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NUMERICAL SIMULATION OF FLOOD INUNDATION OF DELTA LANDS IN CASE OF ASWAN HIGH DAM FAILURE*

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ABSTRACT

This study aims to assess the impact of Aswan high dam failure on the inhabited areas downstream of the Delta barrages to the Mediterranean sea or any urban area which may be in the path of the flood surge waves. The study was based on a large amount of available hydraulic data that were analyzed and used as input to the numerical model SOBEK-1D2D. The problem was studied by simulations performed along the Nile branches as (1D) and Delta lands as (2D). Results such as the inundated area of delta lands, flood depth, flow velocity and travel time of flood wave propagations along Damietta and Rosetta branches were obtained to define the time of response for emergency measures. So the size of expected damage of national main structures, within the extension of the study area (Railways, roads, etc) was identified. GIS maps were prepared to evaluate the effects of the dam failure on the inundated area. Suggestions for the emergency procedures are given. The results which could be part of a flood management plan, propose mitigation plans against inundation and warning system. Finally, the important benefit of the study is that future construction projects and must be outside the boundary of expected inundation area.

KEY WORDS: Catastrophic Flooding, Risk Analysis, Inudation Area, Aswan High Dam Failure.

SIMULATION NUMÉRIQUE DE CRUES INONDATION DES TERRES EN RAISON DE DELTA HAUT BARRAGE D'ASSOUAN PANNE

RÉSUMÉ

Cette étude vise à évaluer l'impact d'Assouan échec élevé des barrages sur les zones habitées en aval des barrages Delta vers la mer Méditerranée ou de toute zone urbaine qui peuvent être dans le chemin des ondes de surtension d'inondation. L'étude a été basée sur une grande quantité de données disponibles hydrauliques qui ont été analysés et utilisés comme entrée pour le modèle numérique SOBEK - 1D2D. Le problème a été étudié par des simulations effectuées le long des branches du Nil comme (1D) et des terres du Delta comme (2D). Des résultats tels que la zone inondée des terres du delta , la profondeur d'inondation , la vitesse d'écoulement et le temps de Voyage de propagations d'ondes d'inondation le long de Damiette et de Rosette branches ont été obtenus pour définir le temps de réponse pour les mesures d'urgence . Ainsi, la taille des dommages prévus des structures nationales principales, dans le prolongement de la zone d'étude (chemins de fer, routes, etc.) a été identifié. Cartes SIG ont été préparés pour évaluer les effets de la rupture d'un barrage sur la zone inondée. Suggestions pour les procédures d'urgence sont données. Les résultats qui pourraient faire partie d'un plan de gestion des inondations, proposer des plans d'atténuation des inondations et d'alerte. Enfin, l'avantage important de l'étude est que les futurs projets de construction et doit être en dehors de la zone d'inondation ofexpected limite.

MOTS CLÉS: Inondations Catastrophiques, Analyse Des Risques, Inudation Région, Haut Barrage d'Assouan Echec.

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1. INTRODUCTION

Within Egypt the River Nile is controlled by two dams at Aswan and a series of seven barrages which are among the most important hydraulic structures in the Egyptian water controls system. They regulate the Nile flow discharge and water levels. In addition to the Aswan High Dam, some of these barrages are producing hydropower. The Nile in Egypt consists of two parts, the Nile valley and the Nile delta. The delta barrages Barrage which were constructed in 1939 at Km 953.5 from Aswan Old Dam.

Recent economic activities especially agriculture and industry activities and populations around delta lands have increased the need for risk management and assessment of damage due to dam failure which can lead to enormous loss of life and property. Flood inundation due to dam failure happens occasionally in the world. Such an event may cause serious loss of life, property, environmental damage, and economic repercussions. This study was put on track with the objective of analysis the hydraulic hazards of inundation of delta lands due to the failure of Aswan High Dam. This study aims to assess the impact of such a catastrophic event on the inhabited areas downstream of the delta barrage to the Mediterranean Sea, or any urban area which might be in the path of the flood surge waves.

During the prediction, the following are achieved:

- The inundated area of delta lands in order to determine possible damages;
- The impact of dam failure on other structures along the Nile River is defined;
- Depth and velocity of flood water (allowing estimation of damage potential);
- The travel time of the flood waves propagations along the Damietta and Rosetta branches have to be calculated in order to define the time of response for emergency measures to be operated;
- The expected damage of national main structures, (Railways, roads, etc) within the extension of the study area was identified;
- Peak water level – extent of inundation;
- Time of peak water level;
- GIS maps were prepared to evaluate the effects of dam failure on extending of delineating area which would be inundated.

2. LITERATURE REVIEW

Flood due to failure of dams induces widespread damages to life and property owing to its high magnitude and unpredictable sudden occurrence. Such flood is required to be simulated to determine the inundated area, flood depth and travel time of the flood waves so that adequate safety measurs can be provided. Therefore, it is a useful tool for establishing flood control and developing evacuation plans and warning systems for the areas having potential flood risk.

Mathematical models are considered powerful tools to assess the impact of flood due to dam failure events. These numerical models were developed and improved from 1D models to 2D models, most of these models formulation are based on the Saint-Venant equations applied to gradually varied unsteady flow, as follows:

- Continuity equation

$$\frac{\partial A_t}{\partial t} + \frac{\partial Q}{\partial x} = q_L \text{ ....(1)}$$

- Momentum equation

$$\frac{\partial Q}{\partial t} + \frac{\partial}{\partial x}\left(\alpha_B \frac{Q^2}{A_f}\right) + gA_f \frac{\partial h}{\partial x} + \frac{gQ|Q|}{C^2 R A_f} = 0 \text{ ....(2)}$$

where: A_f = conveying cross-section, A_t = total cross sectional area, C = Chézy coefficient, g = gravitational acceleration, h = water level relative to reference level, q_L = lateral inflow per unit length, Q = discharge, R = hydraulic radius (roughly equal to the water depth), t = time, W_f = width of conveying cross-section at water surface, x = distance along the channel and α_B = Boussinesq coefficient.

These hydraulic models of unsteady flow were employed with combining with other computer applications, i.e. Geographic Information System, (GIS) network, providing new hydraulic simulations and producing more accurate friendly predicted results.

Dhondia et al. [2] illustrated that the SOBEK-Rural was applied to simulate the flood and assess the damage in the Sistan-Baluchistan River Basin in Iran. The main objective of the study was to assess the effectiveness of the flood control measures constructed in this region based on the available data from flood of year 1992. Thus, the Digital Elevation Model (DEM) of the Sistan-Baluchistan River basin area was built using SOBEK-1D2D. The combined 1D-2D modeling, gave the inundation map, and highlighted the possibilities for studying flood control measures, flood forecasting, and development of flood evacuation plans.

The SOBEK-1D2D integration can be illustrated by examining alternative flood scenarios for the Geldersche Valley in the centre of the Netherlands [7]. The model study had the objective of assessing flood damage and establishing evacuation plans for a number of flood scenarios. Model results showed that, the development of a breach during the passage of the 1:1250 year frequency flood peak on the Rhine. EL-Belsay A. [3] studied the inundation for the Nile Delta due to expected high discharges from delta barrages using SOBEK-1D2D in order to determine the flooded areas for several high discharge releases by producing hazard maps for the Nile Delta. Hassan [6] illustrated the analysis of hydraulic hazards of inundation of Delta lands due to Delta barrages failure by simulating the delta barrages failures by SOBEK 1D2D model and estimation the flooding area in the Nile Delta Land under different flow conditions.

Fahmy, et al. [4, 5], assessed the risk of the Aswan High Dam breaching using HR BREACH 1D numerically model to simulate its failure by overtopping or piping. Five breach scenarios were planned and simulated with HR BREACH model. The outflow hydrographs due to Aswan High Dam failure were obtained for five different scenarios with volume of water released 146.28 BCM, 85.47 BCM, 62.25 BCM, 57.02 BCM, and 38.45 BCM respectively. Also, they declared that the previous outflow hydrographs were applied in 1D 2D SOBEK model and the Nile River DS Aswan High Dam till Delta Barrages was simulated. Results of the simulation shows the flood wave propagation in terms of discharges, water levels, and flood arrival time along the water course from Aswan High Dam to Delta Barrage were calculated for the previous five different scenarios. The first propagation wave for the previous five different scenarios was taken about 95, 143, 145, 148 and 178 hr to travel a distance of 953 km downstream of the Aswan High Dam to reach US Delta Barrages, which allowed a certain reaction time for evacuation measures. The water levels US Delta Barrage due to AHD failure were obtained for the previous five different scenarios. Therefore, the resulting Water levels US Delta Barrages for scenario (1) (from the previous five scenarios) were chosen to be simulated by 1D2D model throughout this research in order to represent the worst case.

3. SOBEK-1D2D MODEL

SOBEK-1D2D is an integrated software package which enables the construction of complex models by dynamically integrating 1D components and 2D components of SOBEK Overland Flow (formerly known as Delft-FLS). It can download information from a variety of standard data formats and GIS systems. SOBEK-1D solves the Saint-Venant equations by means of a finite difference scheme [1]. SOBEK-2D uses a rectangular grid and solves the shallow water equations by means of a finite difference scheme; identical to the one used by SOBEK-1D. SOBEK-2D is capable of handling flooding and drying, spatially varying surface roughness and wind friction [8].

3.1 Model Set Up

Generally, the steps taken to simulate surface-water flow using SOBEK-1D2D is as follows: Data assessment, Network design, Model calibration, Model validation and Model application. These five steps are followed during the application of numerical models.

3.2 Model Schematization

The model schematization will be concerned with 3 reaches (The River Nile US Delta Barrage and its branches DS Delta Barrage) to simulate the 1D modeling of the river flow and concerned with 2D overland flow (DEM of Delta Lands).

The River Nile US Delta Barrage and its branches DS Delta Barrage were modeled as follows:

- The modeled River Nile US Delta Barrage has length 11.0 Km according to the study reaches.
- The modeled Damietta Branch DS Delta Barrage has length 245.807 km. It is divided into 3 reaches by Zefta Barrages and Damietta Dam. 1st reach starts from DS Delta Barrage to US Zefta barrage with a length of 94.285 km. 2nd reach starts from DS Zefta barrage to US Damietta Dam with a length of 134.109 km. 3rd starts from DS Damietta Dam to the Mediterranean Sea with a length of 17.413 km.
- The modeled Rosetta Branch DS Delta Barrage has length 229.995 km. It is divided into 2 reaches by Idfina Barrages. 1st reach starts from DS Delta Barrage to US Idfina barrage with a length of 196.198 km. 2rd starts from DS Idfina Barrages to the Mediterranean Sea with a length of 33.797 km.

The Nile Delta which was simulated in 2D model is 54662 km^2

Figure (1) shows the schematization of the Nile US Delta Barrages, the Nile Delta Branches (Damietta, Rosetta, with their nodes, reaches and its main structures) and DEM of the Nile Delta Lands.

3.2.1 Boundary conditions

SOBEK is based on the unsteady flow regime, so it needs to be provided boundary conditions at the upstream flow and outflow boundaries, and lateral discharges. The following conditions are considered:

- US conditions: were applied at the upstream of Delta Barrage by 11 km according to the study reach. The water levels were entered to the model in m with its time in hr, figure (2).
- DS conditions: were assumed to be the water level downstream of Damietta dam and Idfina Barrage that is the water level in Mediterranean Sea.
- Lateral in/outflow were specified for both point discharges (m^3/s) for the main canals and all pumps that directly withdraw off the river, all minor abstraction canals and all drains returning water to the river within the reach under consideration.

Figure (1): Digital elevation model (DE
the Nile Delta

3.2.2 Numerical grid and time step

Numerical grid was considered as the following:

- In 1D: The dimension of the grid cells in all reaches of the Nile River was 200 m. The calculations were executed to the segments, structures and the intermediate nodes to produce the water levels, depths, velocities, discharges and some hydraulic characteristics.

- In 2D: The cell in the 2D has to be connected with only one calculation or one connection node for 1D model. A spatial step of 250 meter provides a good balance between numerical accuracy and computational effort.

Time step and Simulation period were considered as follows:

- Time step: it was chosen one hour.
- Simulation period: it was six months period after failure.

3.3 Model Calibration and Validation

Calibration and validation of the model of Damietta Branch were carried out based on real measurements of inflows, discharges, and water levels. The measurements were taken during year 2010. Differences between measured and computed water levels were ranged from 0.5% to 5%.

4. BASIC ASSUMPTIONS

The following basic assumptions are considered for simulation:

- The US boundary conditions of SOBEK are set as the water levels US Delta Barrages which are calculated for scenario (1) after Fahmy [5], figure (2). The DS boundary conditions are set as the Mediterranean Sea.

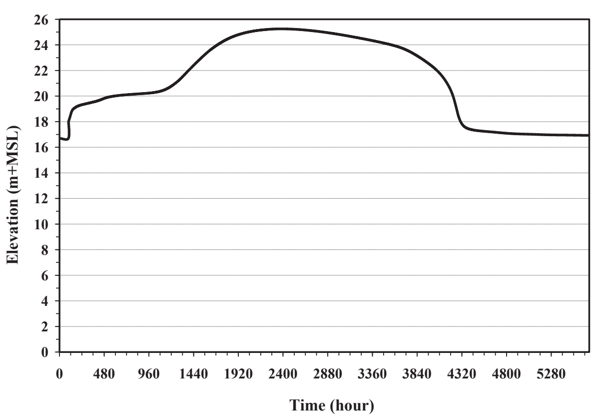

Figure (2): Upstream Delta Barrage water levels, (after Fahmy [5])

- The simulation period is 6 months and the time step is 1 hour.
- Bank failure does not occur due to excessive discharges.
- The debris, present in the barrages fore-bays that could obstruct the vents during the passage of the flood wave, is absent.
- All gates of the main barrages, downstream of the AHD, are opened when the flood wave reaches them. These barrages are sabotaged when the flood discharge reaches 7000 m^3/s.
- The bridges, along the Nile, are sabotaged when the water level reaches their deck.
- Erosion does not take place during the simulations.
- The lateral off-takes, all side canals and Rayahs upstream of the barrages are worked with their maximum capacity during the flood.

5. FLOOD SIMULATION

Flood simulate is used to determine the inundated area, flood depth and travel time of the flood wave so that adequate safety measures can be provided.

The hypothetical failure of the AHD due to this risk causes the highest damages along the Nile Delta Branches, These results are presented in Tables (1) and (2) and can be discussed as follows:

Damietta Branch

The flood wave reaches DS Delta Barrage after 95 hr. The maximum water level DS Delta Barrages 22.16 m was attended after 2389 hr. The water levels increases by 7.77 m in the fore-bay. The maximum flow 5,515.64 m^3/s is reached. A maximum velocity of 1.98 m/s was occurs.

Banha city is the first city touched by the flood wave after 97 hr. The maximum water level 15.40 m is attended after 2444 hr. The water levels increases by 4.64 m in the fore-bay. The maximum flow 3,117.27 m^3/s is reached. A maximum velocity of 1.44 m/s happens.

Kafr Shukr city is the first city touched by the flood wave after 98 hr. The maximum water level 14.09 m is attended after 2455 hr. The water levels increased by 3.94 m in the fore-bay. The maximum flow 2,448.69 m^3/s was reached. A maximum velocity of 4.25 m/s is reached.

The remaining results of the risk analysis at the others structures and cities across

Table (1): Hydraulics characteristics along the Damietta Branch,

Distance from Delta Barrage (Km)	Description	Initial Water Level (m)	Max. Water Level (m)	Time of wave arrival (hour)	Max. Flow (m^3/s)	Max. Velocity (m/s)	Time of Max. Water Level (hour)
0.00	DS Delta Barrage	14.39	22.16	95	5,515.64	1.98	2389
53.92	Banha	10.76	15.40	97	3,117.27	1.44	2444
68.69	Kafr Shukr	10.15	14.09	98	2,448.69	4.28	2455
88.77	Zefta - Mit Ghamr	9.29	11.77	99	3,414.50	1.81	2477
94.29	US Zefta Barrage	9.25	11.27	100	2,866.49	1.48	2494
94.29	DS Zefta Barrage.	4.15	11.00	100	2,866.49	1.48	2500
127.07	Samanoud	3.08	8.40	101	1,933.44	1.53	2686
146.28	El Mansoura - Talkha	2.24	7.13	107	1,594.90	1.08	3000
173.07	Sherbin	1.92	6.39	114	1,318.02	0.67	3175
184.39	El Zarka	1.86	6.26	116	1316.10	0.69	3195
211.82	Farskor – Kafr saad	1.83	6.07	119	925.98	0.46	3226
228.39	US Damietta Dam	1.82	6.03	119	807.21	5.50	3238
228.39	DS Damietta Dam	0.25	5.89	119	807.21	5.50	3242
231.44	Damietta	0.25	5.87	119	799.14	0.72	3243

Damietta Branch are presented in table (1). Figures (4) and (5) present the comparison between the hydrographs (flow) at different sites (structures & cities) across Damietta Branch. Also figures (6) and (7) present the comparison between water levels at different sites (structures & cities) across Damietta Branch.

- **Generally, after the AHD failure**

The first propagating wave takes about 119 hr to reach US Damietta Dam while under the normal flow conditions; the time of water movement from AHD to the Damietta Dam takes about 336 hr, Figure (8).

The wave travels downstream Damietta Branch with a velocity ranges between o.24 and 7.89 m/s, according to its natural bed slopes, and the Nile cross-section width. Figures (9) and (10) show the maximum velocity and the maximum flow along the Damietta Branch

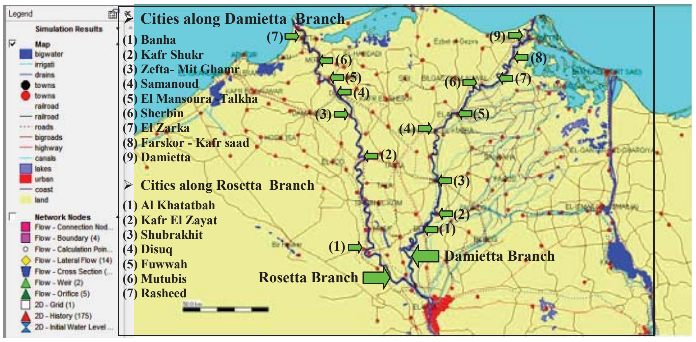

Figure (3): Cities along River Nile Branches Damietta and Rosetta

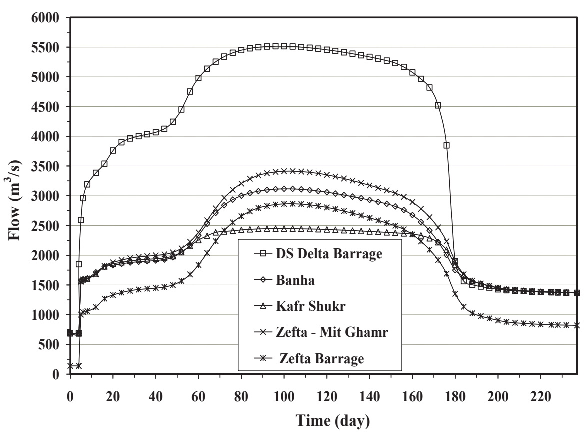

Figure (4): Hydrographs at different sites across 1st reach of Damietta Branch

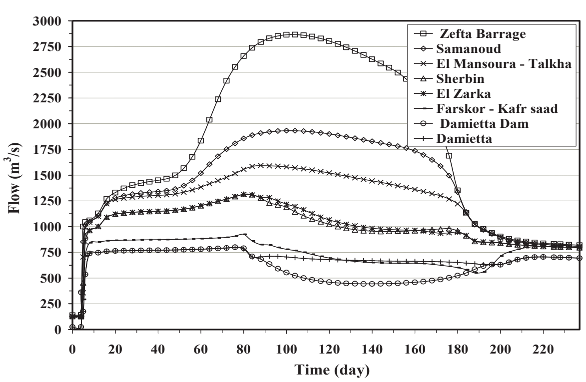

Figure (5): Hydrographs at different sites cross 2nd and 3rd reaches of Damietta Branch

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- **Rosetta Branch**

The flood wave reaches DS Delta Barrage after 95 hr. The maximum water level DS Delta Barrage 22.25 m is attended after 2390 hr. The water levels increased by 8.81 m in the fore-bay. The maximum flow 6960.86 m^3/s is reached. A maximum velocity of 2.58 m/s is reached. The flood wave reaches Al Khatatbah city after 98 hr. The maximum water level 16.42 m is

attended after 2439 hr. The water levels increased by 8.80 m in the fore-bay. The maximum discharge 3121.32 m^3/s is reached. A maximum velocity 0f 1.32 m/s is reached.

Kafr El Zayat city was the first city touched by the flood wave after 108 hr. The maximum water level 9.18 m is attended after 2657 hr. The water levels increases by 5.75 m. The maximum flow 4203.45 m^3/s is reached. A maximum velocity 0f 0.66 m/s is expected.

The results of the risk analysis at the others structures and cities across Rosetta Branch were presented in table (2). Figure (11) presented the comparison between the hydrographs (flow) at

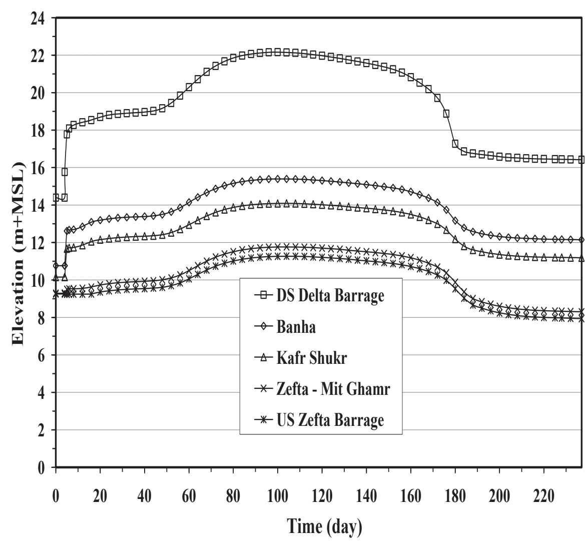

Figure (6): Water levels at different sites along 1st .reach of Damietta Branch

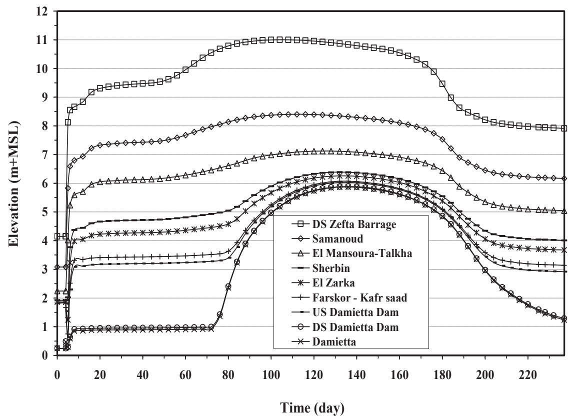

Figure (7): Water levels at different sites along 2nd and 3rd reaches of Damietta Branch

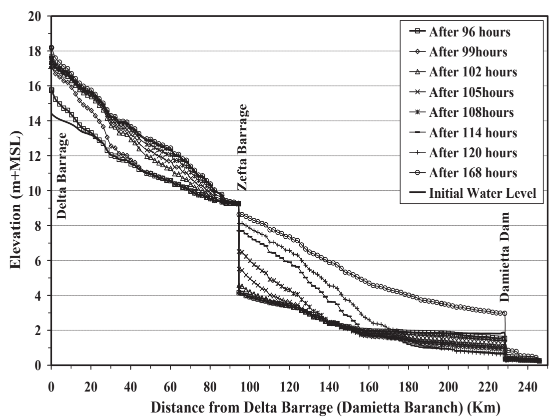

Figure (8): Longitudinal profile of flood wave propagation along

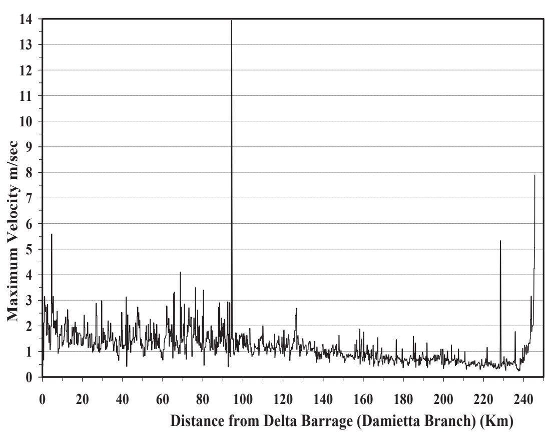

Figure (9): Max. velocity along Damietta Branch

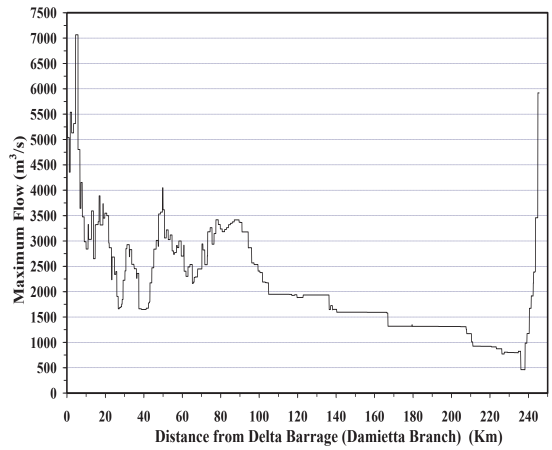

Figure (10): Max. flow along Damietta Branch

different sites (structures & cities) across Rosetta Branch. Also figure (12) presentS the comparison between water levels at different sites (structures & cities) across Rosetta Branch

The wave travels downstream Damietta Branch with a velocity ranges between o.24 and 7.89 m/s, according to its natural bed slopes, and the Nile cross-section width. Figures (9) and (10) show the maximum velocity and the maximum flow along the Damietta Branch.

- **Generally, after the AHD failure**

The first propagating wave takes about 116 hr to reach US Idfina Barrage while under the normal flow conditions; the time of travel from AHD to the Idfina Barrage takes about 336 hr, Figure (13).

The wave travels down Rosetta Branch with a velocity ranged between o.30 and 6.59 m/s according to its natural bed slopes, and the Nile cross-section width. Figure (14), (15) show the maximum velocity and maximum flow along Rosetta Branch respectively.

The wave travels down the first reach between Delta Barrage and Idfina Barrage with a velocity ranged between o.38 and 4.63 m/s. The wave travels down the second reach between Idfina Barrage and the Mediterranean Sea with a velocity ranged between o.30 and 6.59 m/s.

Table (2): Hydraulics characteristics along Rosetta Branch

Distance from Delta Barrage (Km)	Description	Initial Water Level (m)	Max. Water Level (m)	Time of wave arrival (hour)	Max. Flow (m^3/s)	Max. Velocity (m/s)	Time of Max. Water Level (hour)
0.00	DS Delta Barrage	13.44	22.25	95	6960.86	2.58	2390
45.03	Al Khatatbah	7.62	16.42	98	3121.32	1.32	2439
115.04	Kafr El Zayat	3.43	9.18	108	4203.45	0.66	2657
150.00	Shubrakhit	3.12	6.94	112	3407.00	0.94	3071
166.48	Disuq	2.99	6.31	114	2936.44	1.06	3160
177.97	Fuwwah	2.91	6.05	115	2696.10	1.30	3199
194.70	Mutubis	2.88	5.81	116	2542.95	1.13	3221
196.20	US Idfina Barrage	2.88	5.79	116	2542.86	1.18	3222
196.20	DS Idfina Barrage	0.30	5.74	116	2542.86	1.04	3225
215.59	Rasheed	0.27	5.39	117	3243.51	0.97	3236

5.1 Bank Overtopping and Violation Sites

If the flooding continues for 6 months until the water level profile gets down. The banks are overtopped at most of the sites along the Nile Delta Branches. Figure (16), presents the maximum water profile along Damietta Branch. Figure (17), shows the maximum water profile along Rosetta Branch.

5.2 Inundated Areas and Maps (GIS database)

The total gross flooded area resulted from this study is about 21833.18 Km^2, table (3).
Figures (18) and (19) show the GIS maps of inundated areas, and the inundated depth.

5.3 Means of Transportations

Emergency plan evacuates the affected areas (i.e. roads, and railways that subjected to inundation).

Roads: 107 roads with total length 2749.357 Km will be inundated and its inundated length are 2230.657 km.
Railways: 45 railways with total length 2204.049 Km will be inundated and its inundated length are 1555.153 km.

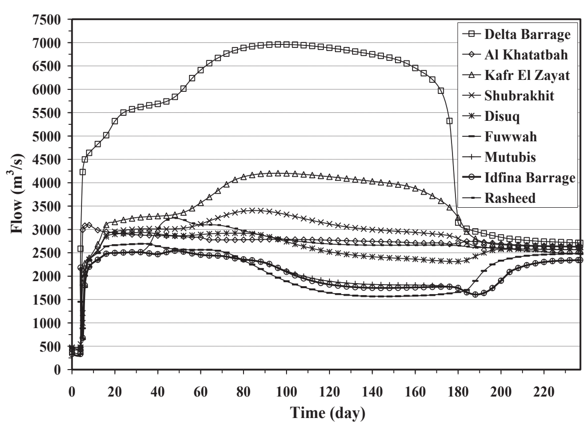

Figure (11): Hydrographs at different sites across Rosetta Branch

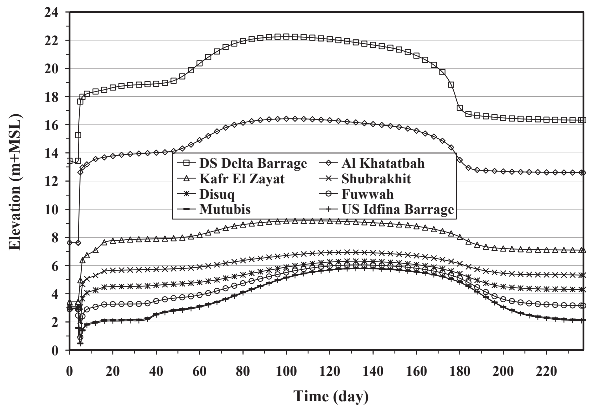

Figure (12): Water levels at different sites along Rosetta Branch

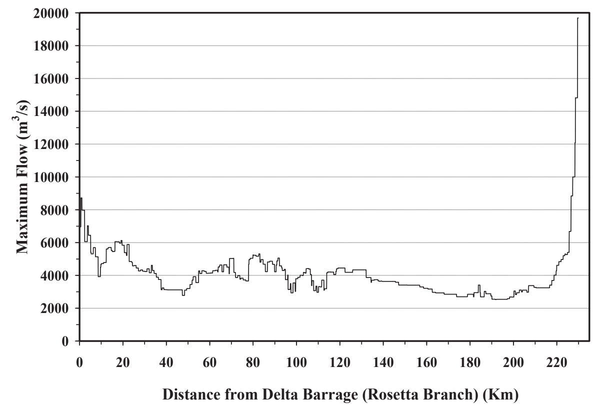

Figure (15): Max. Flow along Rosetta Branch

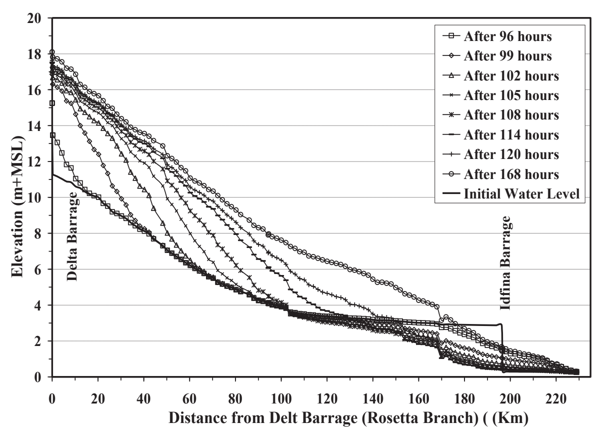

Figure (13): Longitudinal profile of flood wave propagation along Rosetta Branch

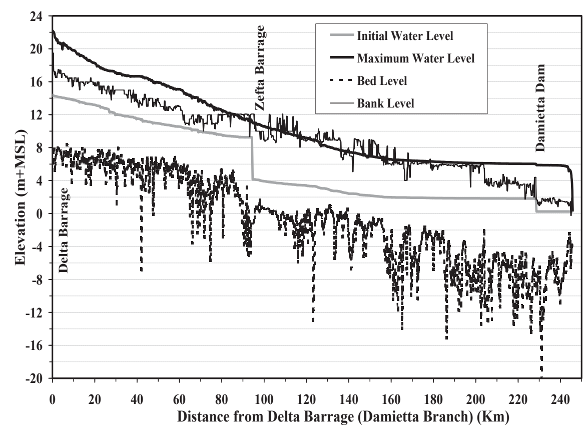

Figure (16): Peak water profile on Damietta Branch

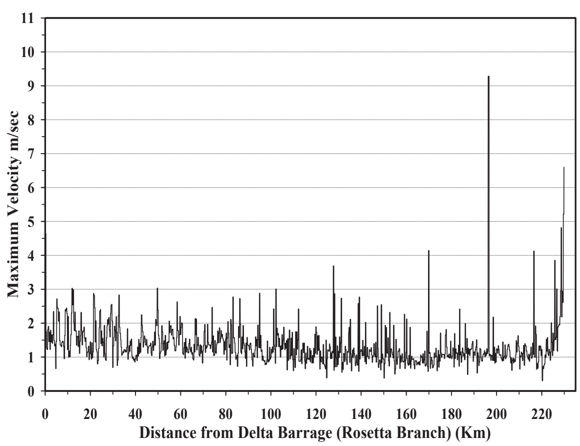

Figure (14): Max. Velocity along Rosetta Branch

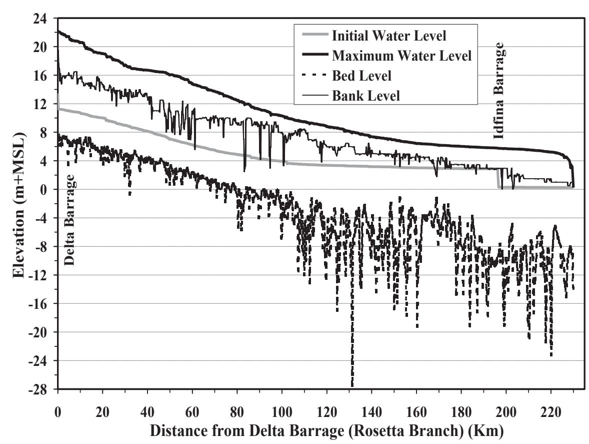

Figure (17): Peak water profile on Rosetta Branch

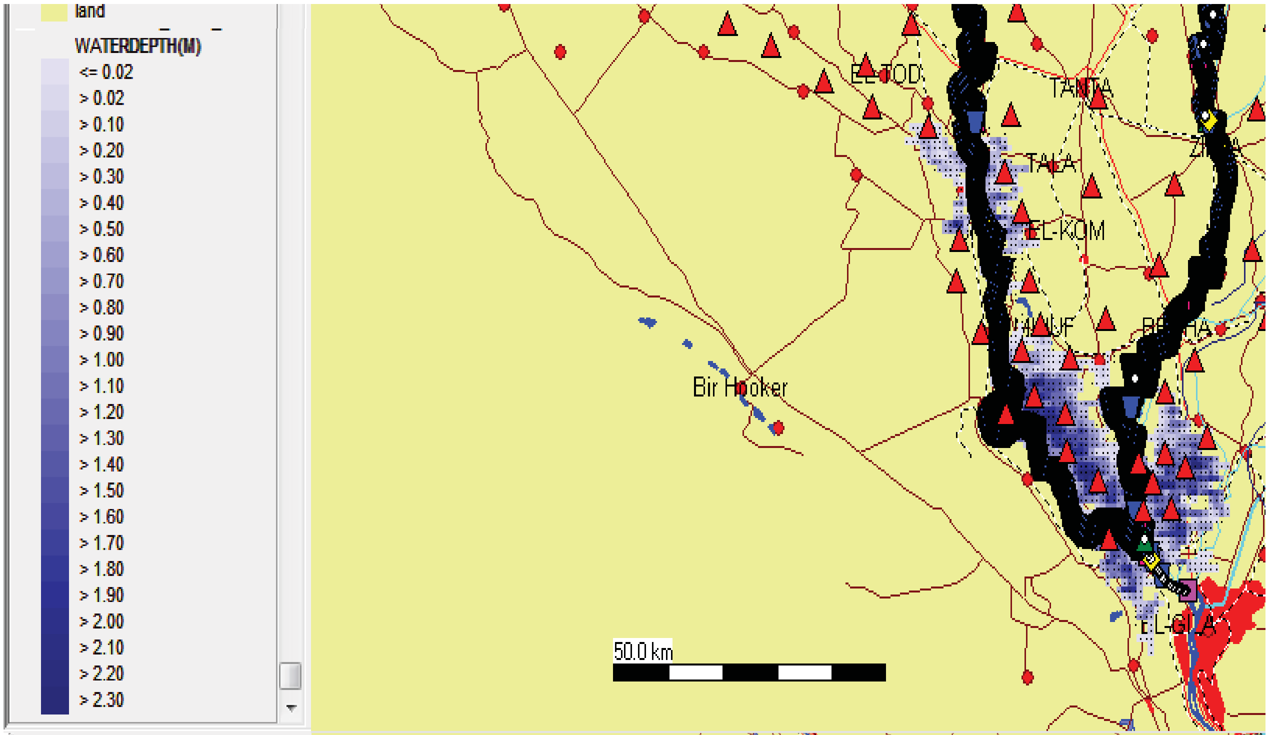

Figure (18): GIS map of inundated areas of Delta Lands after 1 week due to AHD failure

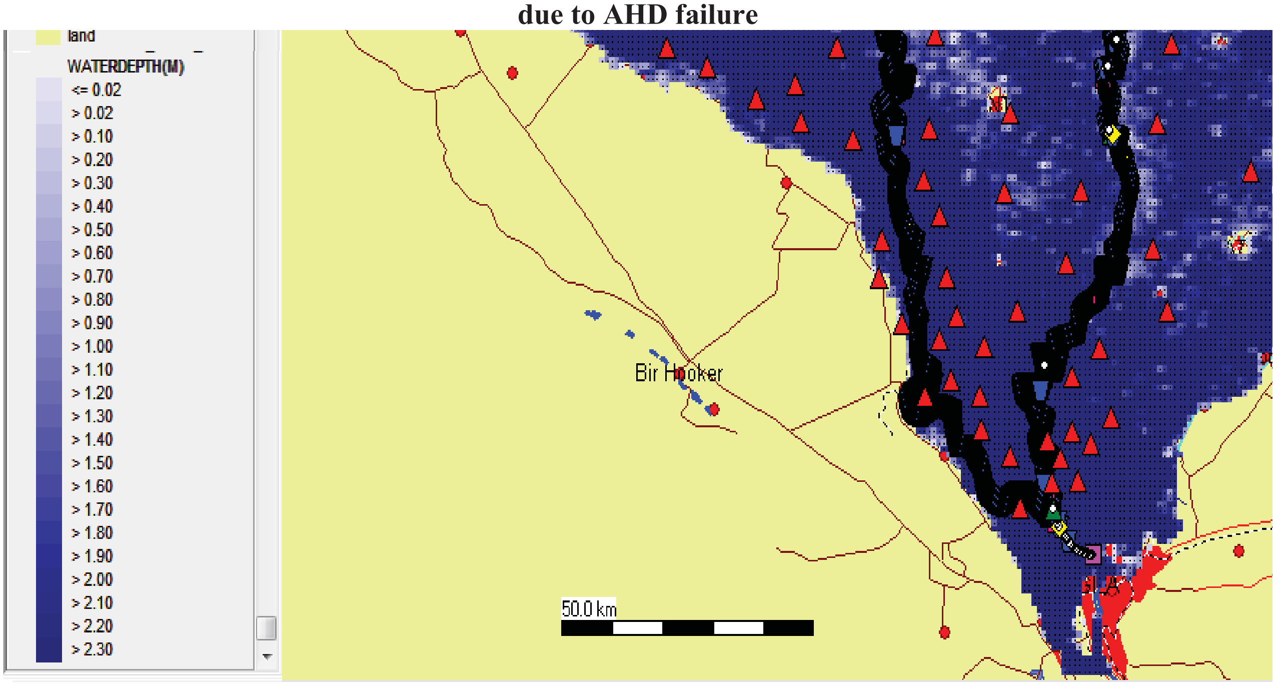

Figure (19): GIS map of inundated areas of Delta Lands after 4 months due to AHD failure

Table (3): Inundation areas

Governorate	Total Area (Km^2)	Inundated Area (Km^2)	Inundated percentage (%)
El Menoufia	2157.91	1559.33	72.26
El Qalyubia	1166.89	974.89	83.55
El Gharbia	1984.10	1830.80	92.27
Damietta	860.30	712.19	82.78
El Beheira	11471.30	3972.15	34.63
Prot Said	1339.12	1311.81	97.96
Alexandria	2558.53	395.78	15.47
El Sharqia	4825.37	3332.70	69.07
El Ismailia	6196.34	794.84	12.83
El Suez	9439.33	76.49	0.81
El Dakahlia	3891.00	3404.05	87.49
Kafr El Sheikh	3750.79	3468.15	92.46
Total	49640.98	21833.18	43.98

6. CONCLUTIONS AND RECOMMENDATIONS

6.1 Conclusions

The following was concluded:

1. Based on the results of simulations the following conclusions could be drawn:

a. Damietta Branch

The first propagating wave takes about 95 hr.

to reach DS Delta Barrage and 119 hr to reach US Damietta Dam, which allows a certain reaction time for evacuation plans.

- the maximum peak outflow of Delta Barrage (Damietta Branch) is 5,515.64 m^3/s
- The wave travels downstream with a velocity ranges between o.24 and 7.89 m/s.
- The water levels increase by 7.77 - 2.02 m in the first reach, 6.85 – 4.21 m in the second reach and 5.64 m in the third reach.

b. Rosetta Branch

- The first propagating wave takes about 116 hr to reach US Idfina Barrage.
- The maximum peak outflow of Delta Barrage (Rosetta Branch) is 6960.86 m^3/s.
- The wave travels downstream with a velocity ranges between o.30 and 6.59 m/s.
- The water levels increased by 8.81 - 2.91 m in the first reach, 5.44 m in the second reach.

2. The total gross flooded area resulted for this study is about 21833.18 km^2.

6.2 Recommendations

The following considerations could be recommended for future studies:

- Each hydraulic structure on the Nile River should have its own emergency action plan tailored to the site specific condition, and an alarming system should be established along the main river system connecting all structures along the Nile and its two branches, computerized in a central unit similarly to Telemetry system.
- Preparing an emergency action plan with local authorities to organize evacuation plans in case of emergency.
- Study of the protection and raising of the Nile banks.
- Study of the need of increasing the capacity of Toshka Spillway.
- Planning of the future construction projects and new cities could be outside the boundary of inundation area.

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NOTATION AND ABBREVIATIONS

Notation

A_f	: conveying cross-section	$[L^2]$
A_t	: total cross-sectional area	$[L^2]$
C	: Chézy coefficient	[-]
g	: gravitational acceleration	$[LT^{-2}]$
h	: water level relative to reference level	[L]
q_L	: lateral inflow per unit length	$[L^2T^{-1}]$
Q	: discharge	$[L^3T^{-1}]$
R	: hydraulic radius (roughly equal to the water depth)	[L]
t	: time	[T]
W_f	: width of conveying cross-section at water surface	[L]
x	: distance along the channel	[L]
α_B	: Boussinesq coefficient	[-]

Abbreviations

AHD : Aswan High Dam,

AOD : Aswan Old Dam,

BCM : Billion Cubic Meters,

DEM : Digital Elevation Model,

GIS : Geographic Information System,

MCM : Million Cubic Meters,

MSL : Mean Sea Level,