Simulation of River Regulation Works to Improve Navigation Condition in Damietta Branch

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Abstract

Dredging as a tool to enhance river transport in Damietta branch was conducted since 1999. About six million meter cubic of bed material was removed with a total cost of 60 million Egyptian pounds. The navigation channel has an average width of 40 m. However, the last 12 km of the route to Damietta port is via an artificial canal of water depth of 4 m and channel width of 40 m at bed level which is sufficient for two way traffic for container vessels. The waterway design specification has guaranteed a minimum water depth for navigation of 2.3 m for uninterrupted period of 365 day a year. A navigation hazard represented by a drop in the design water level was evident in 2006. The drop of water level was threatening the satisfaction of 2.3 m water depth in some days within the year. This was attributed that the channel carrying capacity was increased after the dredging process. This study aims at improving the navigation condition downstream Zefta barrage, Damietta branch by installing permanent regulation structure such as weirs. The weirs will enhance heading up of water in the weir back water zone to solve some of navigational bottlenecks. A one dimensional mathematical model (SOBEK) was used to simulate a study reach of 134 km downstream Zefta. Low discharge of 3 mm^3/day is used as critical cases to represent a number of bottleneck locations of 165 and 75 respectively. The weirs are simulated in three locations according to the intensity of the bottlenecks. Different crest level for the weirs is tested. The number of simulated cases is twelve. The model enables the simulation of the hydraulic structures along the branch such as Zefta and Damietta barrages. The study concluded that the weir installation has resulted in solving some of navigational bottlenecks vary between 22 to 88%. The study recommended to combine between different regulation work (dredging and weir installation) to get the best results from the economical point of view. Ship transport activity can be put off when the required water depth is not available. Specific type of ships with less draft can also be used during the hazard periods. The clearance can be less than 0.5 m according to the environmental conditions and the number of ships in the waterway.

Key words: Navigation, dredging, permanent structures, Weirs, navigation hazards, Damietta, mathematical model

1. INTRODUCTION

"Egypt is the gift of the River Nile" said Herodotus, the great Greek historian. The River Nile is considered the main route of inland navigation in Egypt. A large project was started by the River Transport Authority in 1999 to enhance river transportation from 0.4% to 10%, which will increase the country income and decrease the pressure on the other transport sectors (roads and railway). The project covers the entire main river. This study is concerned about Damietta branch. As a part of this project, a hydrographic survey was conducted for the purpose of designing the waterway started from Delta barrages and ended at the Mediterranean Sea. The required dredged material was determined. The resulted material was a function of maintaining a depth of 2.3 m at river lower stage. About 1 million m^3 was dredged from Damietta branch between 2000 and 2005 (Attia and Fahmy, 2006). The navigation channel has a average channel width of 40 m. However, the last 12 km of the route to Damietta port is via an artificial canal of water depth of 4 m and channel width of 40 m at bed level which is sufficient for two way traffic for container vessels.

A navigation hazard represented by a drop in the water level was evident in 2006 after the dredging works. The drop of water level was threatening the satisfaction of 2.3 m water depth in some days within the year. This was attributed that the channel carrying capacity was increased after the dredging process. This study is concerned about the navigation hazards with special emphasis on the hydraulic conditions related to released discharge downstream the main barrages on the branch. Weirs as channel regulation works are introduced to overcome those hazards. A one dimensional mathematical model (SOBEK) is used to simulate the water surface profile. The model uses the actual data of the final survey of 2005 for the branch. The data is analyzed and stored digitally. The model deals with several scenarios including the change of location and crest level of the designed weir.

2. METHODOLOGY

2.1. Data Collected

The navigation waterway along Damietta Branch is about 227.25 km long. This waterway can be considered as the most important transportation path between Cairo and the outer exposed waterway to the open sea at Damietta and Raas El-Barr harbors. It is divided into 3 reaches by two intermediate barrages, which are Zefta and Faraskour barrages. Locations and dimensions of those barrages are illustrated in Table 1. Hydraulics Research Institute (HRI), National Water Research Center, conducted a hydrographic field survey and the relevant hydrological information was collected. Also bed slope and velocity measurements were surveyed. . The survey was conducted for the purpose of designing the navigation waterway. A hydrological investigation was conducted to study the reach and collect the required information to determine the flow discharges and the corresponding water levels. Daily monitoring to the released discharges was executed at the hydraulic structures (downstream the barrages, and at the location of gauge stations). The available hydrological data were accumulated. Minimum discharges for the years from 1985 to 2005 downstream Zefta Barrage are tabulated in Table2. Figure 1 shows the maximum and minimum discharges downstream Zefta Barrages from 1985 to 2005. It can be noticed that the discharge has been increased in the recent years. Due to dredging works that was done in the branch, it leads to an increase in the branch capacity which caused a drop in the water level. So an increase in the discharge was a must to satisfy the safe depths required. Also to satisfy El-Salam canal needs. Nile Research Institute (NRI), National Water Research Center, conducted a field reconnaissance in 2005, to address the actual situation of navigation hazards at the location of Zefta Barrages and the new eastern side lock at km 93.5 downstream (DS) Delta Barrage. It was found that an increase in the channel carrying capacity was occurred as a result of dredging process, which leads to the drop in the water level and unsafe navigation during minimum discharges.

Table 1: Historical Data for Barrages along Damietta Branch

Barrage	Construction Date	Location DS Delta Barrage) (Km)	Gates			Pier Width (m)
			No.	Width (m)	Level (m)	
Delta Barrage	1939	0.00	34	8	11	2.5
Zefta Barrage	1901-1903	93.5	50	5	3.5	2
Damietta (Faraskour) Barrage	1985-1988	227.45	5	5.25	-1	1.5

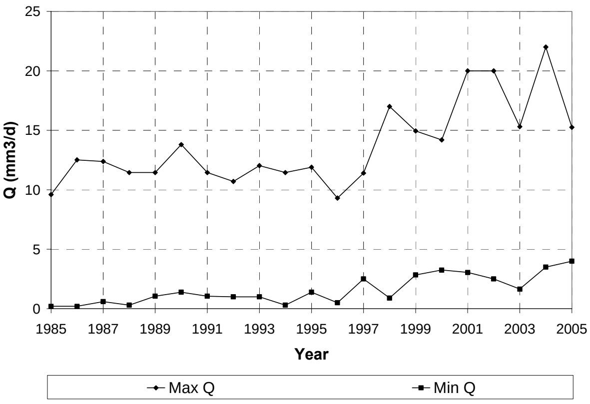

Figure 1: Maximum and Minimum Discharges DS Zefta Barrage

Table 2: Discharges DS Zefta Barrage from 1985 to 2005

Year	Min. Q (mm^3/d)	Year	Min. Q (mm^3/d)
1985	0.2	1996	0.5
1986	0.2	1997	2.5
1987	0.6	1998	0.9
1988	0.3	1999	2.85
1989	1.05	2000	3.25
1990	1.4	2001	3.05
1991	1.05	2002	2.5
1992	1	2003	1.65
1993	1	2004	3.5
1994	0.3	2005	4
1995	1.4		

2.2. Mathematical Model

SOBEK is a one-dimensional model that can simulate the flow and water quality in river, and estuary systems. It was developed by "WL | Delft Hydraulics" in partnership with the "National Dutch Institute of Inland Water Management and Wastewater Treatment" (RIZA), and the major Dutch consulting companies. The model is used to simulate water surface profile for the study area. It calculates the flow in simple or complex channel networks, consisting of thousands of reaches, cross sections and structures.

The **SOBEK-Flow-module** uses the Chézy bed friction value in solving the water flow equations. The Chézy coefficient, C is computed as a function of Manning's roughness coefficient, n_m:

$$C = \frac{R^{1/6}}{n_m} \tag{1}$$

For the Nile River, the Manning type roughness coefficient provides a good representation of hydraulic roughness for a wide range of discharges. Hydrographic data describe the geometry of the physical system including the assignment of the bed elevation to the study reach and evaluation of surface roughness to be used in estimating bed friction coefficients. The hydraulic data are used to establish the model boundary conditions, model calibration, and model testing process.

Calibration and validation of the model of Damietta Branch were performed using actual cross section data, discharge-water level (Q-W.L.) relationship at control structures. The control points for the reach downstream Zefta Barrage were:

1- Upstream control point downstream Zefta Barrage
2- Downstream control point at upstream Farskour.

The calibration for water levels was performed by determining the roughness coefficients for the flow equation. Manning equation was used as the flow equation and the roughness coefficient (Manning-n) was determined during the calibration analysis. This equation was described as:

$$Q = \frac{1}{n} \cdot R^{\frac{2}{3}} \cdot S^{\frac{1}{2}} \cdot A \qquad (2)$$

where :	Q	=	water flow		
	n	=	roughness coefficient		
	R	=	hydraulic radius	=	A/P
	A	=	cross sectional area		
	P	=	wetted perimeter		
	S	=	energy slope		

The calibration was done by adjusting the roughness coefficient for the reach of length 134.1 km to get close agreement between the predicted and measured water levels. The measured discharges and water levels (20-3-2004) were used to calibrate the reach. Boundaries used for this calibration were:

US boundary condition	:	Discharge DS Zefta Barrage	=	66	m^3/s
DS boundary condition	:	Water Level US Farskour Dam	=	1.05	m

Assisting points along the reach were:

Water Level DS Zefta Barrage	=	3.20	m
Water Level at km 152	=	1.3	m
Water Level at km 219	=	1.1	m

Those measured points were plotted in Figure 2 and compared with computed water levels from the model. Calibration results showed that measured and computed water levels are very similar, and average manning roughness coefficient for the reach is 0.028. It can be noticed that there are some sudden changes of water level slope, which is due to the irregularity of Damietta Branch bed .It should be noted that all distances are measured from Delta Barrage. Figure 3 shows the study area in Sobek interference.

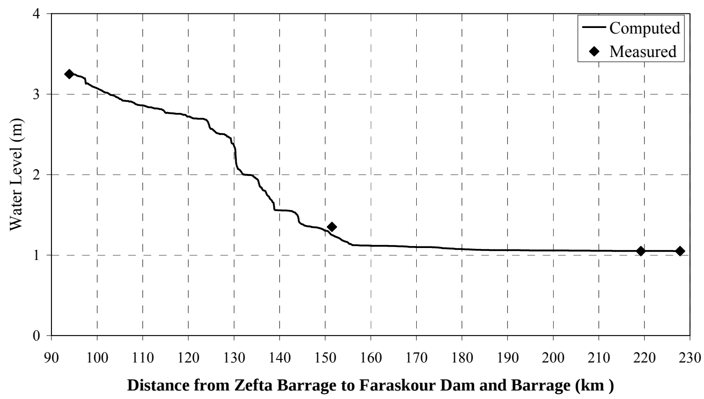

Figure 2: Computed and Measured Water Levels from Zefta Barrage (km 93.5) to Farskour Dam (km 227.45)

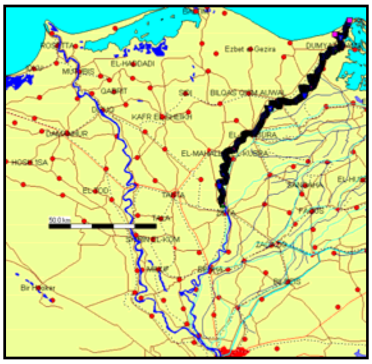

Figure 3: The Study Area "Damietta Branch"

2.3. The Study Cases

According to previous minimum discharges, discharge of 3 mm^3/d (34.7 m^3/s) was chosen as critical value to be simulated. The frequency of passing the discharge of 3mm^3/d is about 25 days/year. It was chosen to represent the worst case for navigation hazards along the reach and as a guide for any other reaches. To satisfy the safe navigational depth, weirs as a river regulation works were chosen. The primary impact of a weir on the river is rising of upstream water level above the natural level in order to satisfy safe navigation depth for navigation. The model simulation process started with a base case where the study reach is simulated without any weirs. This run will be used as a reference for the other alternatives to define the navigational bottlenecks.

After simulating the reach downstream Zefta Barrage without installing any weirs, 165 navigational bottlenecks were found for the discharge 3 mm^3/d. Figure 4 shows the center line for the bed of the navigation channel, the water surface for the simulated discharge, and the safe navigation depth that should be provided to satisfy safe navigation. Safe navigation depth is 2.3m above bed level. All points of bed level above the line representing the safe navigation depth are considered navigational bottlenecks. A detailed chart for navigational bottlenecks according to safe navigation depths 2.3 m is illustrated in Figure 5.

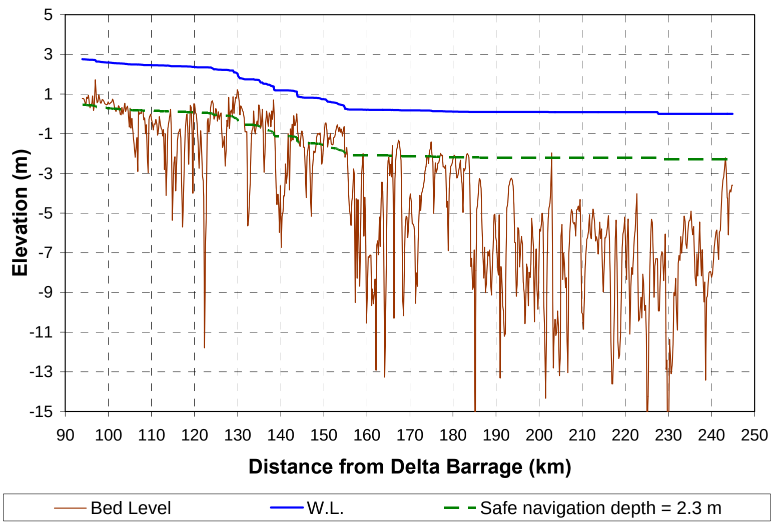

Figure 4: Predicted Water Surface Profile (Q = 3mm^3/d)

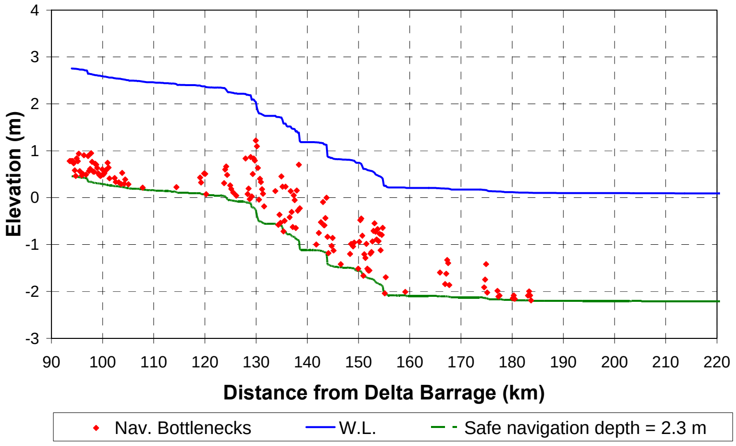

Figure 5: Detailed Navigational Bottlenecks (Q = 3mm^3/d)

It can be observed from Figures 4 and 5 that the navigational bottlenecks are concentrated at the first 90 km DS Zefta Barrage. They can be considered as 3 zones for all bottlenecks, (km 94:105), (km 119:155) and (km 165:185). Determining those sites will assist in finding the more suitable locations for constructing weirs to solve the navigational bottlenecks as the weir construction will result in heading up the water upstream of the weir location by raising the water level in the back water zone of the weir, the weirs are located at the downstream end of the zones. Four cases with 12 runs are simulated. Location and dimension of weirs will be functions for case definitions.

Case 1 represents the installation of one weir at location of km 138.9 DS Delta Barrage. Three values of weir crest level will be simulated under this case. They are 2.2, 2.7 and 3.2 m respectively.

Case 2 represents the installation of two weirs. Weir one depends mainly on the result from **Case 1** simulation. The weir in **Case 1** with crest level 2.7 m will be installed at the same location at km 138.9 DS Zefta Barrage. In addition a new second weir will be installed at km 177.5. This second weir will include two cases for crest levels. They are 1.13 and 1.63 m respectively.

Case 3 represents the installation of two weirs. Weir one depends mainly on the result from **Case 1** simulation. The weir in **Case 1** with crest level 2.7 m will be installed at the same location at km 138.9 DS Zefta Barrage. In addition a new second weir will be installed at a different location from **Case 2**. It is installed at km 155.5. This second weir will include three cases for crest levels. They are 1.2, 1.7 and 2.2 m respectively.

Case 4 represents the installation of just one weir within the whole reach from Zefta Barrage to the Mediterranean Sea at km 155.5 DS Zefta Barrage. Four values of crest level will be simulated under this case. They are 1.2, 1.7, 1.95 and 2.2 m respectively.

It should be noted that the run name is chosen according to characteristics of chosen weir in the following format:

$$\mathbf{W}_{\text{(weir location)}\ \text{(weir crest level)}}$$

The first letter "W" indicates the weir, the first subscript represents the weir location and the second subscript indicates the weir's crest level. Tables 3 and 4 define the specifications for each subscript.
Table 5 and Figure 6 details the different cases and runs simulated as a flowchart.

Table 3: Weirs Locations

1st subscript	Location from Delta Barrage (km)
1	138.9
2	177.5
3	155.5

Table 4: Weirs Crest Levels

2nd subscript	Crest Level (m)
1	1.13
2	1.20
3	1.63
4	1.70
5	1.95
6	2.20
7	2.70
8	3.20

Table 5: Mathematical Model Cases and Runs

Cases	Run Name	Weir 1			Weir 2		
		Distance from Delta Barrage (km)	Width (m)	Crest Level (m)	Distance from Delta Barrage (km)	Width (m)	Crest Level (m)
Case 1	W_{16}	138.9	100	2.2			
	W_{17}			2.7			
	W_{18}			3.2			
Case 2	$W_{17} + W_{21}$	138.9	100	2.7	177.5	250	1.13
	$W_{17} + W_{23}$						1.63
Case 3	$W_{17} + W_{32}$	138.9	100	2.7	155.5	100	1.2
	$W_{17} + W_{34}$						1.7
	$W_{17} + W_{36}$						2.2
Case 4	W_{32}	155.5	100	1.2			
	W_{34}			1.7			
	W_{35}			1.95			
	W_{36}			2.2			

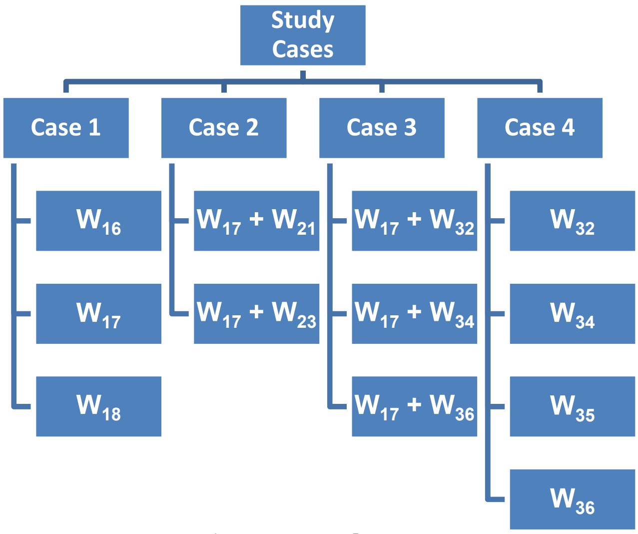

Figure 6: Study Cases

3. RESULTS AND DISCUSSIONS

3.1. Case 1

Case 1 represents the installation of one weir at a location of km 138.9 DS Delta Barrage. Three values of weir crest levels will be simulated under this case. They are indicated as $\mathbf{W_{16}}$, $\mathbf{W_{17}}$ and $\mathbf{W_{18}}$ for crest levels 2.2, 2.7 and 3.2 m respectively. Choosing the location of the 1st weir depends on how many navigational bottlenecks existed upstream of its position and how many of them will be solved according to its backwater curve length. The weir would be installed on km 138.9 downstream Delta Barrage (km 45.4 DS Zefta Barrage). The weir's width is determined according to the width of the cross-section is to be installed upon, which is 100 m width in this location, taking into account the navigation lock which will be constructed beside the weir. According to the minimum water level passing through the chosen cross-section, the weir crest level will be determined. It is tested for different cases by raising the crest level over the minimum water level by 1.0 m or 1.5 m or 1.75 m. According to those cases, the most appropriate weir will be chosen. Figures 7:9 show the predicted water surface profile for the different runs.

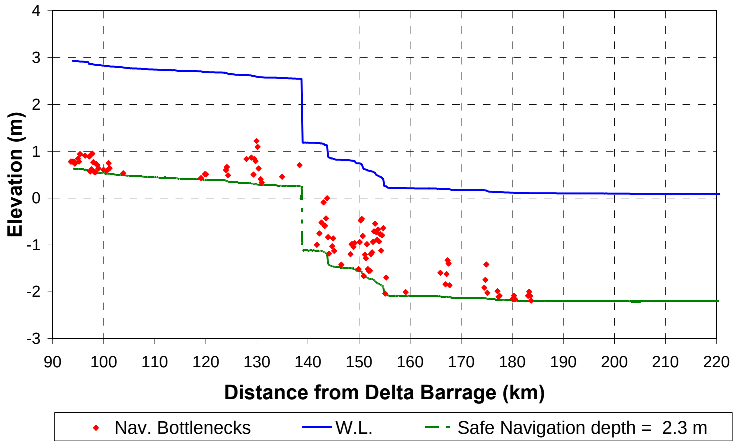

Figure 7: Detailed Navigational Bottlenecks for (Case 1, W_{16})

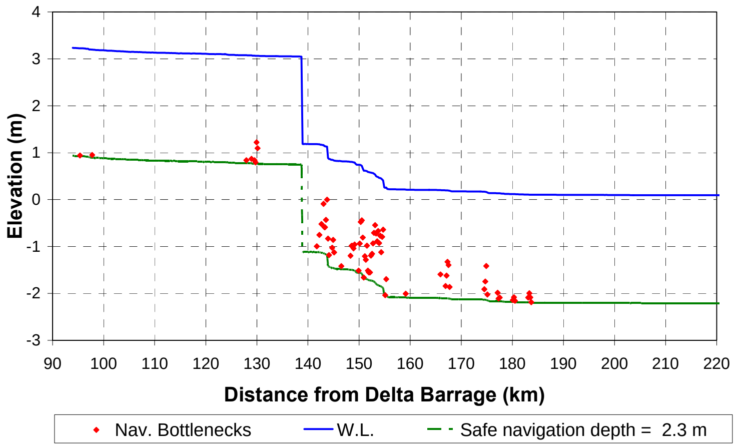

Figure 8: Detailed Navigational Bottlenecks for (Case 1, W_{17})

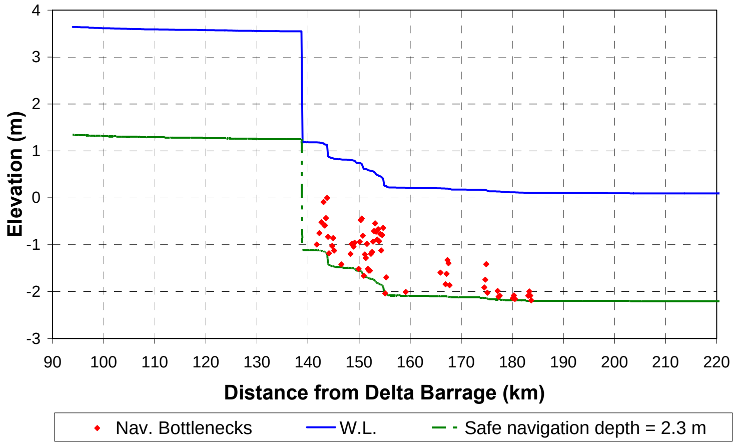

Figure 9: Detailed Navigational Bottlenecks for (Case 1, W_{18})

Case 1, Run W_{16} solved 33.33% of the navigational bottlenecks along the reach.
Case 1, Run W_{17} solved 54.55% of the navigational bottlenecks along the reach.
Case 1, Run W_{18} solved 59.39% of the navigational bottlenecks along the reach.

It was concluded that the best weir is $\mathbf{W_{18}}$ according to the percentage of solving navigational bottlenecks. But $\mathbf{W_{17}}$ can be chosen as the optimal solution as it's more economical for less dimensions of the designed weir, and the solved bottlenecks in $\mathbf{W_{18}}$ can be solved by other means.

3.2. Case 2

After settling on the first weir location, dimension and crest level, the second weir's best location will be chosen, and the work on the second weir will be done related to the installation of the first weir. The second weir's best location will be tested at two locations, which will be detailed in **Case 2** and **Case 3**. Km 177.5 was tested as a location for the second weir. According to the minimum water level passing through the chosen cross-section, the weir crest level will be determined. It is tested for different cases by raising the crest level over the minimum water level by 1 m or 1.5 m. Two values of the weir crest level will be simulated under this case. They are indicated as $\mathbf{W_{21}}$ and $\mathbf{W_{23}}$ for crest levels 1.13 and 1.63 m respectively. This weir is combined with the first weir W_{17} resulted from Case 1. The weir's width is determined according to the width of the cross-section it's built on, which is 250m in this location, taking into account the navigation lock which will be constructed beside the weir. Figures 10 and 11 shows the predicted water surface profile for the different runs.

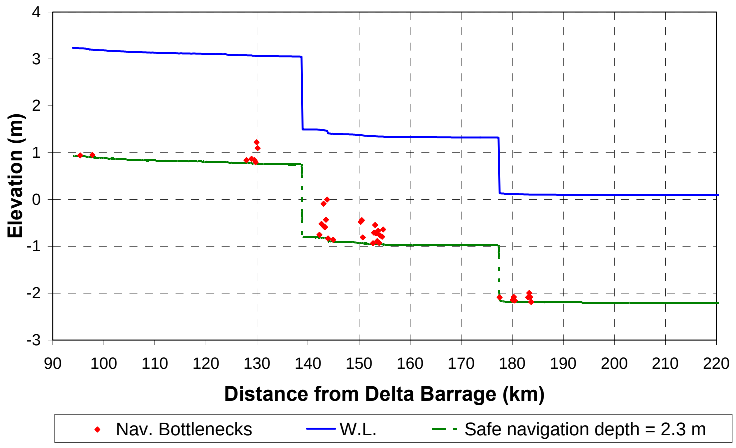

Figure 10: Detailed Navigational Bottlenecks for (Case 2, W_{17}+W_{21})

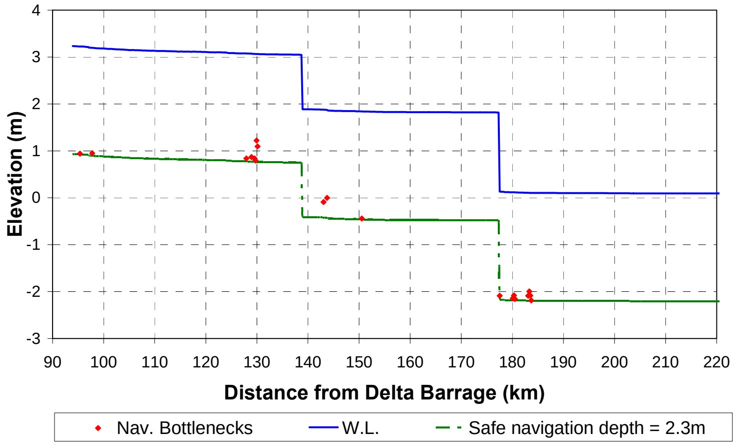

Figure 11: Detailed Navigational Bottlenecks for (Case 2, W_{17}+W_{23})

Case 2, Run (**W_{17}+W_{21}**) solved 76.97% of the navigational bottlenecks along the reach.
Case 2, Run (**W_{17}+W_{23}**) solved 88.48% of the navigational bottlenecks along the reach.

3.3. Case 3

After settling on the first weir location, dimension and crest level, the second weir's best location will be chosen, and the work on the second weir will be done related to the installation of the first weir. The second weir's best location will be tested at two locations, which will be detailed in **Case 2** and **Case 3**. Km 155.5 was tested as a location for the second weir . According to the minimum water level passing through the chosen cross-section, the weir crest level will be determined. It is tested for different cases by raising the crest level over the minimum water level by 1 m, 1.5 m or 2 m. Three values of the weir crest level will be simulated under this case. They are indicated as **W_{32}**, **W_{34}** and **W_{36}** for crest levels 1.2, 1.7 and 2.2 m respectively. This weir is combined with the first weir W_{17} resulted from Case 1. The weir's width is determined according to the width of the cross-section it's built on, which is 100m in this location, taking into account the navigation lock which will be constructed beside the weir. Figures 12:14 show the predicted water surface profile for the different runs.

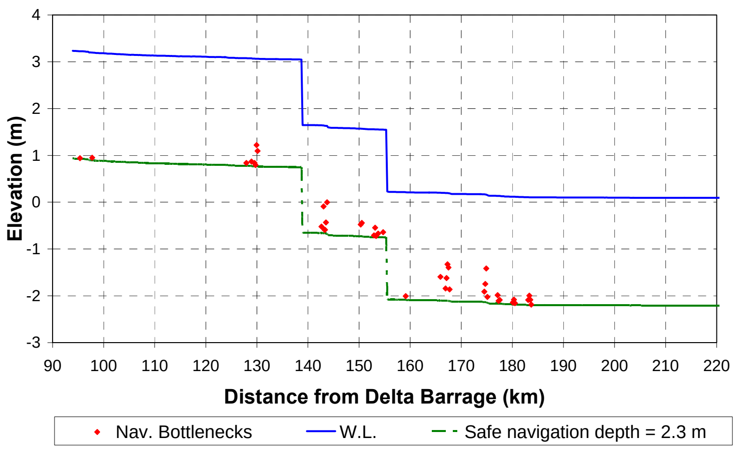

Figure 12: Detailed Navigational Bottlenecks for (Case 3, W_{17}+W_{32})

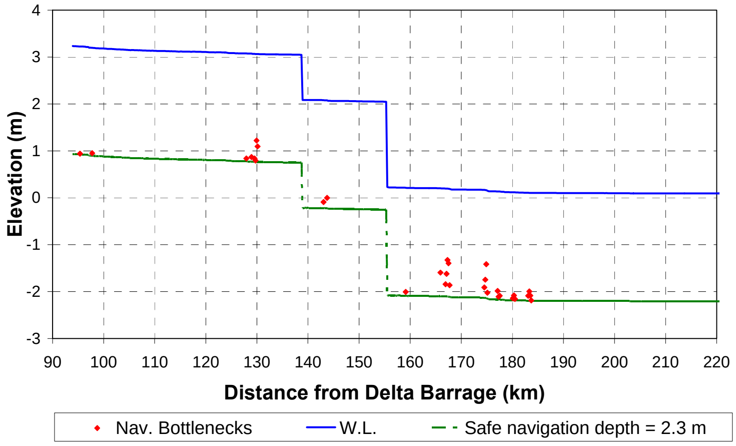

Figure 13: Detailed Navigational Bottlenecks for (Case 3, W_{17}+W_{34})

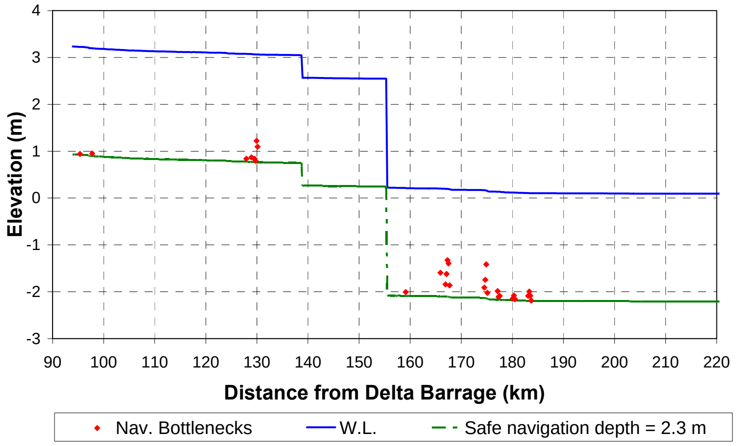

Figure 14: Detailed Navigational Bottlenecks for (Case 3, W_{17}+W_{36})

Case 3, Run (**W_{17}+W_{32}**) solved 74.55% of the navigational bottlenecks along the reach.
Case 3, Run (**W_{17}+W_{34}**) solved 81.21% of the navigational bottlenecks along the reach.
Case 3, Run (**W_{17}+W_{36}**) solved 82.42% of the navigational bottlenecks along the reach.

According to the shown figures from this table Location 2 at km 155 is more appropriate for solving navigational bottlenecks**.**

3.4. Case 4

It represents the installation of one weir in the whole reach from Zefta Barrage to the Mediterranean Sea at km 155.5 DS Delta Barrage or km 62 DS Zefta Barrage to solve the navigational bottlenecks. Four values of crest level will be simulated under this case. They are indicated as **W_{32}**, **W_{34}**, **W_{35}** and **W_{36}** for crest levels 1.2, 1.7, 1.95 and 2.2 m respectively. The scope of work is to indicate the weir location and best dimensions according to number of bottlenecks solved. It appears to be that most of navigational bottlenecks are more concentrated in the first 50-60 km DS Zefta, where the weir will be located. As most of navigational bottlenecks are concentrated at the first 61.5 km DS Zefta Barrage, the weir's location is assumed to be at km 155 DS Delta Barrage. Figures 15:18 show the predicted water surface profile for the different runs.

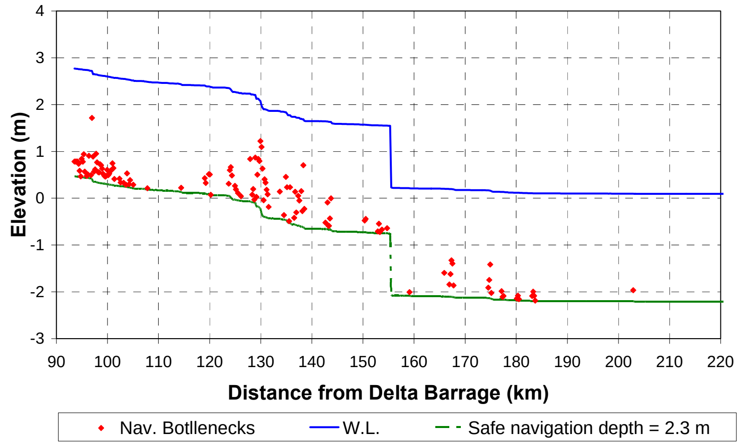

Figure 15: Detailed Navigational Bottlenecks for (Case 4, W_{32})

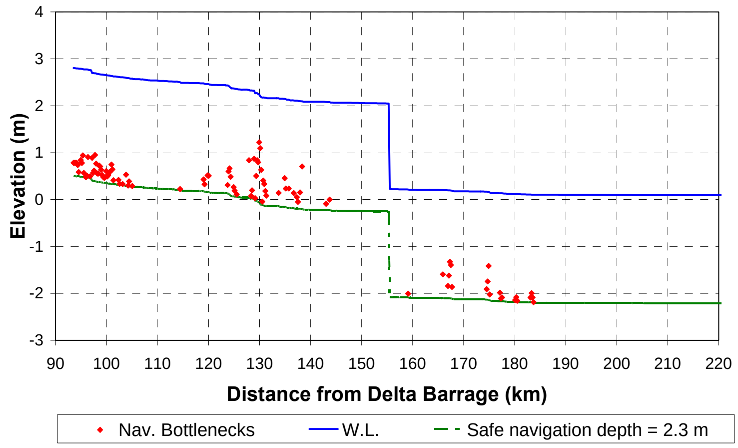

Figure 16: Detailed Navigational Bottlenecks for (Case 4, W_{34})

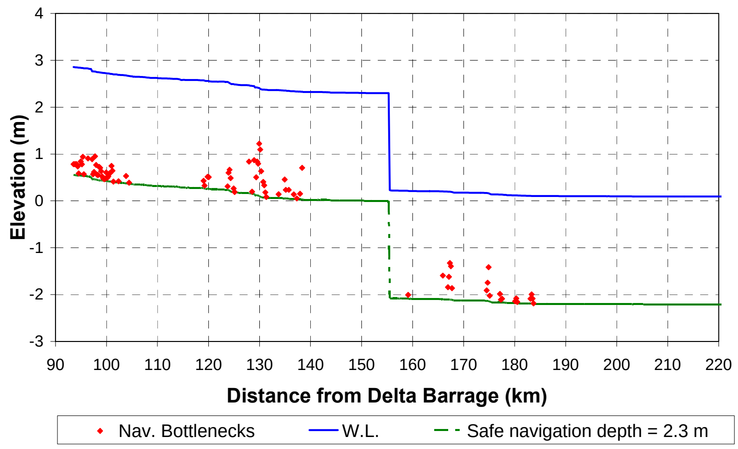

Figure 17: Detailed Navigational Bottlenecks for (Case 4, W_{35})

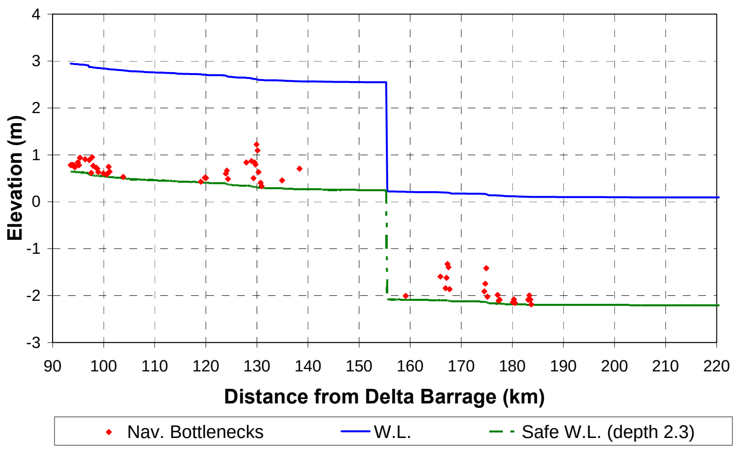

Figure 18: Detailed Navigational Bottlenecks for (Case 4, W_{36})

Case 4, Run (**W_{32}**) solved 22.09% of the navigational bottlenecks along the reach.
Case 4, Run (**W_{34}**) solved 36.81% of the navigational bottlenecks along the reach.
Case 4, Run (**W_{35}**) solved 46.01% of the navigational bottlenecks along the reach.
Case 4, Run (**W_{36}**) solved 62.58% of the navigational bottlenecks along the reach.

Though single weir 3 along the reach has lower percentage of solving navigational bottlenecks than other cases, it may be accompanied by dredging works to solve most bottlenecks and avoid more expenses in establishing two weirs along the reach.

4. CONCLUSIONS AND RECOMMENDATIONS

4.1. Conclusions

The study proved that weirs can be used for improving navigation conditions by raising water levels. They can enhance heading up of water in the weir back water zone to solve some of navigational bottlenecks. For the first 90 km DS Zefta Barrage, two weirs are implemented on the reach to raise the water level to satisfy navigation requirements. About 74 to 88 % of navigational bottlenecks can then be solved. Alternatively, one weir is implemented at km 155.5 in order to raise water level to satisfy navigation requirements. About 22 to 62 % of navigational bottlenecks are solved. Though the percentage is lower than implementing two weirs, but it's more economic to construct just one weir instead of two. The remaining navigational bottlenecks can be removed by some other solutions that will be mentioned in the recommendation. However, dredging must be tested in models first, because the major problem occurred DS Zefta barrage was due to not testing the dredging effect, so the capacity of the cross section increased, and a water drop occurred.

4.2. Recommendations

The study has further recommendations after those conclusions:

1. Mathematical models should be utilized to test the impact of an alternative solution with only dredging of all navigational bottlenecks on the channel hydraulic performance without implementation of weirs.
2. Dredging works can be done besides constructing weirs in order to lower the expenses, though dredging needs continuous observations.
3. Since the critical discharge just passes about a month/year, small draft ships should be used through the reach during the period of critical water levels.
4. Inland water transport activity can be put off during certain number of days each year when the required water depth is not available.

5. If ships are restricted with dimension, under keel water clearance may be lowered with some precautions of the ship movement and cargo.

Further studies should be applied to continue the objectives of developing inland navigation studies:

1. Mathematical models should be utilized to test the impact of dredging process on the channel hydraulic performance before deciding on implementation the dredging works.
2. The current location of Zefta gauge station should be tested for heading up of water as a result of spur dike existence in the gauge location and the gauge reading should be calibrated.
3. The critical discharge downstream Zefta barrage should be defined more accurately and submitted to the discharge implementing sector in the Ministry of Water Resources and Irrigation.
4. Other river regulation works should be tested instead of weirs, like groins.
5. Future development of the cross sections of Damietta Branch should be predicted through simulating different scenarios of morphological changes.

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