was concluded that deposition had more frequent occurrence than erosion on the bed for the whole reach during the past decades. For future discharges, the application of low flows scenarios resulted in 15 water stations and 8 potable water stations will be affected by passing the discharges of 35 and 39 Mm^3/day , respectively. The water levels at these stations will be below the critical level of the stations' operation. Also, two other locations were identified to have navigational bottlenecks in case of passing these low flow rates (39 and 35 Mm^3/day). For the application of the high flows scenarios of high flows, the total lengths of the inundated regions at both banks will be about 79.89, 26.06, and 15.01 km for the discharges 350, 200, and 190 Mm^3/day , respectively. The expected areas of the inundated regions might be 4,777, 962, and 448 feddans (1 feddan = 4,200 m^2). The Nile River reach from Esna Barrage to Naga Hammadi Barrage; about 192 km length was studied for the period from the year 1982 to the year 2005 [20]. The investigation focused on the hydraulic impacts due to erosion, sedimentation, and over topping on the Nile River. About 26 cross sections were selected along the study reach with space of 4 km. The GSTARS model was used in the simulation. These cross sections were used to compare the results of simulation for the year 1982 and the year 2005 in order to calculate erosion and sedimentation quantities. Finally cross sections of the year 2005 were used to develop water surface profile and to map the overtopping areas by applying a future discharge of 4,051 m^3/s using topographic maps. It was concluded that 16 sections out of 26 were affected by overtopping.

For Damietta branch, Moussa and Aziz [21] compared the performance of several sediment evaluation equations of Ackers and White, Engelund and Hansen and Yang to predict the amount of sediment discharges in the Nile River at Damietta branch in the period from 1982 to 2001. They found that the equations of Ackers, White, and Yang produced comparable results with a predicted percentage of 76.34%. The rate of

error for the cross sections is small for Ackers and White equation compared to the other two equations. Also, the morphological changes in the Delta Barrages area (Damietta and Rosetta Branch) were analyzed to emphasize the aggradations in the 40 km upstream of Delta Barrages [22]. The degradation in the downstream area extends to 10 km along the two branches. The hydrographic survey of the river bed in 1982 and 2002 was used in building the model. 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 [22].

This chapter aims at investigating the impact of increasing the flow rate from the current maximum of $60 \text{ Mm}^3/\text{day}$ to the expected in the future of $80 \text{ Mm}^3/\text{day}$ on the meandering geometry of Damietta branch reach of the Nile River from downstream Delta Barrage up to Zefta Barrage. The CCHE2D model [23] is adopted for the morphological study to propose the location of protection works to avoid the banks overtopping and satisfy the navigation requirements.

2 Study Area and Field Data Collection

Damietta branch (see Fig. 1) is one of the two River Nile branches (Damietta and Rosetta branches). It is considered an important water way 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 surface slope of

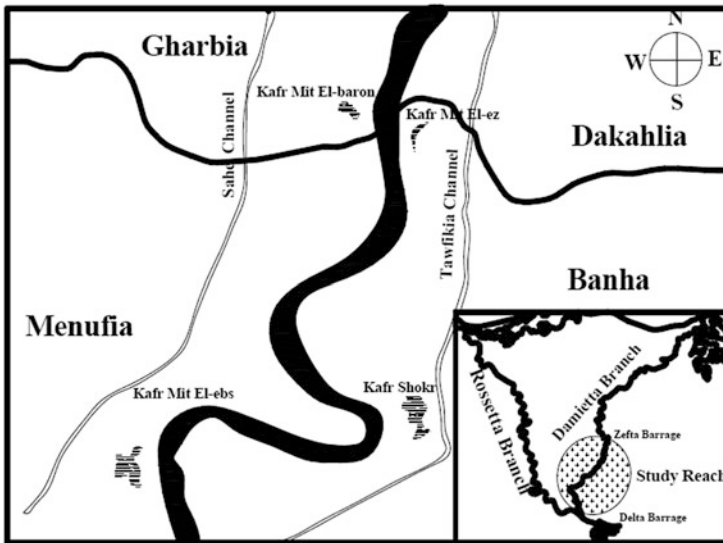


Fig. 1 The Damietta branch topography [24]

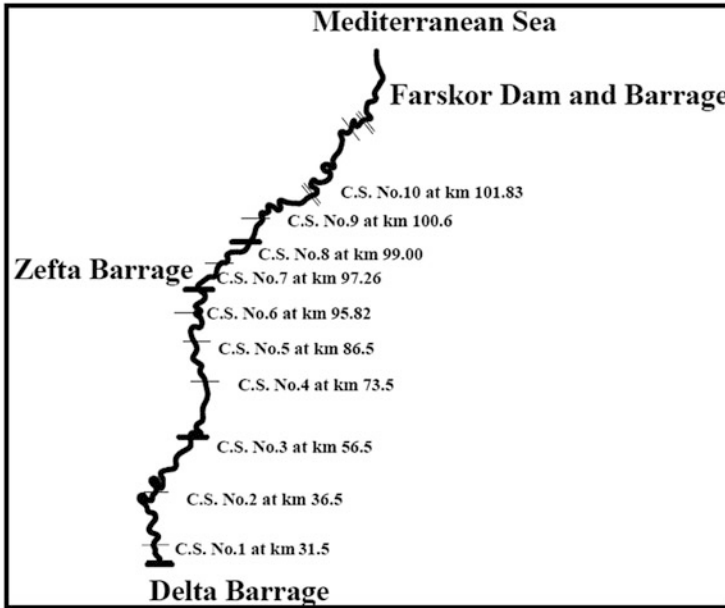


Fig. 2 Location of cross sections (C.S.) along the study area where the measurements were done [24]

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 surface 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 27.3 km from EL-Roda Gauge with five vents (openings). The width of each vent is 5.25 m while the pier's width is 1.5 m. The flow rate through the reach is 22 Mm³/day. This branch is morphologically unstable and comprises many local changes by hydraulic characteristic changes and morphological changes as scour, deposition, and bank erosion. Additionally, encroachment by people on the flood plain during the last three decades was observed. The result is the capacity of the river to convey high discharges was reduced. In this study, the considered reach is 90 km length starting at km (26.5) and ends at km (116.5) and contains ten cross sections (see Fig. 2).

3 Collection of Field Data

The collected data (e.g., bed levels, velocities, discharges, and suspended sediment concentration) were obtained from two institutes, the Nile Research Institute (NRI) and Hydraulic Research Institute (HRI) that belong to the National Water Research

Center (NWRC), Ministry of Water Resources and Irrigation, Egypt [4–8]. The NRI and HRI performed a complete hydrographic survey and collected the data of the water levels, corresponding passing discharges, and suspended sediment concentration for Damietta branch as well for the whole Nile River. 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 about 365.07 m at km 101.83 downstream EL-Roda Gauge and a minimum width of about 244.6 m at km 95.82 downstream EL-Roda Gauge. Figure 2 shows the locations of cross sections where the velocities, bed levels, and water levels were measured.

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 was 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. 3. Table 2 shows the computed average velocities at the ten cross sections. The bed material samples were collected at the ten cross sections along the

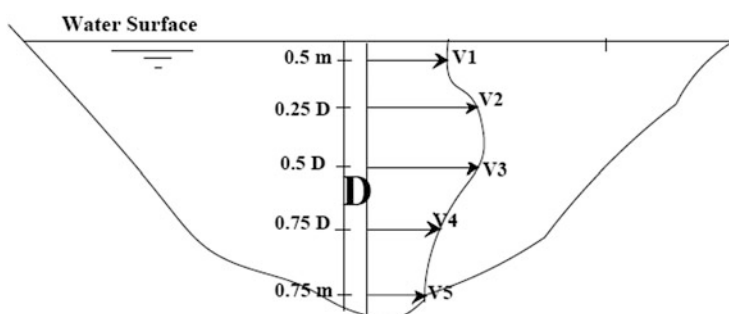


Fig. 3 Computation of the average velocity at any section [24]

Table 2 The average velocity along the study area [24]

C.S. No.	Distance downstream 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

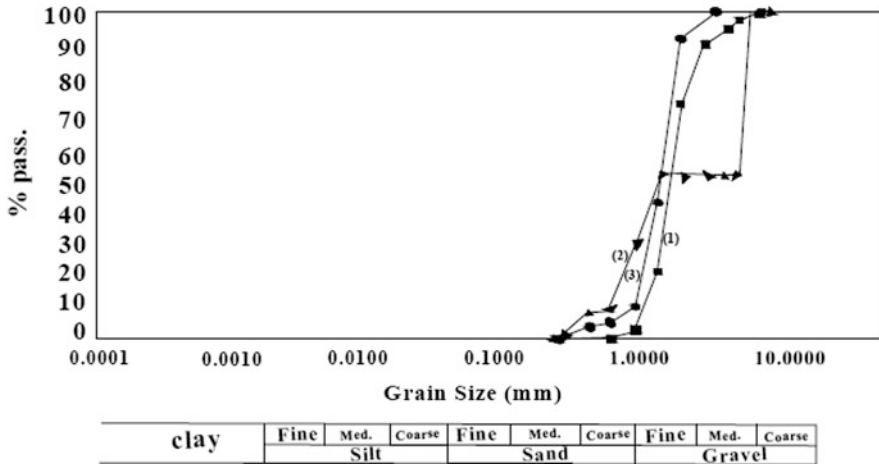


Fig. 4 Typical grain size distribution curves at C.S. No. (6) for three samples [24]

study reach from data gathered by NRI. The grain size distribution curves at the C.S. No. 6 are shown in Fig. 4.

4 Methodological Steps

The following procedure was adopted to achieve the objective of the study:

1. Determination of the hydrographic data for 460 cross sections along the study reach with a spacing of 200 m between sections to construct the mesh of the reach.
2. Collecting the velocities and discharges which were passed during the last years to facilitate the model calibration.
3. Selecting the freely available CCHE2D model and calibrate it using part of the collected data.
4. Verifying the CCHE2D model by determining the reach characteristics such as velocities along the study area and compare the simulation results with the collected field data.
5. Applying the model for the base case having $60 \text{ Mm}^3/\text{day}$ and for the case of extra discharge of $80 \text{ Mm}^3/\text{day}$.
6. Assessment of the results of the extra flow rate case compared to the results of the base case compared to $80 \text{ Mm}^3/\text{day}$ on river banks and bed levels.
7. All the results were analyzed to propose the proper protection measures for the banks if needed.

5 CCHE2D Model Governing Equations

This study used the hydrodynamic model (CCHE2D) [23] which was based on the solution of Navier–Stokes equations for turbulent flow. The model used the finite volume method for solving the sediment transport equation. The model is applied to determine the changes in the cross sections as a result of passing discharges greater than the current one. This model will be used for calculating and predicting different hydraulic parameters such as average velocity and bed levels (cross sections) at different locations (see Fig. 2).

The governing equations (continuity equation, the momentum equations, and the sediment transport equation) of (CCHE2D) used by the model read:

Continuity equation:

$$\frac{\partial Z}{\partial t} + \frac{\partial(h_u)}{\partial x} + \frac{\partial(h_v)}{\partial y} = 0 \quad (1)$$

Momentum equation:

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

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

Sediment transport equation:

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

where u and v were 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, $\varepsilon_s = \nu_s/\sigma_s$; V_t is the eddy viscosity of flow; and σ_s is the turbulent Prandtl–Schmidt number (between 0.50 and 1.0); C_k is the depth averaged concentration, and C_{*k} is the transport capacity of total load.

6 Model Calibration

The required data for the CCHE2D model are geometric and hydrologic data. The hydrologic data is the flow discharges and average velocities along the study area. The geometric data were composed of 90 cross sections, with spacing of 1 km apart. These cross sections were surveyed by HRI in the year 2000 [4–8]. Typical measured velocities and bed levels for two cross sections No. 2 and No. 3 are presented in Figs. 5, 6, 7, and 8 (solid lines). The comparisons between measured (solid line) and computed velocities (dashed line) at the two cross sections are shown in Figs. 5 and 7 for C.S. No. 2 and No. 3, respectively. The corresponding comparison for the bed levels for both sections No. 2 and No. 3 are presented in Figs. 6 and 8. It is clear that the model results are comparable with the measured values. The statistical parameters presented in Table 3 which include the root mean square error (RMSE) and the coefficient of determination between the measured and the simulated confirm the good agreement between the simulated and the measured values.

Fig. 5 Comparison between measured and simulated velocity at C.S. No. (2)

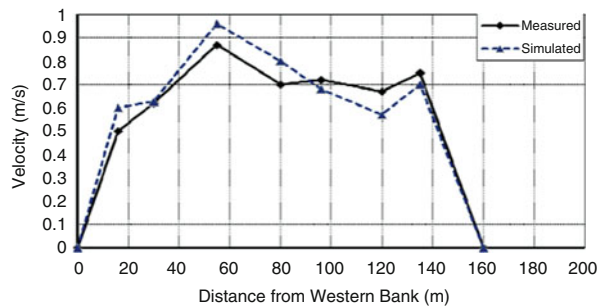


Fig. 6 Comparison between measured and simulated bed levels at C.S. No. (2)

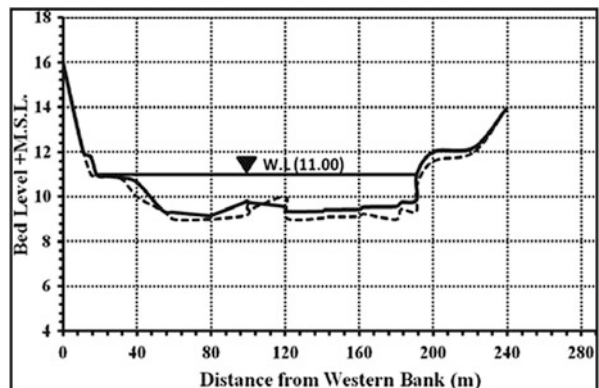


Fig. 7 Comparison between measured and simulated velocity at C.S. No. (3)

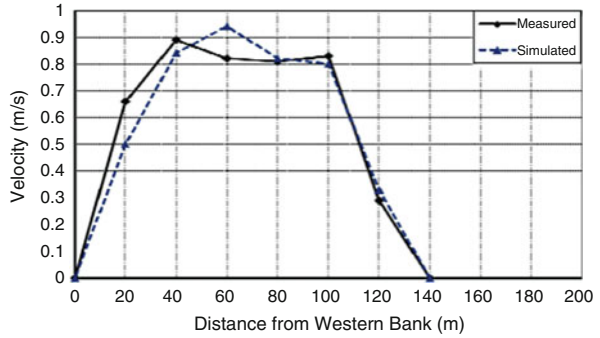


Fig. 8 Comparison between measured and simulated bed levels at C.S. No. (3)

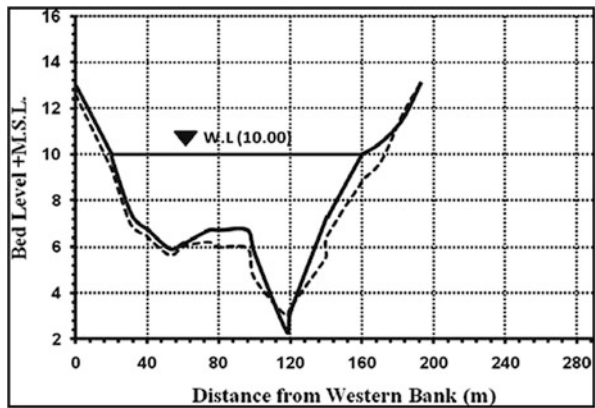


Table 3 Values of the statistical indicators for the velocity simulations compared to the measured values

Parameter	Symbol	Values (%)	Ideal (%)
Root mean square error	RMSE	13.64	0
Correlation coefficient	R	9.10	100

7 Effects of the Increase of the Flow Rate on the Water Way

In the following subsections, the effects of the increase in the flow rate on the width (Sect. 7.1), depth (Sect. 7.2) of Damietta branch at different sections are presented and discussed as long as the effects of the increase in the flow rate on thalweg line level (Sect. 7.3) and on scour and deposition (Sect. 7.4).

7.1 Channel Width Variation

Table 4 and Fig. 9 show that the outer curve of the meandered reach is subjected to erosion and continuous deposition and sedimentation along the inner curve. The C.S. No. 7 indicated high scour potential 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. The simulated bed level reached a level higher than the measured low water surface level. Consequently, lateral migration of curved river reaches cause several morphological problems that affect the navigation waterway. Maintaining of the navigation path needs dredging of about 3.2 m in the West side.

Table 4 The basic information for the parameters of the cross section from 1 to 10 along Damietta branch [24]

C.S. No.	Discharge (Mm 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	2,192.92
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	4,887.13
4	580.51	743.9	196.3	189	–	163.39	2,450.85
5	859.52	1,076.9	282.79	275	–	217.4	2,424.01
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	1,171.6	1,204.41	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 (m ³)							12,921.90

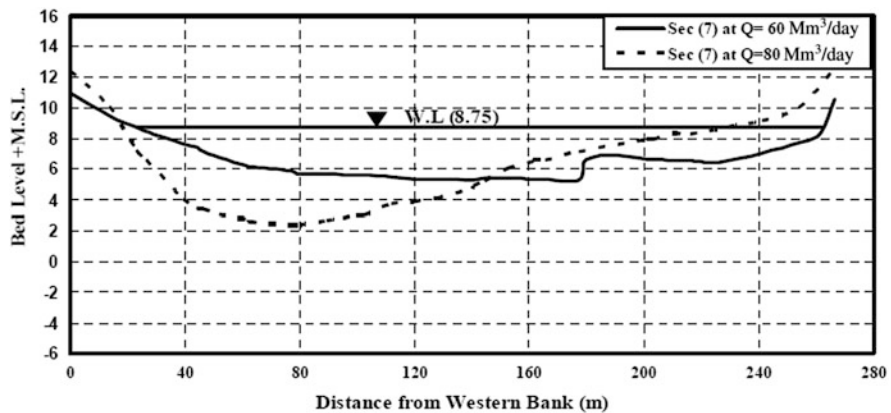


Fig. 9 Comparison of simulated and measured bed levels at $Q = 60$ and 80 Mm³/day for C.S. No. (7)

The C.S. No.(10) has an island as shown in Fig. 10. 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 current sand caused degradation in this cross section. The bed level near the East bank was lowered to about 2.41 m 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 $80 \text{ Mm}^3/\text{day}$. 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 shown in C.S. No. (7). Any increasing in degradation will result in instability of the bank and consequently failure may occur which in turn will lead to an increase in the width. This means that the outer curve of the meandered reach is subjected to erosion while deposition will take place along the inner curve.

7.2 The Variation of Average Depth

The change in the bed mean depth for the two discharges may be used as an indication of either silting or scouring process. The river meandering variation that took place within the study areas is shown in Table 5 and Fig. 11. At the outer curves of the study reach, there is an increase in the average depth which had taken place due to two factors: (1) The construction of spur dikes at the outer curve that increases the scour depth at the tip. (2) The continuing formation of the island towards the upstream direction as in C.S. No. (9) at km 100.6 downstream EL-Roda Gauge constricts the effective channel width causing the channel to grow deeper.

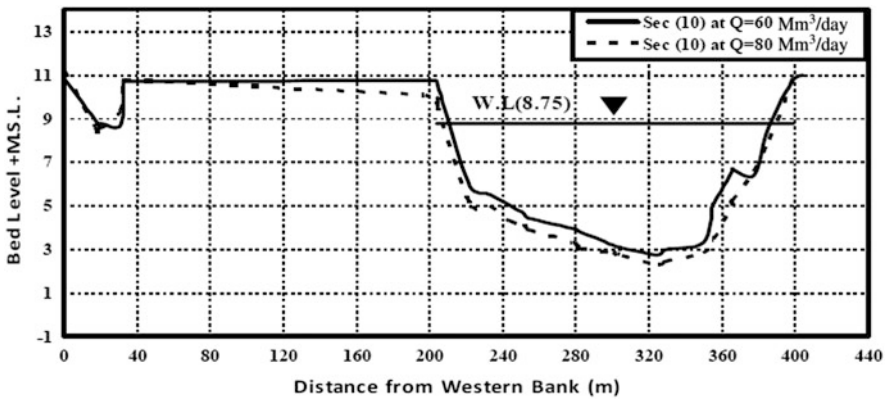
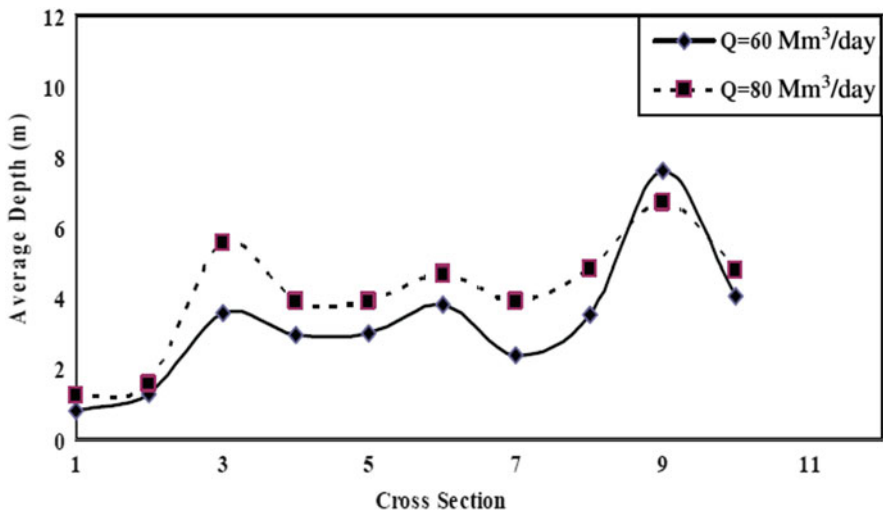


Fig. 10 Comparison of simulated and measured bed levels at $Q = 60$ and $80 \text{ Mm}^3/\text{day}$ for C.S. No. (10)

Table 5 The average depth at the cross sections from 1 to 10 for $Q = 60 \text{ Mm}^3/\text{day}$ and $Q = 80 \text{ Mm}^3/\text{day}$

C.S. NO.	Average depth (m)	
	Discharge (Mm^3/day)	
	$Q = 60$	$Q = 80$
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. 11** The average depth at the cross sections from 1 to 10 for $Q = 60 \text{ Mm}^3/\text{day}$ and $Q = 80 \text{ Mm}^3/\text{day}$ along the reach of Damietta branch

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 6. The worked out analysis illustrates that the average value of the minimum bed level is lowered from the range between (3.73–2.48 m) to the range between (1.74–0.93 m). The results appeared the morphological changes and the river meandering variation along the study area.

Table 6 The minimum bed level of the cross sections from 1 to 10 along the reach of Damietta branch at $Q = 60 \text{ Mm}^3/\text{day}$ and $Q = 80 \text{ Mm}^3/\text{day}$

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

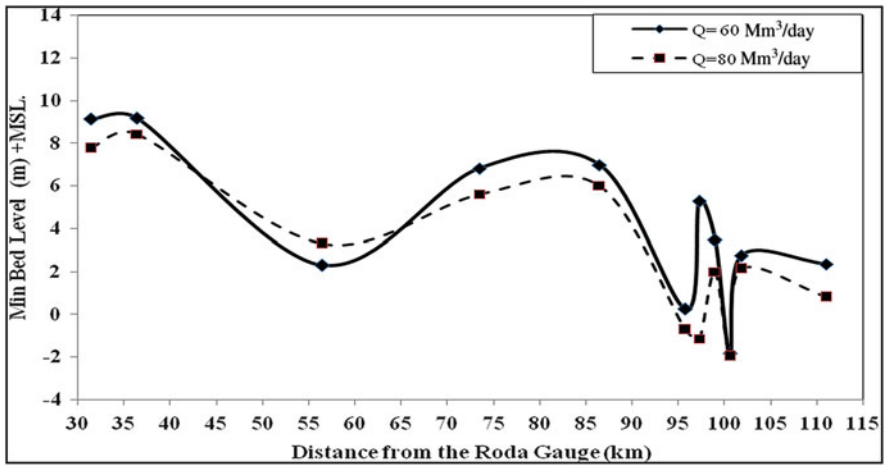


Fig. 12 The minimum bed level at $Q = 60 \text{ Mm}^3/\text{day}$ and $Q = 80 \text{ Mm}^3/\text{day}$ along the reach of Damietta branch

The comparison between the deepest bed levels corresponding to the previous and future discharges is shown in Fig. 12.

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 6 the positive difference value means an increase in the bed level (deposition), while the negative difference values mean a corresponding decrease in the bed level (scour). It can be stated that the average bed level decreases and scour is taken place along the curved meandering zones while low deposition occurred in the transition zones.

7.4 Scour and Deposition

The analysis of simulation results indicated that:

- At C.S. No. (1) the percentage of erosion was approximately 76.11% but the deposition was about 23.8% at the East side.
- At C.S. No. (2) the percentage of erosion was about 57% while the deposition was about 43% at the East side.
- For the C.S. No. (3) and C.S. (4) the percentage of erosion was higher in the whole cross section about 98.7% and little aggradations.
- For C.S. No. (5) there was a gradual widening in the channel cross section, the percentage of erosion was approximately about 79.3% but deposition was about 20.7%.
- At C.S. No. (6) more local scour was accomplished along the West side. 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 clockwise direction.
- For C.S. No. (7) and C.S. No. (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.
- For the C.S. No. (9) and C.S. No. (10) the deposition zones (islands) increased in width and more local scour occurred with about 87% along the East side of the river, and aggradations were about 13%.
- For the scenario at a discharge equals $80 \text{ Mm}^3/\text{day}$, it showed that the bed level at the outer curve increased from 1.0 to 3.8 m for safety, and the eroded volume is $12,921.90 \text{ m}^3$.
- The maximum erosion appeared at C.S. No. (3), No. (4), and No. (10), while the maximum deposition occurred at C.S. No. (2) and C.S. No. (6) as shown in Fig. 13.

8 Conclusions

This chapter presented the results of the hydrodynamics simulating of the Nile River (Damietta branch reach) from km 26.5 to km 116.5 downstream EL-Roda Gauge with a total length of 90 km. The calibrated hydrodynamic model (CCHE2D) was used to investigate the impact of increasing the current maximum discharge from $60 \text{ Mm}^3/\text{day}$ to a maximum expected of $80 \text{ Mm}^3/\text{day}$ on the morphology of the reach. The following conclusions could be stated:

1. The maximum erosion occurred at C.S. No. (3), C.S. No. (4), and C.S. No. (10), while the maximum deposition was detected at C.S. No. (2) and C.S. No. (6).

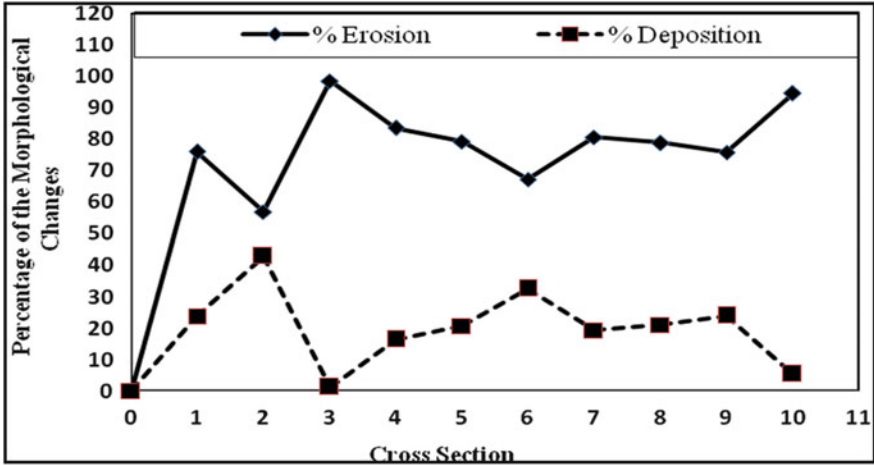


Fig. 13 The percentage of the morphological changes at cross sections from 1 to 10 along the reach of the Damietta branch

- For the 80 Mm³/day scenario, the bed level at the outer curve increased from 1.0 to 3.8 m, and the eroded volume was 12,921.90 m³ compared to the base scenario of 60 Mm³/day.
- The widths of the C.S. No. (3), C.S. No. (9), and C.S. No. (10) were increased while the widths of the rest were decreased.
- The average value of the minimum bed level was lowered from 3.73 m above mean sea level to 0.93 m below mean sea level.

9 Recommendations

Based on the results of the calibrated hydrodynamic model (CCHE2D) in case of releasing an additional discharge of 20 million Mm³/day in Damietta branch reach, it is recommended to:

- Dredge about 3.2 m in the West side for the whole study area to sustain safe navigation waterway.
- 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.
- Continuous monitoring of the cross sections along the reach to measure water levels and velocity pattern and observing the morphological changes in the reach if any.
- Updating the hydrodynamic simulation for the reach once new updated data are available or a change in the morphology is observed.

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