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The Impact of Manmade Interventions on the River Nile at Elrayramoun, Egypt

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Abstract: Many regions of the Nile River are subjected to continuous morphological changes such as bank failure, bed degradation and aggradations, and the formation of new islands. Some of these changes resulted as a side effect to man made interventions. These morphological changes have a negative impact on the efficiency of navigation, pump intakes, and the loss of agricultural lands. A serious and harmful example of such interventions to the river occurred in the Elrayramoun district, where the people constructed a road to a ferryboat which extended about 400 meters across the River Nile. A detailed survey for the river bed and banks were conducted at the site in 2005. The survey results were compared with old maps from 1982, before the intervention. The results indicated that several morphological changes occurred at the site, where erosion took place at the east bank, and great deposition occurred at the west bank. Surface water Modeling System (SMS) was used to simulate the study area to predict the expected changes at flood flow condition. Moreover, the model was also used to test the best alternatives to reduce the negative impact on the river. The model was calibrated using actual measurements including bed levels data, water levels, water current velocity measurements and grain size distributions of bed samples. Location of erosion zones were determined by estimating the zones subjected to velocity larger than incipient velocity. Three solutions were tested to remove a portion of this road which contradict the river and affect its characteristics. The three tested portions were removing 25%, 50% and 75% of the road length. The locations of erosion and sedimentation zones were determined. The study recommended the best solution to reduce the harmful effects on the Nile River morphology.

Key words: River Nile – Morphology – Human Interventions – Erosion – Sediment Transport.

INTRODUCTION

Rivers have been a focus of human activities throughout ancient and modern times. Also it has been a subject of study by engineers and scientists who have been fascinated by the self-formed geometric shapes and their responses to changes in nature and human interferences. Engineers are interested in water supply, channel design, flood control, river regulation, navigation improvement. In addition to engineering, understanding river behavior is also necessary for environmental enhancement.

The study of morphological changes in the River Nile is important practically when it is related to human interventions. A severe man-made intervention on the River Nile occurred in the Elrayramoun district where the people built a road across the River Nile to a ferry boat in this area. As a result of the construction of this road, severe morphological changes occurred. In this paper, the changes which occurred to the river bed and banks will be discussed. A numerical model was used to predict the expected changes which might take place due to flood flow condition. Moreover, alternatives to minimize the negative impact of such construction will also be discussed.

Elrayramoun Study Area:

Area Description: The Elrayramoun area illustrates the consequences of man-made interventions on the River Nile characteristics due to a construction of a road, with an approximate length of 442.00 meters on the west side of the River Nile to serve a ferry located there. This road was constructed at a shallow area where the boat could not reach the river bank at minimum water levels.

The study reach is approximately 8.700 km long, which is located - as shown in Fig. (1) - downstream of Malawy City from km 284.400 to km 293.100, upstream of El Roda Gauge Station. The study reach contains two islands: a big one to the South of the ferry and another small island to the north of the ferry. The study reach was selected to start and end in a relatively straight portion of the river and also away from the ferry boat, where the effect of the construction of the road is invisible.

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Fig. 1: The Ryramoun study area

The width of the study reach is about 580.0 meters at the start and extends to 847.0 meter upstream from the island and about 580 meter from the middle of the island to both channels East and West. The river contracted at the position of the road to the ferry and the width became 373.0 meters, which means that the river width is reduced by 35.0%. The width of the river varies from 636.0 to 690.0 meters for the remaining portion of the study reach.

The navigation path at the study reach start is to the West side of the island located to the South of the reach and then is directed to the East downstream the contraction by the road. It goes back to the West again after the effect of the road vanished.

Hydraulic and Hydrologic Condition: The study area D/S Assiut barrage shows where the passing flow varies from $29.20x10^6$ m^3/day to $181.30x10^6$ m^3/day. Meanwhile, the water levels at the study area fluctuated between a minimum level of 36.74 m and a maximum level of 40.28 m (above MSL). The measured flow velocity indicated that the average velocity, between kilometer 634.0 and kilometer 642.6, was varying from 0.63 m/s to 0.25 m/s (at a flow of $83.330x10^6$ m^3/day D/S Assiut barrage). The velocity distributions along the study reach varies as a result of the reach morphology. At the South of the study reach, the maximum velocity was 1.3 m/s and then it reduced to 0.72 m/s at the West side of the island because the river flow was divided into two channels. At the middle part of the study reach, the river continues as one channel so the velocity increased again to reach the value of 1.03 m/s. Then the velocity reduced to a value of 0.9 m/s due to the widening of the river at the area downstream the road of the ferry boat.

The analysis of some bed material samples collected from the study area indicated that the geometric mean diameter D50 of the collected samples ranges between a maximum value of 0.44 mm and a minimum value of 0.15 mm. Most of the study reach soil samples are considered as medium sand except on some spots which are located at the end of the southern island where the soil samples were medium to coarse sand towards the East bank. Moreover, the soil samples were medium to coarse sand at the East side downstream the road to the ferry boat.

It was noticed that the obtained samples from the outer curve contain such a higher percentage of sand grains than that of the inner curve which mainly consists of muddy grains with fine grains. This would be an indication to the action of the surface transverse flow velocity components which attack the bank and bed of the outer curve causing fine grains to travel from the outer curve to sediment at the inner curve zone.

Morphological Changes at the Study Area: The results of the recent survey and the results of new topographical maps based on recent aerial photos were used to detect the morphological changes occurred at the study area. It can be shown from Figures (2&3) that great morphological changes took place between the year 1982 and the year 2005. Location of erosion and deposition areas was determined, as shown in Figures (4&5), and the following morphological changes were concluded:

- Remarkable deposition occurred at the West side of the study area, downstream the road to the ferry boat. This resulted from the construction of the road which contradicts the river creating a dead zone in the D/S West side.
- There is erosion concentrated at the East side of the study area downstream the road. The construction of the road directed the river flow towards the East bank which caused erosion in the East bank.
- Silting zones appeared at the North island. Moreover a big silting area appeared at the downstream end of the study reach which may cause navigation problems.
- On the other hand, erosion zones appeared in the upstream part of the study reach towards the South island. This erosion was concentrated at the Western channel as it passes most of the flow.

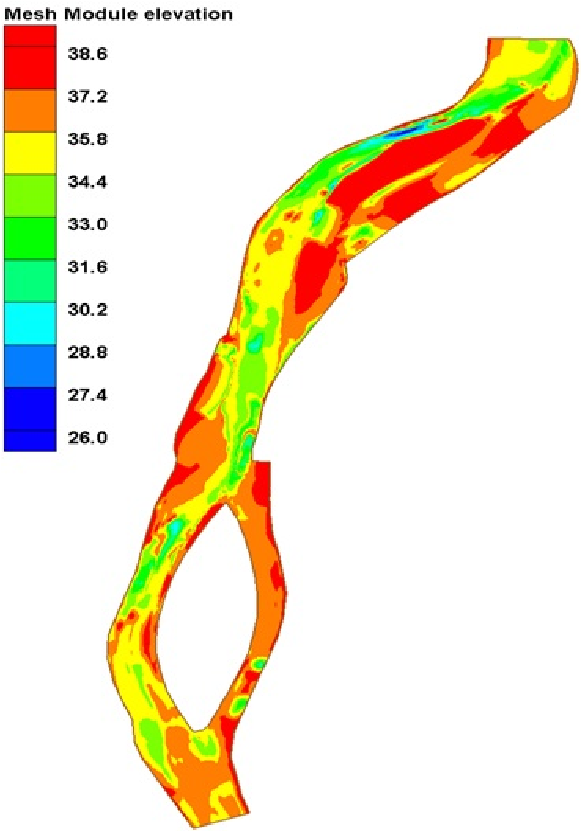

Fig. 2: Bed levels of study Reach in 1982

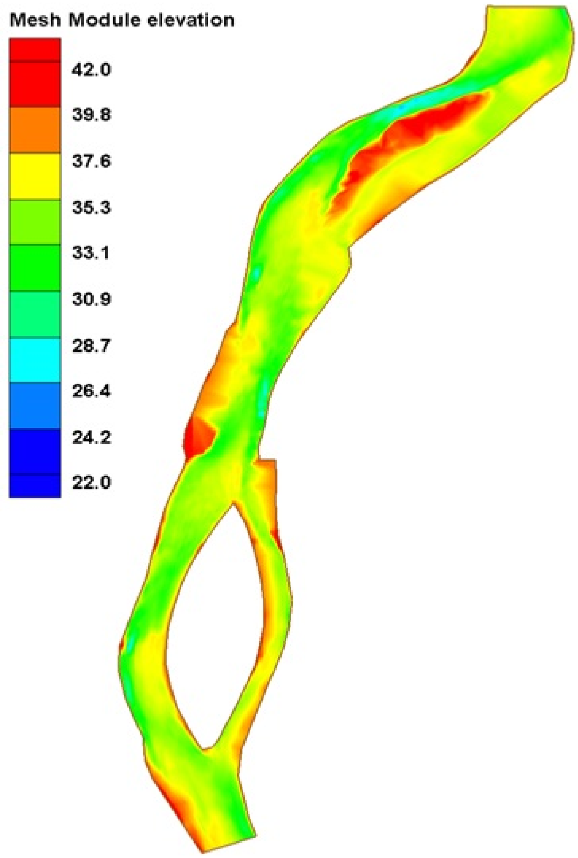

Fig. 3: Bed levels of study Reach in 2005

MATERIALS AND METHODS

Modeling of Study Area:

Mathematical Model: Numerical models could be considered as the most widely applied technique to solve mathematical expressions that describe any physical phenomena. Those models are mainly classified by number of spatial dimensions over which variables are permitted to provide much more detailed results than others. However, collection of adequate and reliable field data is highly required to fulfill suitable model calibration and verification leading to successful application. In this respect, in case of large width to depth ratio of the water body, the horizontal distribution of flow quantities might be the main interest, and two-dimensional solutions based on depth-averaged flow approximations will provide an acceptable description of flow motion. For this purpose, the finite element Surface water Modeling System "SMS" 2-D mathematical model would be used to simulate the water flow along the study reach.

The depth averaged velocity components in horizontal *x* and *y* coordinate directions would be respectively defined as follows:

$$U = \frac{1}{H}\int u\Delta dz \qquad (1)$$

$$V = \frac{1}{H}\int v\Delta dz \qquad (2)$$

$$z_s = z_b + H \qquad (3)$$

In which:

H : flow water depth (m)
z : vertical direction
z_b : bed elevation (+msl)
z_s : water surface elevation (+msl)
U : horizontal velocity in the x direction at a point along the vertical coordinate (m/s)
V : horizontal velocity in the y direction at a point along the vertical coordinate (m/s)

The depth-averaged surface water flow relationships would be established by integrating the three dimensional mass and momentum transport equations with respect to the vertical coordinate from

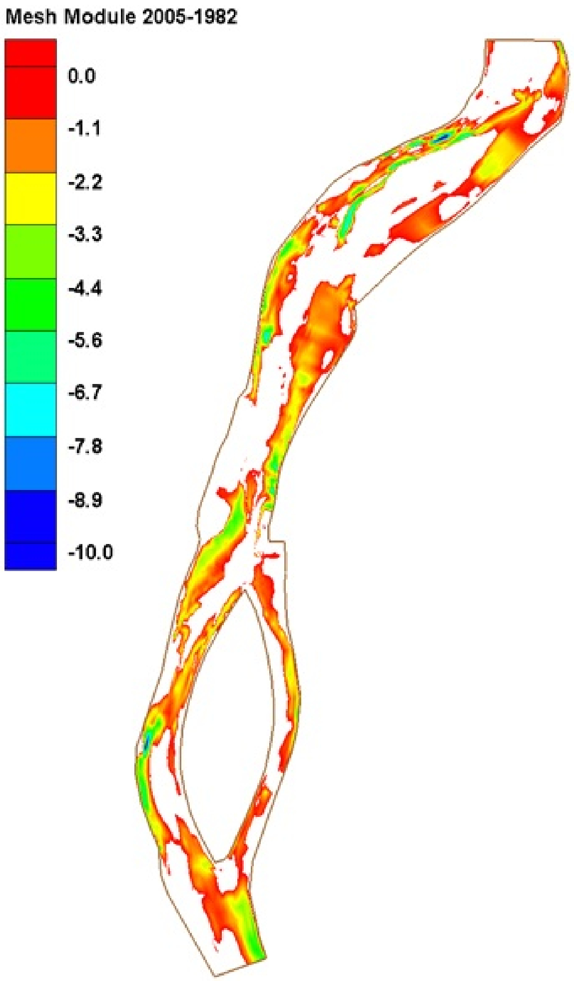

Fig. 4: Erosion in meter in 2005.

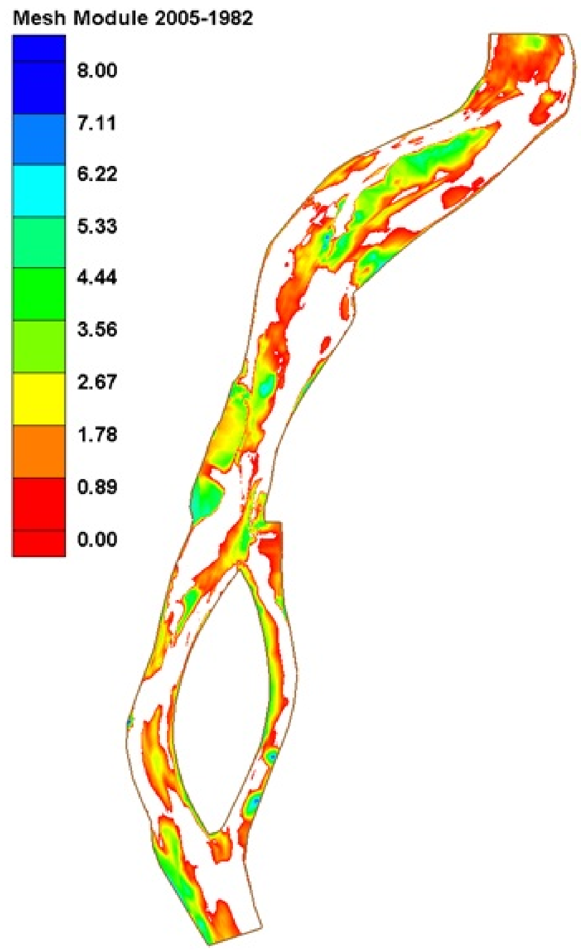

Fig. 5: Deposition in meter in 2005

the bed to the water surface. Considering vertical velocities and accelerations to be negligible, the vertically integrated mass transport equation or continuity equation can be derived as follows:

$$\frac{\partial z_w}{\partial t} + \frac{\partial q_1}{\partial x} + \frac{\partial q_2}{\partial y} = q_m \quad (4)$$

In which:
$q_1 = U_H$ = unit flow rate in the x direction
$q_2 = V_H$ = unit flow rate in the y direction
q_m = mass inflow or outflow rate per unit area

Directional components of bed shear stress are computed as follows:

$$\tau_{bx} = \rho\, c_f m_b \frac{q_1\sqrt{q_1^2 + q_2^2}}{H^2} \quad (10)$$

$$\tau_{by} = \rho\, c_f m_b \frac{q_2\sqrt{q_1^2 + q_2^2}}{H^2} \quad (11)$$

Where c_f = dimensionless bed-friction coefficient, and m_b is a factor that accounts for increased shear stress caused by a sloping bed. Bed friction coefficient c_f is given by

$$m_b = \sqrt{1 + \left(\frac{\partial z_b}{\partial x}\right)^2 + \left(\frac{\partial z_b}{\partial y}\right)^2} \quad (12)$$

$$c_f = \frac{gn^2}{\phi_n^2 H^{1/3}} = \frac{g}{c^2} \tag{13}$$

Where n is Manning roughness coefficient, f_n = 1.486 for U.S. customary units, or 1.0 for SI units, and c is Chézy roughness coefficient.

Both Manning and Chézy coefficients can be described by linear functions of water depth in Finite Element of Surface Water Modeling Systems (FESWMS). Variations in flow resistance with water depth might occur when short vegetation is submerged and possibly bent by the flow, or where tree branches come into contact with flow at high stages. Appropriate flow resistance coefficients for natural and constructed channels and for floodplains can be estimated using references such as Chow[3], Barnes[2], and Arcement and Schneider[1].

The sediment transport equations used by the numerical model can be any of the following concepts:
1-Meyer-Peter and Muller's (1948).
2-Laursen's method (1958).
3-Engelund and Hansen's (1967).
4-Ackers and White's Formula (1973).
5-Power formula.
6-Yang's sand and gravel Formula (1972,1973,1984).
7-Garbrecht, et al. Approach.
8-Ackers and White's Day Formula (1983).

RESULTS AND DISCUSSION

Model Calibration: Several model tests were run to achieve the best agreement between measured and resulted values from the model. This was carried out by adjusting roughness coefficients at various locations along the modeled study reach according to the mentioned ranges in Table (1) till the best results were achieved. Field water current velocity was measured at six cross sections along the study area. These observations were taken at a flow of 83.330×10^6 m^3/day downstream from the Assiut barrage at a water level of 37.15 meter above MSL. Comparison of the measured field velocities and obtained velocity profiles at the six cross sections are shown in Fig (6) to Fig (14).

Determination of Erosion Zones: The model output can give a good picture of the mean velocity distribution along the study reach. Moreover, bed shear stress distribution along study reach can be estimated. The erosion occurs only in the zones which are subjected to a velocity higher than incipient velocity. Incipient velocity is the velocity at which the bed particles are starting to move. The incipient velocity is dependent upon water depth and grain size diameter. Figure (15) presents the values of the incipient velocity with respect to average water depth and average bed size diameter D50[5].

Effect of Different Flow Scenarios Passing Through the Study Area: The model was used to predict the impact of the different flow scenarios passing through the study area. Two flow conditions were considered in the study including a case of maximum flow of 184.30 m.m^3/day with water level of 40.28 meters above MSL, and the case of flood flow of 350 m.m^3/day with water level of 41.68 meters above MSL.

The model results indicated that the mean velocity along the study area ranged from 0.3 m/sec to 1.44 m/sec in case of maximum flow condition. Meanwhile, the velocity increases when passing flood flow to reach a maximum value of 1.89 m/sec. These maximum values appeared downstream of the road, and also at the Western channel of the North island. Figures (16 & 17) show the velocity distribution along the study area for the maximum and flood flow conditions.

The incipient velocity was determined, using Neill's velocity curves, at the study area, and consequently the erosion zones were estimated. The results indicated that three main erosion zones appeared at the case of maximum flow condition (Figure 18). The southern erosion zone, at the main channel, has a length of 2.84 km with an area of 0.47 km^2. While the middle erosion zone, at the road location, has a length of 1.35 km with an area of 0.18 km^2. Meanwhile the North erosion zone, towards the West bank, has a length of 1.52 km. with an area of 0.22 km^2. Moreover, bank failure might take place at the North zone.

On the other hand, the erosion zones increased in length and area in the case where the flood flow was passing through the study area (Figure 19). The southern zone has an erosion length of 3.5 km with an area of 0.97 km^2. The middle erosion zone has a length of 1.7 km with an area of 0.69 km^2. Meanwhile, the North zone has an erosion length of 2.12 km with an area of 0.42 km^2. This indicated that the erosion, due to flood flow, at the northern and southern zones is twice the erosion in the case of maximum flow condition. Meanwhile, the erosion due to the flood at the middle zone (at the road location) is four times the case of maximum flow condition. Moreover, bank failure might take place at both the North and South zones.

This indicated that the study area is not stable and is subject to erosion at high flows. Moreover, the construction of the road increased the erosion in the river bed at its location.

Table 1: Estimated Roughness Coefficients

Region No.	Region Class	Estimated Manning factor (n)	
		Min.	Max.
1	Original bed Profile	0.015	0.020
2	River banks	0.020	0.025
3	Vegetative areas	0.025	0.045

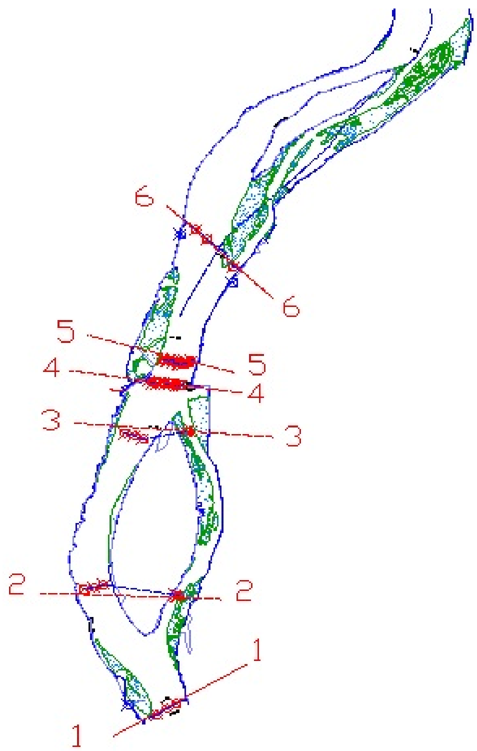

Fig. 6: Location of Velocity Measurement Sections

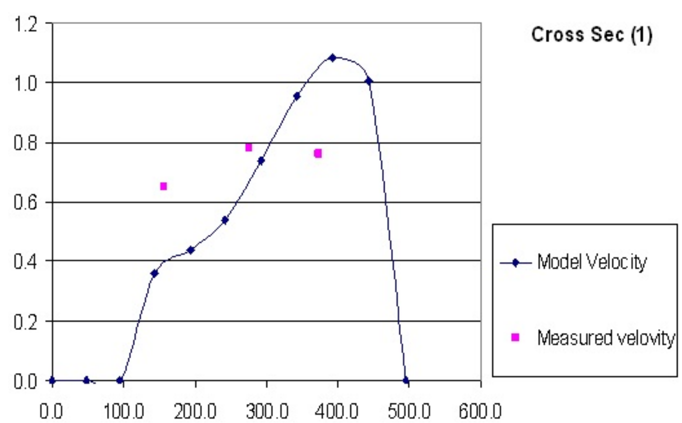

Fig. 7: Calibration of Flow Velocity at Sec. (1)

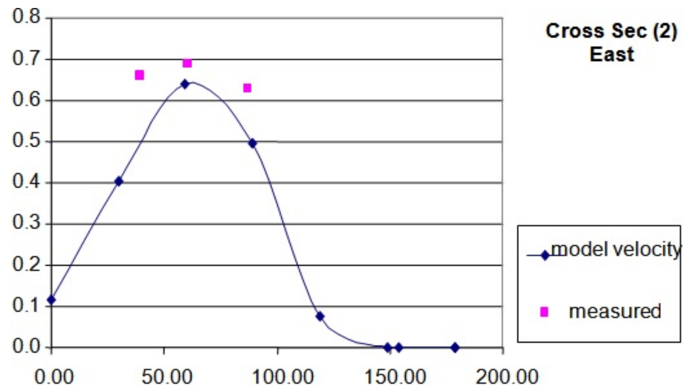

Fig. 8: Calibration of Flow Velocity at Sec. (2) East

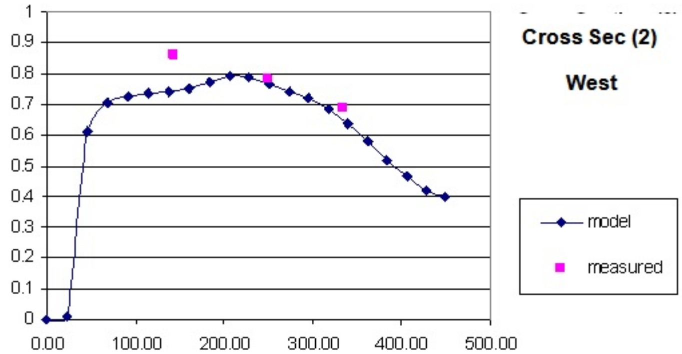

Fig. 9: Calibration of Flow Velocity at Sec. (2)

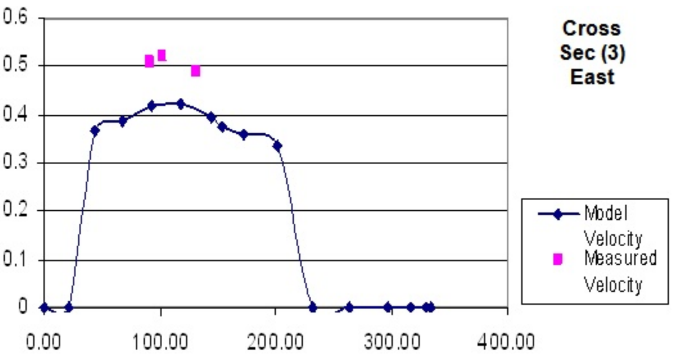

Fig. 10: West Calibration of Flow Velocity at Sec. (3) East

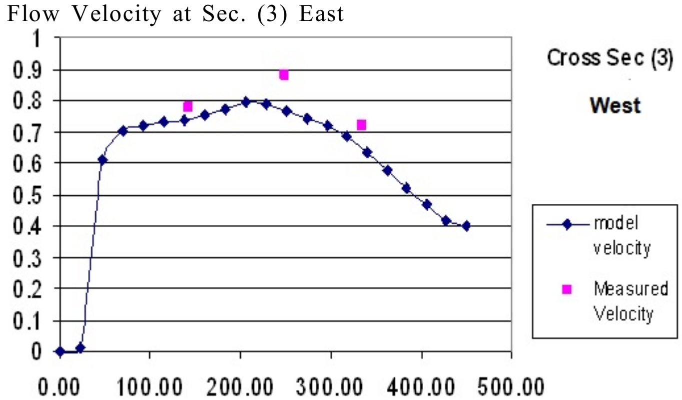

Fig. 11: Calibration of Flow Velocity at Sec. (3) West

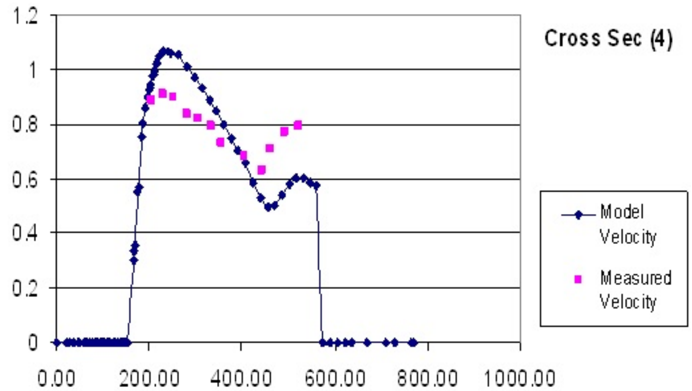

Fig. 12: Calibration of Flow Velocity at Sec. (4)

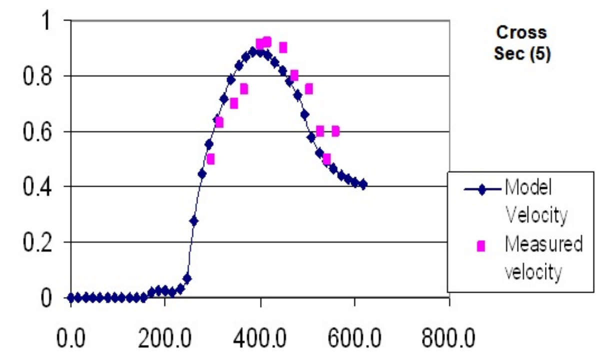

Fig. 13: Calibration of Flow Velocity at Sec. (5)

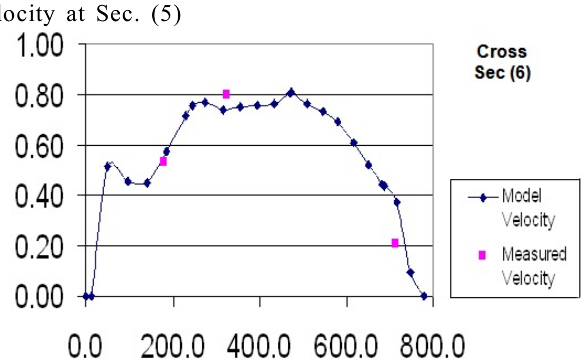

Fig. 14: Calibration of Flow Velocity at Sec. (6)

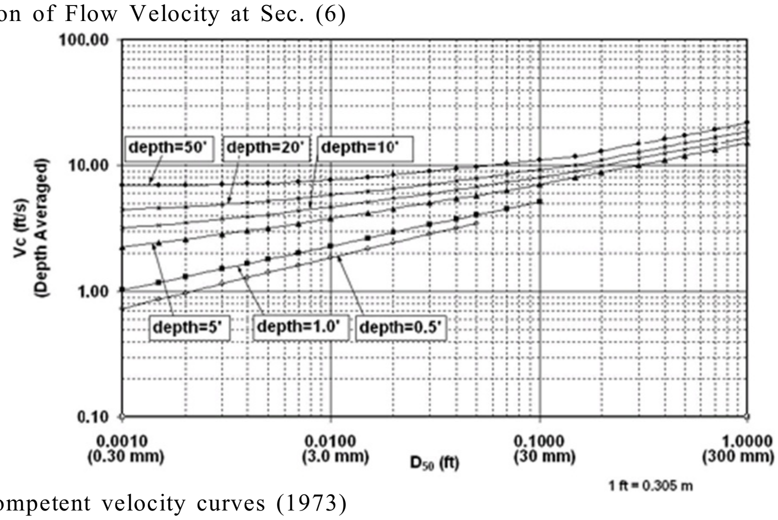

Fig. 15: Neill's competent velocity curves (1973)

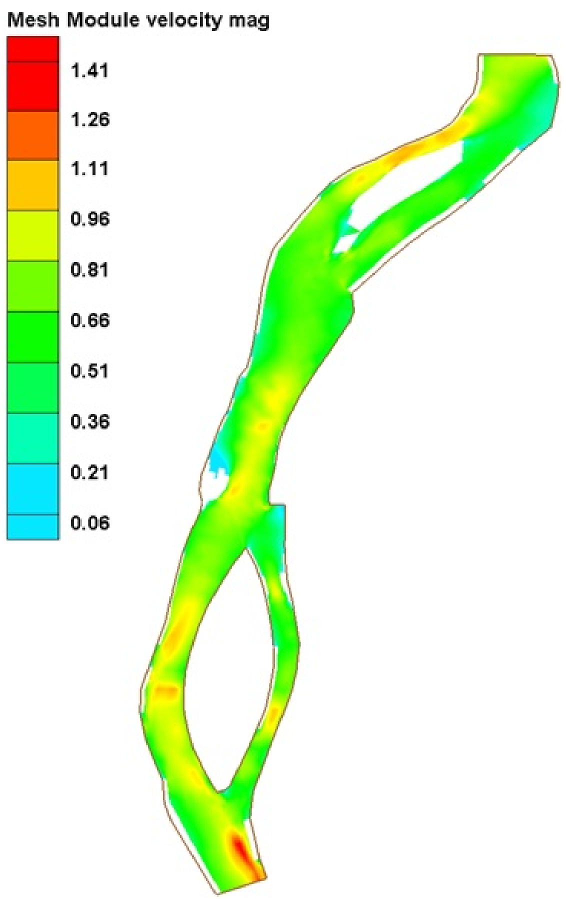

Fig. 16: Velocity Distribution at Maximum Flow

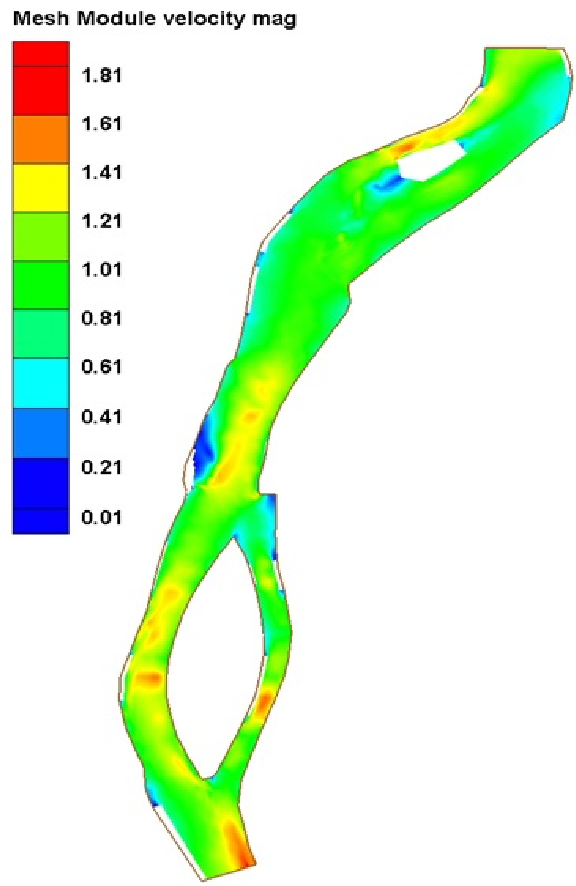

Fig. 17: Velocity Distribution at Flood Flow

Different Alternatives to Reduce Negative Impacts: The numerical model was used to study the best alternative to reduce negative erosion impact resulting from the construction of the road. The effect of removing 25%, 50% and 75% of the road was tested. Each alternative was studied in both the maximum and the flood flow scenarios. The mean velocity distribution was estimated along the study area for each of the study cases. Figures 20, 21, and 22 illustrate the mean velocity distribution at the locations of erosion zones in the different flow scenarios. It can be concluded that, there was no significant change in the mean velocity at the southern and northern zones (at sec. 2 and sec. 6 respectively). Meanwhile, the velocity at the middle zone (at sec. 5) was reduced due to removing parts of the road. The removal of 25% had a minor effect. However, the removal of higher percentages (50% and 75%) is much more significant.

The mean velocities were compared with the incipient velocity and consequently erosion zones were estimated. Figures (23 to 28) show the estimated erosion zones along the study reach for different alternatives with different flow discharges. The length and the area of each of the erosion zones were determined (Tables 2 and 3).

It can be concluded that there is no effect of the road length on the size of the southern erosion zone. This indicates that the southern zone was affected only by the river characteristics in the upstream side of the study area. This zone was affected by the size of the South island, as the location of this zone was relatively far from the constructed road.

Also, the northern erosion zone was not significantly affected by the road length. This indicates that the North erosion zone was only affected by the river characteristics in the downstream side of the study area. This zone was affected by the size of the North island, as the location of this zone was relatively far from the constructed road.

The reduction of the road length reduced the erosion at the middle zone. The removal of half of the road length reduced the erosion, due to the maximum flow, by 43%. However, it was not significant in case of flood flow condition as the erosion was reduced by 9% only. Meanwhile, the removal of three quarter of the road length reduced the erosion, due to the

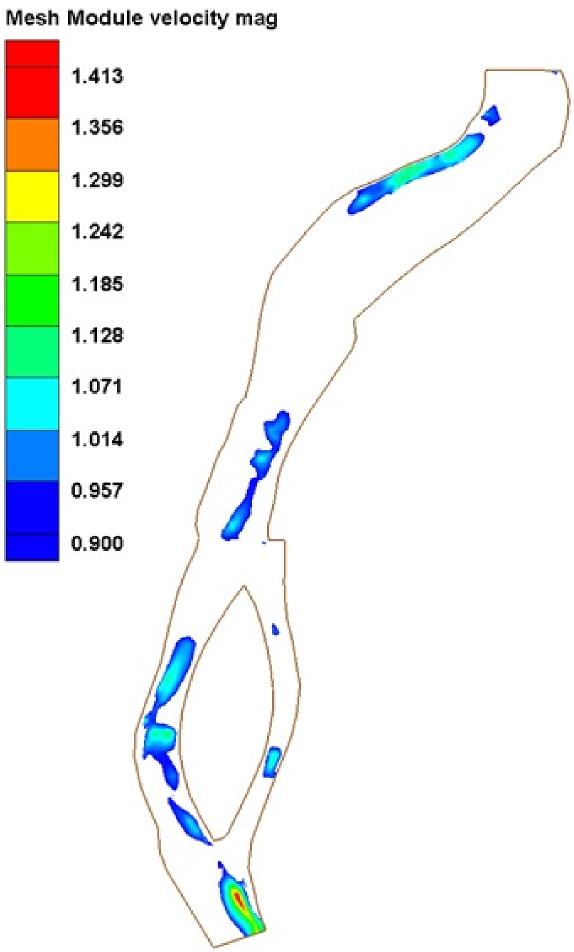

Fig. 18: Erosion Zones with Maximum Flow

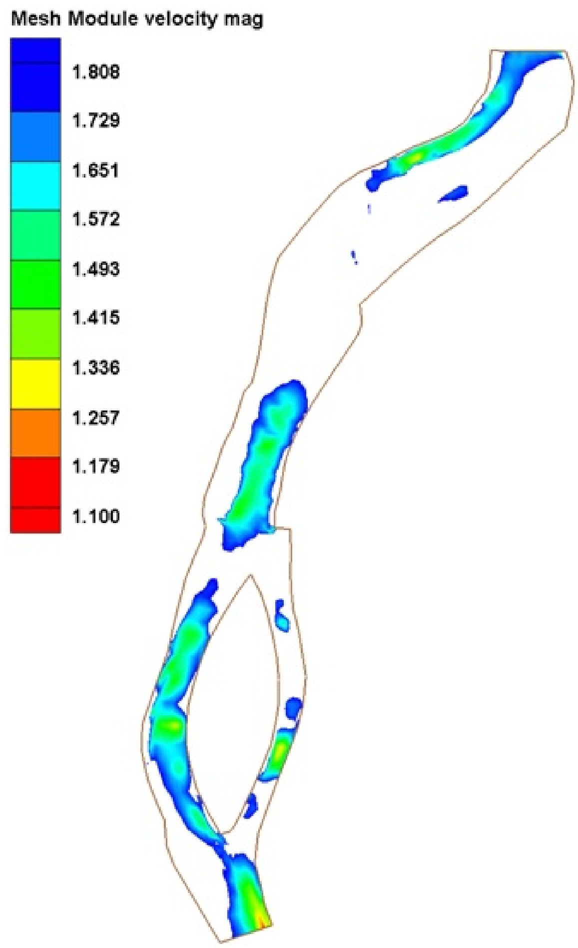

Fig. 19: Erosion Zones with Flood Flow

Table 2: Area and Length of Erosion Zones at Maximum Flow

Case	Maximum Flow Condition					
	South of the Study Reach		Middle of Study Reach		North of Study Reach	
	Area (m^2)	Length (m)	Area (m^2)	Length (m)	Area (m^2)	Length (m)
Current case	471,146	2842	176,223	1347	215,087	1517
Case of removing 25% of the road	471,146	2842	167,282	1334	214,777	1517
Percentage of difference %	100.0%	100.0%	94.9%	99.0%	99.9%	100.0%
Case of removing 50% of the road	471,146	2842	101,393	597	214,658	1510
Percentage of difference %	100.0%	100.0%	57.5%	44.3%	99.8%	99.5%
Case of removing 75% of the road	471,146	2842	87,446	586	214,647	1507
Percentage of difference %	100.0%	100.0%	49.6%	43.5%	99.8%	99.3%

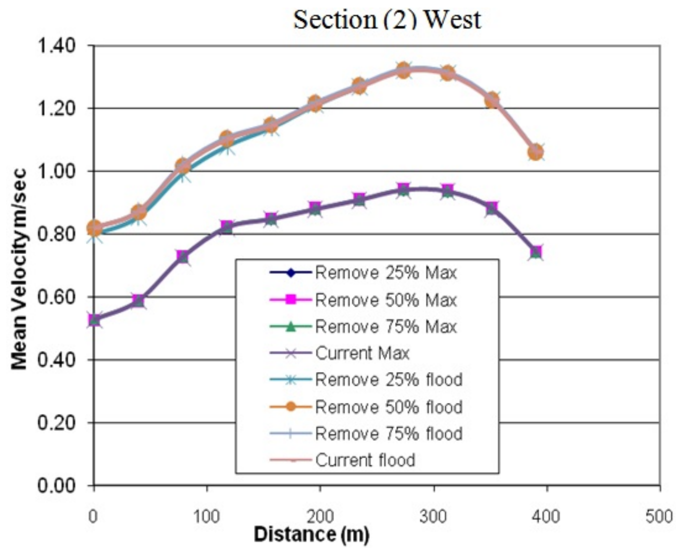

Fig. 20: Velocity Distributions at the Southern Erosion Zone

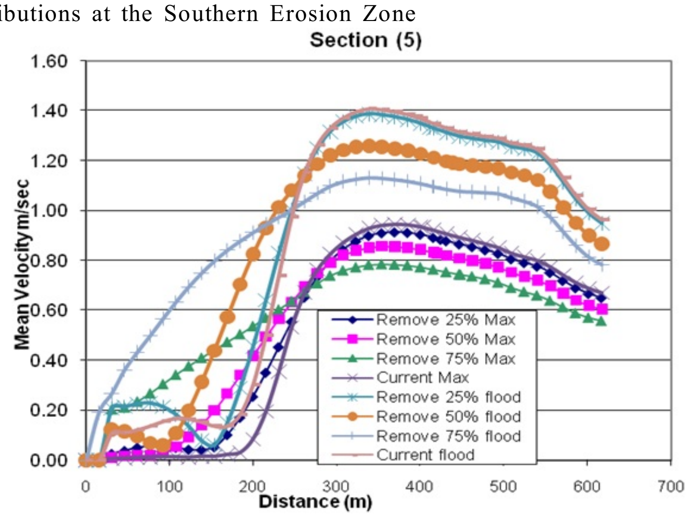

Fig. 21: Velocity Distributions at the Middle Erosion Zone

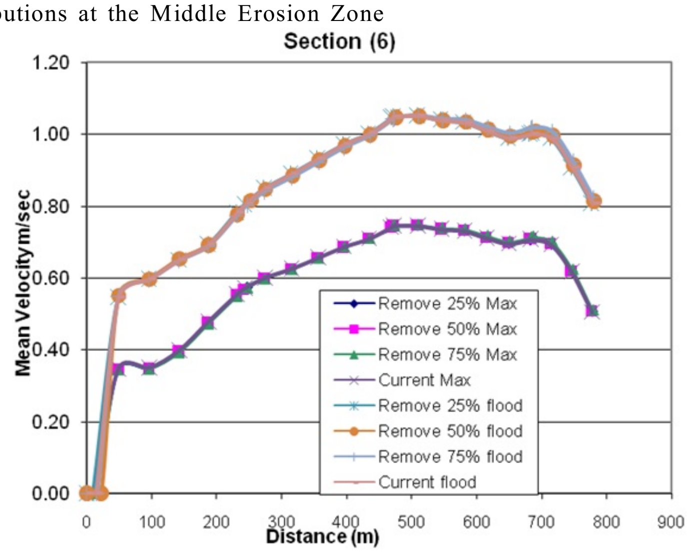

Fig. 22: Velocity Distributions at the Middle Erosion Zone

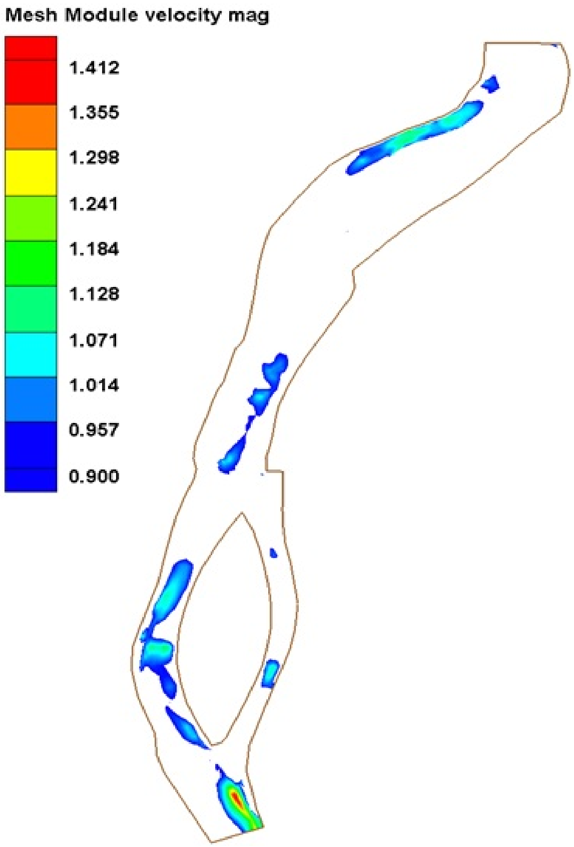

Fig. 23: Erosion zones due to maximum flow when removing 25% of the road

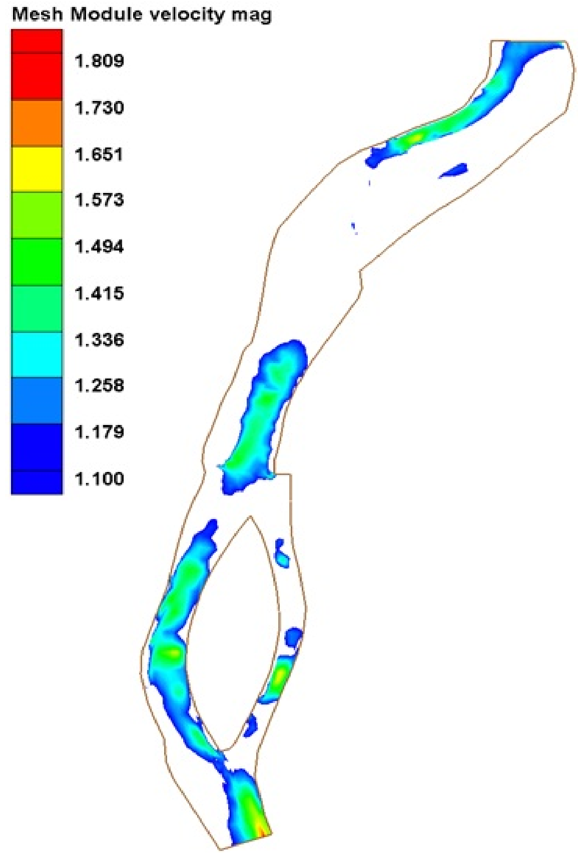

Fig. 24: Erosion zones due to flood flow when removing 25% of the spur dike

Table 3: Area and Length of Erosion Zones at Flood Flow

Case	Flood Flow Condition					
	South of the Study Reach		Middle of Study Reach		North of Study Reach	
	Area (m^2)	Length (m)	Area (m^2)	Length (m)	Area (m^2)	Length (m)
Current case	972,997	3510	692,715	1695	417,619	2118
Case of removing 25% of the road	972,997	3490	646,633	1688	417,509	2020
Percentage of difference %	100.0%	99.4%	93.3%	99.6%	100.0%	95.4%
Case of removing 50% of the road	972,997	3483	632,650	1688	417,439	2013
Percentage of difference %	100.0%	99.2%	91.3%	99.6%	100.0%	95.0%
Case of removing 75% of the road	972,997	3478	464,090	1687	417,339	2006
Percentage of difference %	100.0%	99.1%	67.0%	99.5%	99.9%	94.7%

maximum flow, by 50%. Moreover, it reduced the erosion at flood flow condition by 33%. This was occurred as the removal of parts of the road length reduced the contraction of the river cross section at the middle zone of the study area.

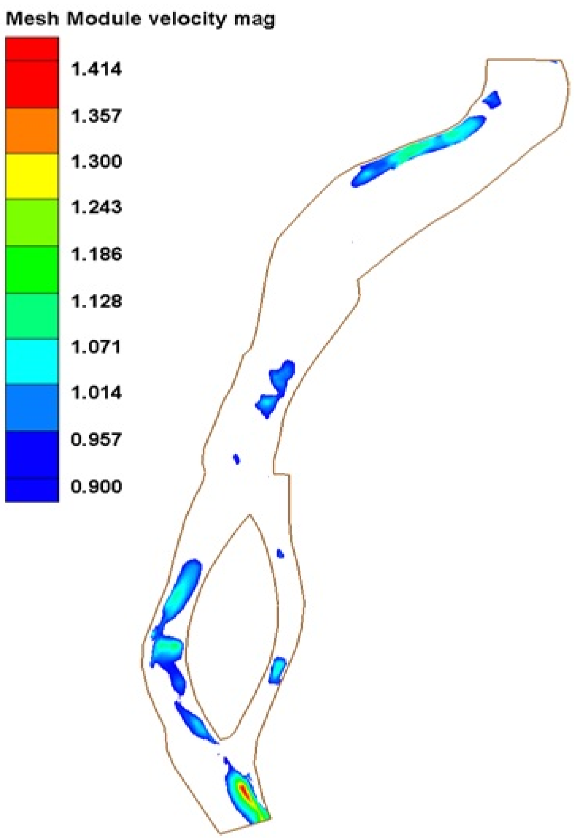

Fig. 25: Erosion zones due to maximum flow when removing 50% of the road

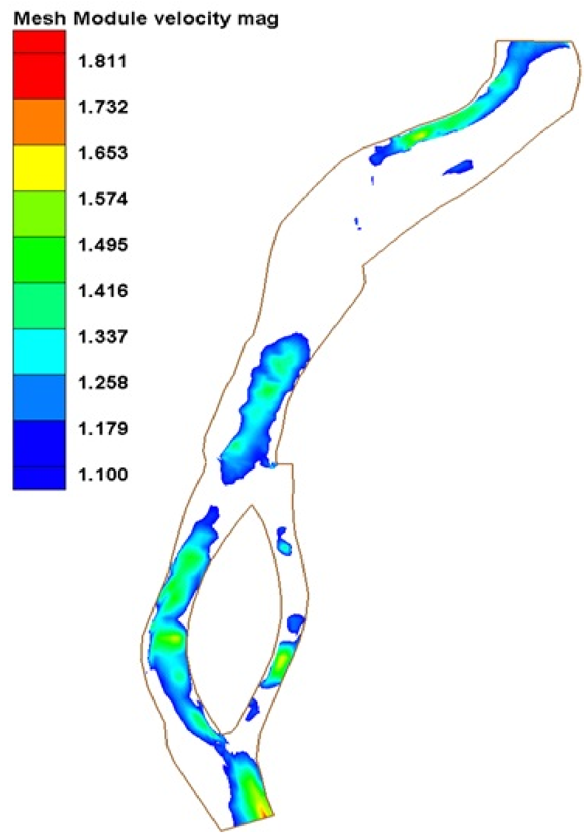

Fig. 26: Erosion zones due to flood flow when removing 50% of the spur dike

Summary and Conclusions: This study investigated the impact of man-made interventions on the River Nile morphology and hydraulic characteristics. The study area was selected where the local people at Elrayramoon (288 km upstream from Cairo) constructed a 440 m road inside the river to serve a ferry boat. The road construction caused several morphological changes to the river bed at the study area. A two dimensional numerical model (SMS) was used to simulate the study area. The model was calibrated to actual field water velocity profiles at different locations along the study area. The model was used to study the effect of different flow discharge scenarios passing through the study area. Maximum flow discharge of 184.30 m.m^3/day, and a flood flow discharge of 350 m.m^3/day were considered passing through the study area. Average mean velocities were estimated along the study area for each of the studied cases. The mean velocities were compared with the incipient velocity to determine the erosion zones. The model was used to investigate three alternatives to reduce the negative impact on the river. The effect of removing 25%, 50% and 75% of the road was tested. Each alternative was studied in both the maximum and the flood flow scenarios. The study concluded the following:

1. The road construction caused erosion concentrated on the East side of the study area downstream from the road. Moreover, remarkable deposition occurred on the West side downstream from the road; in addition, silting zones appeared at the North island and towards the downstream end of the study reach.
2. High velocities were encountered at three locations along the study area as a result of maximum and flood flow passing through the study area. Consequently, three main erosion zones will be initiated. For the maximum flow condition, the southern erosion zone has a length of 2.84 km with an area of 0.47 km^2. While the middle erosion zone, at the road location, has a length of 1.35 km with an area of 0.18 km^2. Meanwhile the north erosion zone, towards the west bank, has a length of 1.52 km with an area of 0.22 km^2.

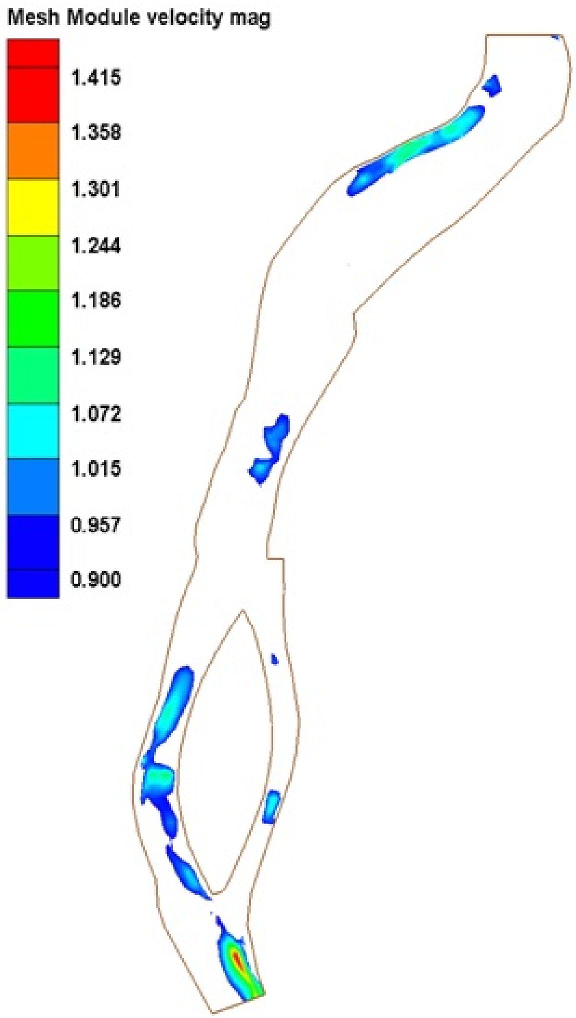

Fig. 27: Erosion zones due to maximum flow when removing 75% of the road

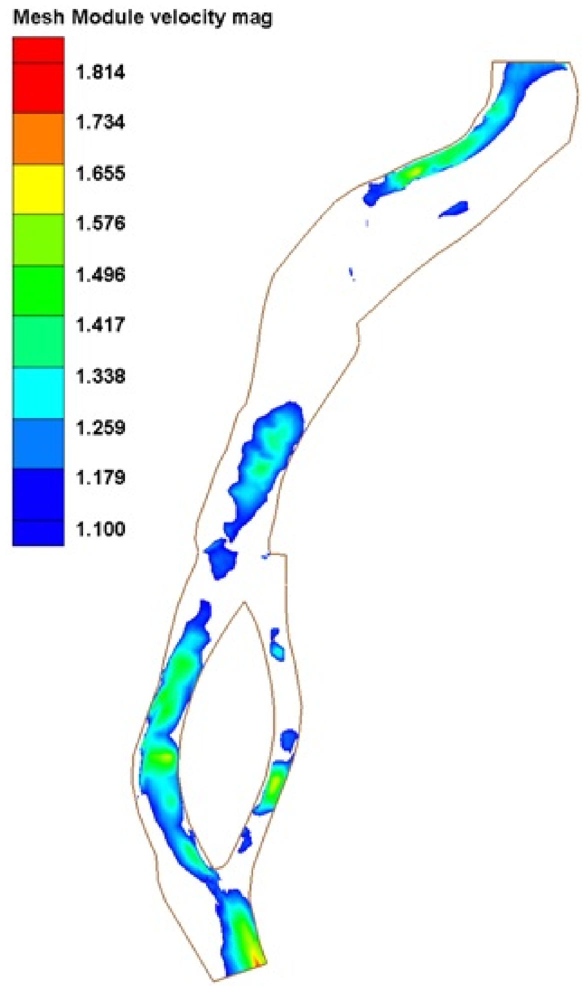

Fig. 28: Erosion zones due to flood flow when removing 75% of the spur dike

3. The erosion zones increased in length and area in case of the flood flow passing through the study area. The erosion, due to flood flow, at the northern and southern zones is twice the erosion in case of maximum flow condition. Meanwhile, the erosion due to the flood at the Middle zone (at the road location) is four times the case of maximum flow condition.
4. It was found that the road length has no effect on the size of both the southern and northern erosion zones.
5. The reduction of the road length reduced the erosion at the Middle zone. This indicates that the effect of the road is only limited for about 1.5 km downstream from the road.
6. The removal of half of the road length reduced the erosion, due to the maximum flow, by 43%. However, it was not significant in case of flood flow condition as the erosion was reduced by 9% only. Meanwhile, the removal of three quarter of the road length reduced the erosion, due to the maximum flow, by 50%. Moreover, it reduced the erosion at flood flow condition by 33%.

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