Meandering river morphology characteristics
Case study of Damietta branch, Egypt

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ABSTRACT

The HAD impacts, especially the changes to the river hydraulic geometry (width, depth, slope, and channel pattern) are the main concern of scientists and engineers. These changes are indirect relation with the imposed discharges and sedimentation processes. In order to understand and predict future changes and responses due to future releases and human intervention, it is necessary to understand the existing changes and development over space and time. This paper evaluates and analyzes the measurements of a series of field survey used to investigate morphological changes for the S-shaped reach located downstream of Benha City from Km 69.220 to Km 76.080 downstream of Delta Barrages Damietta Branch of about 6.860 km length, twenty two cross sections were studied. These cross sections were selected to illustrate the hydraulic geometry changes as well as aggradations and degradation processes over the studied years. These sections indicate some of the changes that have occurred during these series that may reflect the overall changes to Damietta branch. Different hydraulic parameters such as width, depth, and area of these cross sections are calculated under a fixed datum. This datum is defined as the water level corresponding to maximum and minimum discharges of 62.1 and 9.90 Mm^3/day respectively. Since the change in the geometrical properties of the curved river parts are non-uniformly distributed over the cross section. Therefore, mean depths of the cross sections are calculated by dividing the effective cross section area under the fixed datum over the corresponding cross section width. The variation in the mean depths indicates either aggradation or degradation trend. The ability of the main channel to tolerate navigation is also tested. The study concluded that overall aggradations are formed especially at the inner curves of both bends as well as a significant degradation along the outer curves. The study proposed some training structures to strength the main channel.

Key word: Damietta, River Morphology, Silting and Scouring, Field Survey, Cross Section Changes .

INTRODUCTION

Generally a certain length of an alluvial channel is said to be in equilibrium or in regime if the amount of sediment entering this reach is equal to the sediment outgoing. Hence the channel bed elevation will not change over a long period of time. However, if incoming and outgoing sediment loads are different, the sediment transport process is active and the bed level will either rise or fall respectively. A rise in the bed level is known as aggradation while a fall in the bed level is known as degradation. On the other hand, if the channel cross section undergoes erosion at one side and deposition at the other side the channel is in a non-equilibrium state which usually occurs due to bends in river planform.

Damietta branch has experienced dramatic changes in channel configuration and sediment processes since the construction of the High Aswan Dam (HAD) in 1968. In addition, Damietta branch is meandered and its sediment transport is governed by interaction of many complex processes resulting that the geometrical configuration is complex and is continuously changing.

This research is based on field data gathered since1982. A certain reach of the Damietta branch was chosen to illustrate and study the consequence of all aforementioned irrigation and navigation problems. This reach is approximately 6.869 km long which located ; as shown in Fig. (1), downstream of Benha City from km 69.219 to km 76.088 downstream of Delta Barrages Damietta Branch and from km 95.219 to km 102.088 downstream of El-Roda Gauge Station as illustrated in Table(1). The reach was selected in such a way to consist of two successive meandering curves where point bars and pools are the dominant bed forms and composed of a relatively homogeneous combination of fine sand and silt. The river free surface width is approximately 200 m at median flow. While some limited sandstone outcrops exist as well as one very limited area of coarse sand, gravel, and cobbles are emerged. Land use in the vicinity is predominated by crop production .

DAMIETTA BRANCH

At the beginning of the delta, the Nile bifurcates into two branches, each of which meanders separately through the delta to the Sea, the eastern which is Damietta, located about 950 km south of Aswan Dam. Damietta branch is mainly used for irrigation purposes . The Damietta branch is closed to the sea by the Damietta Dam located at km 1161 south of Aswan Dam. The average width of the branch is about 280 m with an average sinuosity of 1.3.

This branch is considered an important waterway in Egypt; which is currently not navigable due to major river rehabilitation works . It will be considered as the future cargo corridor between Cairo and the Mediterranean Sea ports, Damietta and Port Said. The volume of cargo transported over waterways is expected to rise considerably when the anticipated container terminal projects in Cairo and along the upper Nile and other infrastructure projects in the Nile Delta are completed.

DATA COLLECTION AND PROCEDURES

In this analysis the study reach plan form development through time starting between years 1982 and 2001 was examined. Two different topographic maps representing Damietta branch stretch from Km 87.500 to Km 103.700 downstream of El-Roda Gauge station were examined which belong to the following years:

- The produced River Nile topographic maps by Kenting Air Science Company in year 1982 of scale 1:10000.
- The conducted hydrographic survey by the Hydraulics Research Institute in year 2001 through the navigation project in the branch.

The recorded monthly mean natural flow at Aswan before the HAD construction ranges between a minimum value of 51 million m^3/day in May and a maximum value of 765 million m^3/day in September while the maximum daily value of 990 million m^3/day was recorded in year 1958. These values significantly altered to a maximum value of 270 million m^3/day after the dam construction.

Similar trend was recorded through Damietta branch where the study reach is situated. The maximum daily flow discharge downstream of Delta barrages, Damietta branch was ranged just prior to the dam construction between 226 million m^3/day and 203 million m^3/day. Bearing in mind that the maximum flow discharge through Damietta branch after the dam construction was 60.6 million m^3/day, this means that the maximum flow is reduced after the dam construction to about 27.3% of that before the dam construction. Consequently the water level was considerably altered, where the maximum water levels downstream Delta Barrages changed from 18.16m to 14.01m before and after the HAD construction respectively. This alteration in the hydrological parameters must have direct impact on the formulation of the morphological parameters.

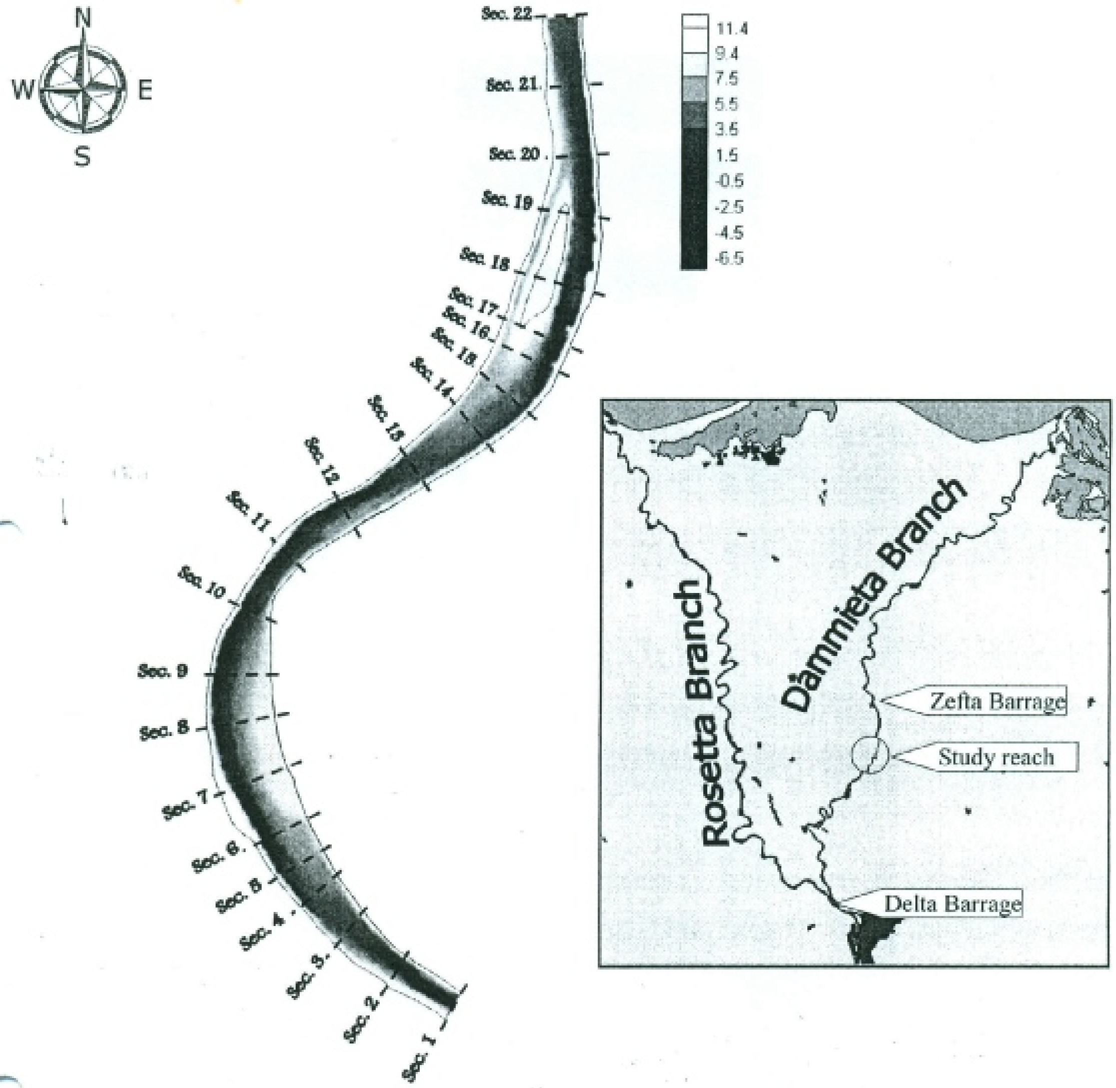

FIG.(1) : General Plan of the Study Reach

ANALYSIS OF RESULTS AND DISCUSSION

Comparison of 1982 and 2001 Morphology

In order to understand the main character of Damietta branch after the construction of HAD, comparison between section profiles along the study reach during years 1982 and 2001 would be illustrated. The total number of 22 cross sections; as shown in Fig. (1) and as illustrated in table(1), were utilized in order to understand the hydrological and morphological change along the study reach as following:

1- Comparison of Bed Profiles:

Comparison between the deduced cross section profiles corresponding to the previous and recent hydrographic measurements of years 1982 and 2001 are shown in Figs. (from 2 to 15). In this case bed profiles corresponding to years 1982 and 2001 would be referred as previous and recent respectively. This description would be presented as follows:

- **Cross Section (1 to 3) from Km. 95.219, to 95.926 respectively DS of El-Rodah Station :** As the specified reach is situated within the transition zone between two successive and opposite meandering curves, the three cross sections are almost in equilibrium state referring to scour and deposition process. The third cross section revealed a significant widening relative to the other two sections as a transition between the previous and next sections.

- **Cross Section (4 to 9) at Km. 96.207, to 97.525 DS of El-Rodah Station:** These cross sections are influenced by the curvature in the clock wise direction where bed level along the west side. More local scour and deeper bed levels were obviously accomplished along the west side of the river which reached about (1.75) m below the Mean Sea Level for the recent measurements than that for the previous bed levels, that is due to the formation of the fully developed helical flow current. While more deposition is taken place along the east side where the inner curve is located which consequently reached a level higher than the low water surface level. As a result of such mechanism, which is a unique relation to dynamics of flow in curved channels, the river reach tends to migrate towards the outer (the west) bank. Consequently, lateral migration of curved river reaches cause several morphology problems that affect the navigation waterway.

- **Cross Section (10 to 13) at Km. 97.896 to 99.155 DS of El-Rodah Station:** It can be easily noticed from the sequence of the sections that the stream tends to be channelized, the bed level near the west bank is raised to level (0.00) m compared to the relevant measurements at the upstream, and the width is decreased to a certain extent. It is also clear that the effect of spiral forces is reduced until reaching section 13 where it is significantly stable. On the other hand the comparison between the previous and recent bed profiles revealed the swinging of the thalweg line from one side to the other.

- **Cross Section (14 to 19) at Km. 99.528 to 100.908 DS of El-Rodah Station:** These cross sections; located at the upstream of the second curve, influence the effect of the spiral currents. In this case scour is clearly taken place along the outer curve east side of the river while deposition is occurred along the west side of the river. More over, as the section width is significantly enlarged; compared to the relevant upstream condition, the average flow velocity was reduced and consequently such remarkable deposition took place near the inner bank in the form of an island. On the other hand the comparison between the previous and recent bed profiles revealed some variations especially at the deposition locations which revealed that those islands are recently developed which increases in width towards the downstream direction.

  It can be noticed that as the deposition zone (island) increased in width and water area, the effective channel width is drastically reduced. Consequently, more local scour and deeper bed levels were obtained along the east side of the river which reached about (3.00) m and (6.50) m below the Mean Sea Level for the recent measurements than that for the previous bed levels for cross sections No. (16) and (17) respectively. As a result of such mechanism, the east side slope would be very steep and consequently the river reach tends to migrate towards the outer (the east) bank and lateral migration of curved river reach was developed. In order to face such situation a spur dike was erected at this side of the river as a bank protection.

- **Cross Section (20 to 22) at Km. 101.233, 101.636 and 102.088 DS of El-Rodah Station:** It can be easily remarked from Fig.(14 to 15) that the influence of the upstream meandering conditions is gradually wearing off. For that reason, the bed level near the east bank was raised to level (2.00) m and the channel is being narrowed along the downstream direction compared to the upstream sections. Additionally, the comparison between the bed profiles revealed the same tendency for the previous and recent measurements.

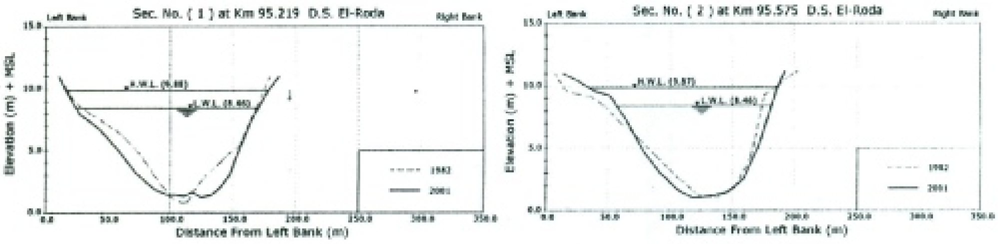

FIG.(2) : Comparison between Bed Profiles at Cross Section (1,2)

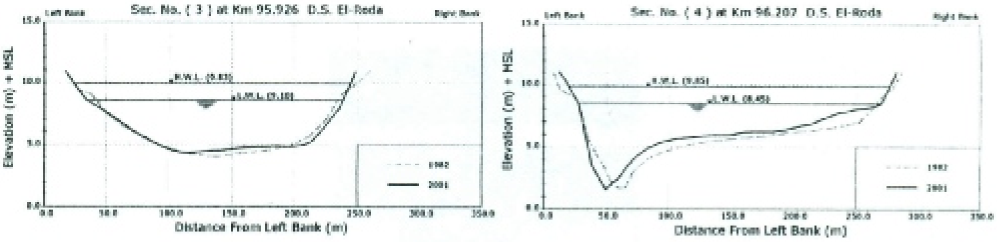

FIG.(3) : Comparison between Bed Profiles at Cross Section (3,4)

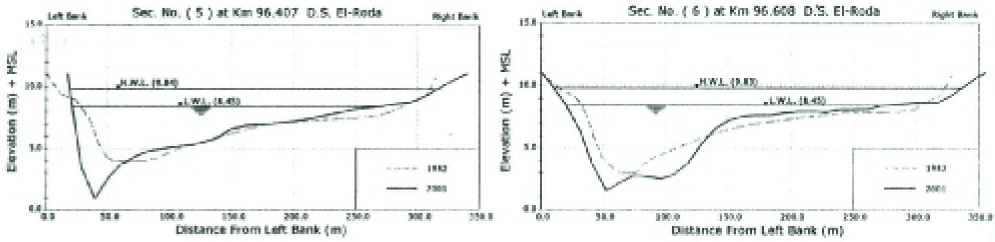

FIG.(4) : Comparison between Bed Profiles at Cross Section (5,6)

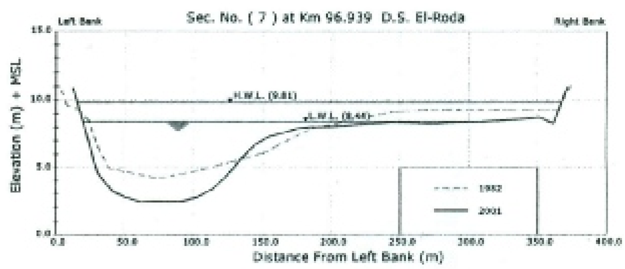

FIG.(5) : Comparison between Bed Profiles at Cross Section (7)

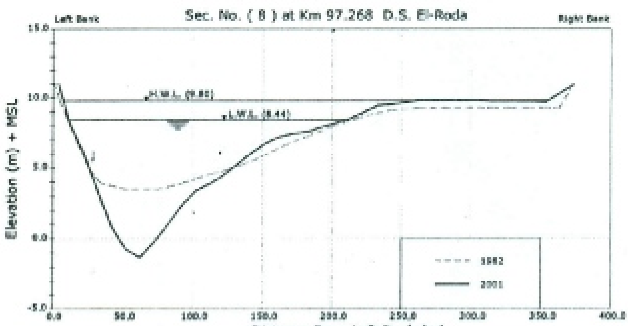

FIG.(6) : Comparison between Bed Profiles at Cross Section (8)

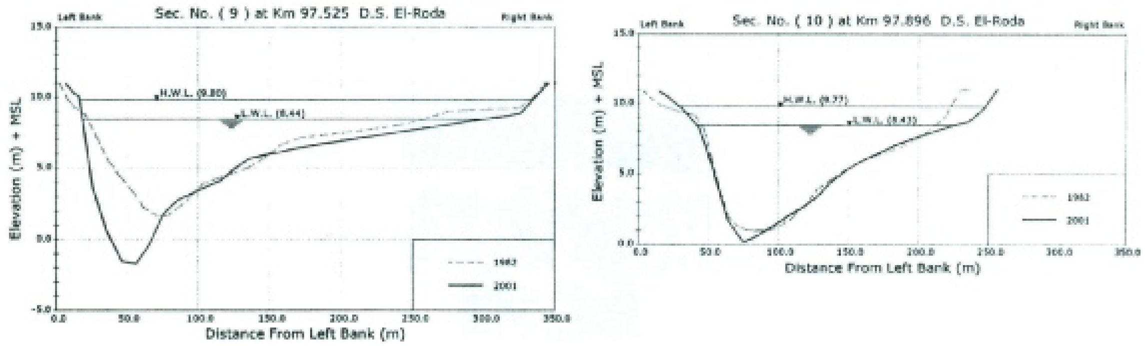

FIG.(7) : Comparison between Bed Profiles at Cross Section (9,10)

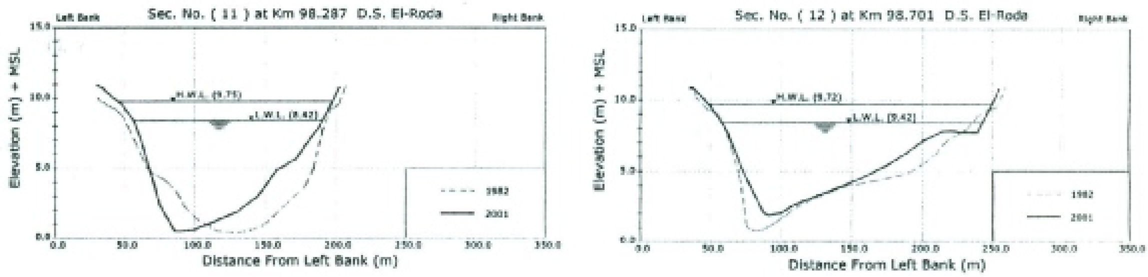

FIG.(8) : Comparison between Bed Profiles at Cross Section (11,12)

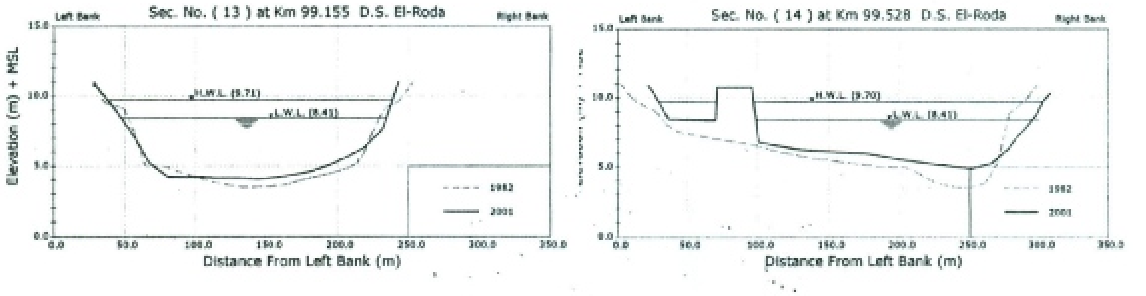

FIG.(9) : Comparison between Bed Profiles at Cross Section (13,14)

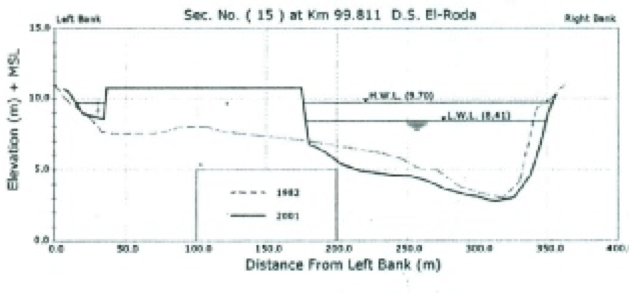

FIG.(10) : Comparison between Bed Profiles at Cross Section (15)

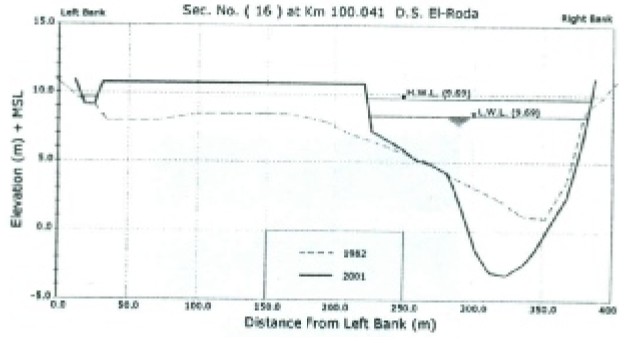

FIG.(11) : Comparison between Bed Profiles at Cross Section (16)

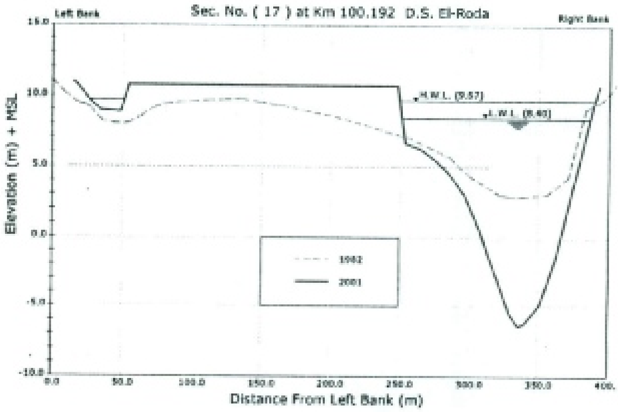

FIG.(12) : Comparison between Bed Profiles at Cross Section (17)

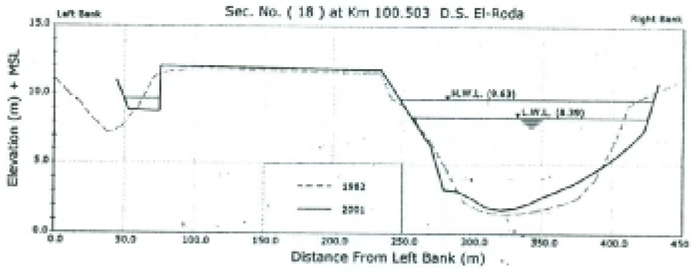

FIG.(13) : Comparison between Bed Profiles at Cross Section (18)

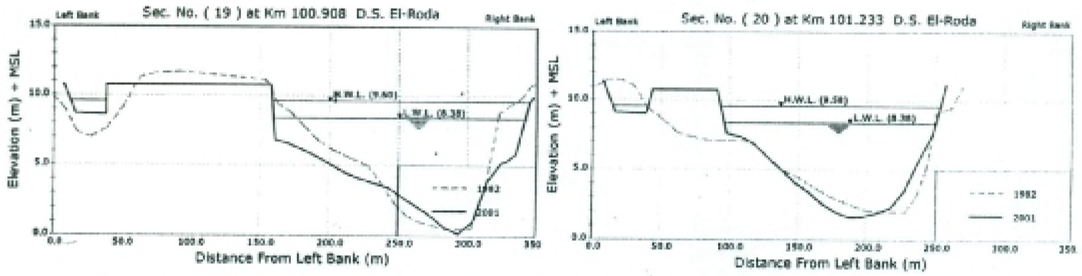

FIG.(14) : Comparison between Bed Profiles at Cross Section (19,20)

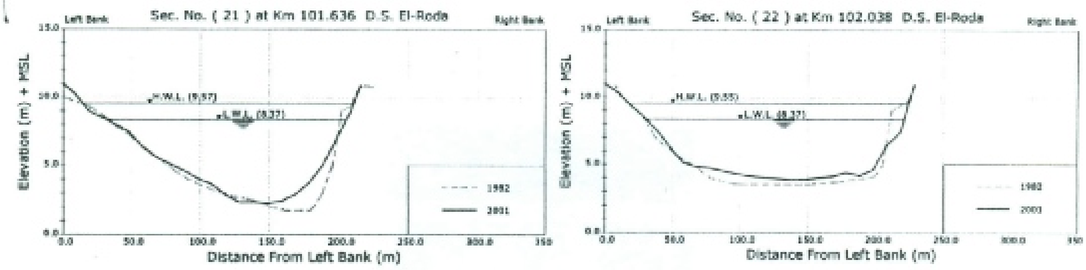

FIG.(15) : Comparison between Bed Profiles at Cross Section (21,22)

2- Variations in Channel Width

The max. and min. water levels are computed at the locations of the twenty two cross sections representing the study area. The water levels corresponding to the max. and min. flow discharges are 62.90 and 9.90 million m^3/day respectively downstream the delta barrages.

TABLE (1): Water Surface Level for Various Cross Sections

C.S. No.	Distance D.S. El-Roda (km)	Water level		C.S. No.	Distance D.S. El-Roda (km)	Water level	
		Max. (m)	Min. (m)			Max. (m)	Min. (m)
1	95.219	9.88	8.46	12	98.701	9.72	8.42
2	95.575	9.87	8.46	13	99.155	9.71	8.41
3	95.926	9.86	8.46	14	99.528	9.70	8.41
4	96.207	9.85	8.45	15	99.811	9.70	8.41
5	96.407	9.84	8.45	16	100.041	9.69	8.41
6	96.608	9.83	8.45	17	100.192	9.67	8.40
7	96.939	9.81	8.44	18	100.503	9.63	8.39
8	97.268	9.80	8.44	19	100.908	9.60	8.38
9	97.525	9.80	8.44	20	101.233	9.58	8.38
10	97.896	9.77	8.43	21	101.636	9.57	8.37
11	98.287	9.75	8.42	22	102.088	9.55	8.37

To enable the comparison of the morphological characteristics between the two tested surveys at 1982 and 2000, the areas of these cross sections are computed under a fixed datum of the maximum water level profile. The selected datum represents the water level corresponding to 62.9 million m^3/day at each cross section. It is assumed that the change in the geometrical characteristics of a cross section is uniformly distributed over the cross section. This is achieved by dividing the computed area of each cross section by the selected datum over its total width at the same datum to produce the sectional mean depth as shown in fig.(16). The change in the bed mean depth between 1982 and 2000 may be used as an indication of either a silting or scouring process.

The worked out top width results in Table (2) concluded moderate variations in the average top width for the compared cross sections within the near straight portions of the study reach. This zone includes each of sections (1 to 6) which are located at the upstream boundary of the study reach, sections (10 to 14) which are located between the two successive curves reaches, and sections (19 to 22) which are located at the downstream end of the study reach. This result is expected as the outer curve of meandered reach subjected erosion and continues deposition and sedimentation along the inner curve zones. This consequently concluded that the increase in river top width usually occurs at the bended reaches rather than that at the straight or transition reaches as shown in Fig.(1).

TABLE (2): The Worked Out Cross Section Parameters

C.S. No.	C.S. Area (m^2)		Top Width (m)		Ave. Depth (m)		Min. bed level (m)	
	1982	2001	1982	2001	1982	2001	1982	2001
1	745.64	876.92	157.00	161.20	4.75	5.44	0.85	1.22
2	770.81	810.42	170.60	151.00	4.52	5.37	1.01	0.99
3	907.53	907.91	226.50	220.30	4.01	4.12	4.08	4.38
4	1082.02	975.13	266.10	256.50	4.07	3.80	1.63	1.54
5	1000.80	1004.90	300.20	295.10	3.33	3.41	4.00	0.97
6	941.15	1066.12	307.60	326.10	3.06	3.27	3.00	1.61
7	823.40	1129.83	360.00	351.60	2.29	3.21	4.22	2.37
8	963.11	1115.91	360.30	305.60	2.67	3.65	3.50	-1.35
9	1050.95	1362.55	322.40	317.60	3.26	4.29	1.67	-1.68
10	938.11	981.86	200.50	218.10	4.68	4.50	1.01	0.21
11	1000.94	865.84	167.00	151.90	5.99	5.70	0.44	0.48
12	1017.71	860.91	210.60	200.70	4.83	4.29	0.75	1.87
13	928.49	882.41	209.40	200.60	4.43	4.40	3.48	4.12
14	1003.28	794.04	274.20	217.00	3.66	3.66	3.50	4.90
15	1056.46	896.74	298.00	177.20	3.55	5.06	3.00	2.80
16	1237.54	1191.23	356.80	161.70	3.47	7.37	0.96	-3.21
17	797.61	1189.80	230.60	140.20	3.46	8.49	2.92	-6.39
18	956.82	971.52	176.20	180.80	5.43	5.37	1.46	1.86
19	897.78	1062.52	173.80	186.10	5.17	5.71	0.54	0.15
20	932.40	821.98	220.00	159.00	4.24	5.17	2.00	1.61
21	956.19	882.52	194.70	196.00	4.91	4.50	1.70	2.32
22	955.01	905.66	205.60	203.00	4.65	4.46	3.50	3.82

4.5.3 Variation of Average Depth

The attainable parameters of the average flow depth in Table (2) for the previous and recent cross sections profiles of years 1982 and 2001 respectively were statistically evaluated. This showed an increase in the average flow depth for the whole study reach from 4.11 m in year 1982 to 4.78 m in year 2001 for the same maximum water level which represents about 16%. These results clarify the morphological changes and the river meandering variation with time that took place within the study reach between years 1982 and 2001.

These variations are demonstrated as shown in Fig.(16) which concludes moderate variations near straight portions of the study reach including each of sections (1 to 6) which are located at the upstream boundary of the study reach, sections (10 to 14) which are located between the two successive curves reaches and sections (19 to 22) which are located at the downstream end of the study reach. This investigation led to terminate the increase of average depth at the locations of maximum curvature. This consequently reveals that the increase in average flow depth usually occurs at the meandered reaches rather than that at the straight or transition reaches.

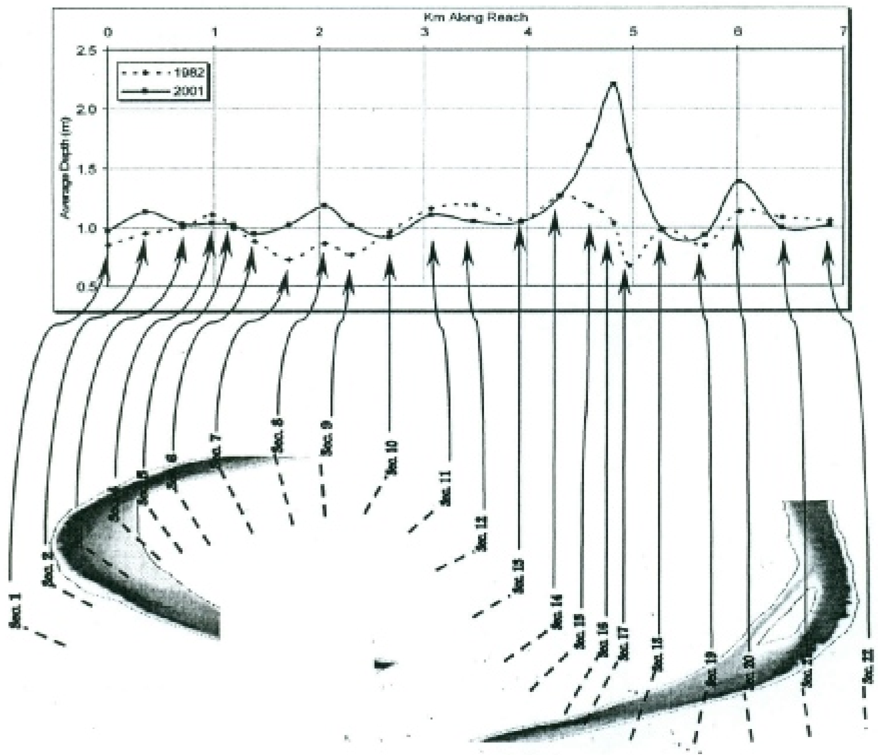

FIG.(16) : Variation of the Average Flow Depth

The reason of the attainable increase is the sediment deposition which took place at the inner curve of the meandered reaches and the severe bed scour which took place at the outer curve of the study reach. This phenomenon can be clearly evident in cross sections (7 to 9) which is representing the upstream curved reach and sections (15 to 17) which is representing the downstream curve reach. It was also evident especially for the downstream curved reach that the increase of the average depth has taken place due to the influence of two factors. The first one; which is the strongest, is the construction of spur dikes at the outer curve which increases the scour depth at the dikes tip. The second factor is the continuing formation of the island towards the upstream direction; clearly evident in sections (14 to 17), which additionally constricts the effective channel width causing the channel to grow deeper Therefore, one may conclude that as the deposition took place around the inner curve of the bended channel during the survey of 2001, the river top width becomes narrower and very deep along the outer curve. Therefore, the average flow depth during the recent survey becomes greater than that of the previous survey especially at the apex location of the curved reach.

4.5.4 Variation in Thalweg Line Level

The attainable parameters of the minimum bed levels in Table (2) for the previous and recent cross section profiles of years 1982 and 2001 respectively can be used to consider the thalweg line profile variation along the reach. The worked out analysis illustrates that the average value of the minimum bed levels is lowered from (2.24) m in year 1982 to (1.12) m in year 2001. This revealed that the calculated mean value of the deepest bed levels along the whole study reach in the recent measurements of 2001 is lowered by 1.12 m than that for the previous cross section profiles of year 1982. These results clarify the morphological changes and the river meandering variation with time within the study reach.

To achieve more benefits out of the deduced cross section profiles, a comparison between the deepest bed levels along the study reach, corresponding to the previous and recent cross section configurations of years 1982 and 2001 respectively, was performed as shown in Fig.(17). In this Figure, the study reach was internally distinguished according to the river plan form as straight, curved and transition zones. In this case the transition zone is defined as that usually located between two successive meandering reaches while the straight zones are located at the upstream and downstream boundaries of the study reach. As the flow condition through this reach is principally influenced by the upstream condition, the corresponding mean bed levels to each internal zone during the previous and recent cross section profiles were worked out as shown in Table (3).

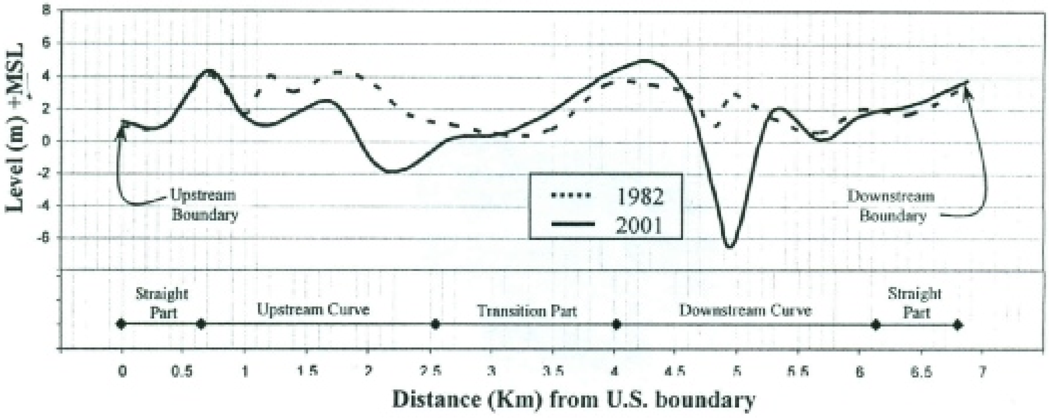

FIG.(17): Variation of the Lowest Bed Levels

TABLE (3): Main Parameters of the Internal Zones

No.	Zone description	C.S. Number		Av. Bed Level (m)		Diff. (m)	Bed condition
		`From	To	1982	2001		
1	Straight	1	2	0.93	1.11	+ 0.18	Deposition
2	U.S. Curve	3	9	3.16	1.12	- 2.04	Scour
3	Transition	10	12	0.73	0.85	+ 0.12	Deposition
4	D.S. Curve	13	17	2.77	0.44	- 2.33	Scour
5	Straight	18	22	1.84	1.95	+ 0.11	Deposition

In the above table the sigh (+) means deposition and higher average bed level during year 2001 survey than that in year 1982. While the sigh (-) means scour and lower average bed level during year 2001 survey than that in year 1982. The achieved results in Table (3) demonstrate the following:

- While comparison between the average bed levels reveals scour which took place through the upstream and downstream curved zones, the other straight and transition zones comprise deposition.
- The average value of the observed scour is ranged between 2.04 m and 2.33 m for the upstream and downstream curved zones respectively.
- The average value of the observed deposition is ranged between a maximum value of 0.18 m at the upstream straight zone and a minimum value of 0.11 m at the downstream straight zone.
- The average value of the observed scour through the transition zone between the upstream and downstream curved zones is equal to 0.12 m.

It can be concluded from this study that the average bed level decreases and scour is taking place along the curved meandering zones while the transition and straight zones sustains such low deposition.

CONCLUSION AND RECOMMENDATION

After HAD construction, comparison of the previous and recent hydrographic measurements of 1982 and 2001 respectively through 22 cross sections along the study reach revealed the lowering of bed level along the outer curves due to erosion which ranged between 2.04 m and 2.33 m for the upstream and downstream curved zones respectively. At the same time, deposition is built up along the inner curve while river width clearly increases to reach its maximum value along the curve apex. While the average value of the observed deposition is ranged between a maximum value of 0.18 m at the upstream straight zone and a minimum value of 0.11 m at the downstream straight zone.

The study revealed that due to river bends, scour takes place at outer curved sides and deposition takes place at the inner bends which may lead to channel lateral migration and navigation deterioration. In order to overcome such effect it is recommended to use permenant training structures such as spur dikes and bendway weirs which may be successfully applied along the outer curved banks on order to protect the banks from collapsing, decrease the scour effect at the outer curves and increase flow along the inner banks. This recommendation may lead to improve the waterway for both irrigation and navigation characteristics.

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