Effect of Main Barrages Failure on the Nile Valley

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Abstract

Flood can be considered as the most severe event that may occur at any country. For this reason, the world most countries began to put general plans to assess the risk of failure of Dams and Barrages located along their rivers to evaluate the inundation areas resulting from failure to protect the infrastructure, human lives, roads, railways, cultivated lands and private properties. Therefore, the present research aimed to study the impact of main barrages failure located along the Nile River (New Esna Barrages, New Naga-Hammadi Barrages and Assiut Barrages) through number of scenarios at different flow conditions. For this purpose, the combined SOBEK 1D-2D software package was employed to simulate the failure of each Barrages individually.
Twelve scenarios were tested to simulate the failure of each of Nile River main barrages. The modeled scenarios studied the failure of each Barrage individually at different flow conditions (maximum passed flow discharge in the Nile River during twelve years starting from 1997 to 2007 as well as the emergency flow discharges). The attainable results showed the change in flow discharges and velocities, bank overtopping, flood wave propagation and the expected flooded areas resulting from the failure. The concluded results can help decision makers to asses the risk of flooding and helps to produce evacuation plans and alarming systems at each barrage site as tools to manage the expected risks.

Keywords*:* Flood, Barrages, Dam failure, Inundation, Numerical model, SOBEK 1D-2D

1. INTRODUCTION

Barrages play an important role in the life and economy of any country by providing essential benefits like irrigation, hydropower, flood control, drinking water, recreation, etc. However, when unforeseen failure happens in rare conditions, catastrophic flooding in the downstream area may occur resulting in huge loss to human life and properties. This loss of life and properties would vary with the extent of inundation area, size of population at risk, and the amount of warning time available. However, the effect of such flood disaster can be mitigated to a great extent if the resultant magnitude of flood peak and its time of arrival at different locations downstream of the dam (barrages) can be estimated, to facilitate planning such suitable emergency measures.

Many studies were achieved to predict the expected inundation due to dams or barrages failure using mathematical models. Dhondia et al. [3] illustrated that the SOBEK-Rural can be applied to simulate floods and assess the anticipated 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 which were constructed in this region based on the available flood data of year 1992. Therefore, the Digital Elevation Model (DEM) of the Sistan - Baluchistan River basin area was built using the combined SOBEK 1D-2D software package, which gave the inundation map, and highlighted the possibilities for study flood control measures, flood forecasting, and development of flood evacuation plans.

The combined SOBEK-1D2D integration was also employed to examine alternative flood scenarios for Geldersche Valley in the centre of the Netherlands [2]. The model study aimed at assessing flood damage and establishing evacuation plans for number of flood scenarios. Model results showed the expected breach development during passage of 1:1250 year frequency flood peak in the Rhine. Moreover, the anticipated inundation in Nile Delta due to high discharges through delta barrages was studied by EL-Belasy A. [3]. The combined SOBEK 1D-2D software package was utilized in this study to determine the flooded areas for several high discharge releases by producing hazard maps for the Nile Delta. Also estimation of the flooding area in the Nile Delta land under different flow conditions due to Delta barrages failure were carried out using SOBEK 1D2D model by Hassan [6].

Furthermore, Fahmy, et al. [5, 6, 7], assessed the risk of the Aswan High Dam breaching using HR BREACH 1D numerical model to simulate its failure by overtopping or piping. Five breach scenarios were planned and simulated. The outflow hydrographs due to Aswan High Dam failure were deduced for five different scenarios with released water volume of 146.28, 85.47, 62.25, 57.02 and 38.45 milliard m^3 respectively. The adopted outflow hydrographs for the Nile River downstream Aswan High Dam till Delta Barrages was simulated in the combined SOBEK 1D-2D software package. The attainable results - for each of the five mentioned scenarios - showed the flood wave propagation in terms of discharges, water levels, and flood arrival time along the water course from Aswan High Dam till Delta Barrages. The study revealed that the first propagation wave lasted for about 95, 143, 145, 148 and 178 hr for the five applied scenarios respectively to travel 960 km distance downstream of Aswan High Dam to reach upstream Delta Barrages which allowed for a certain waiting time for evacuation measures. The water levels upstream of Delta Barrages due to Aswan High Dam failure were obtained for the applied five scenarios. Therefore, in order to represent the worst case, the resulting water levels upstream of Delta Barrages for scenario number (1) were chosen to be simulated by the combined SOBEK 1D-2D software package throughout the present research.

In order to assess the located encroachment areas between Assiut and Delta Barrages, the HEC – RAS 1-D model was employed to simulate the impact of high flow releases of 200, 220, 250, 270, 300 and 350 million m^3/d downstream of Aswan High Dam respectively. HEC-RAS 1-D model was developed by U.S. Army Corps of Engineering, in 1998 and published a number of technical methods documents addressing the full range of hydrologic engineering and planning analysis technologies. For this reason, the model was used to calculate the water surface profile related to each of the mentioned six flow releases. The impact on different types of infra structures within the assigned area was analyzed and evaluated which revealed the inundation of a number of houses and pump stations due to the simulated releases. Moreover, management lines were introduced as a rehabilitation measure to classify and arrange the land use around and between theses lines Attia, K. and Sadek, N [1].

2. MODEL CONSTRUCTION

The Nile River was represented in the combined SOBEK 1D-2D software package with the most recent bathymetric and topographic surveyed data that was carried out by Hydraulic Research Institute (HRI) for the hydraulic structures. The latest corresponding information for cross sections, lateral off-takes, water levels and discharges were also deduced which covers the Nile River for 960 km started from the downstream of High Aswan Dam till upstream of Delta Barrages. For simulation of the 2D model the entire length of the Nile River valley was simulated through a grid with vertical and horizontal grid lines of 200 m apart. The simulated area was divided into mesh 1069 x 1333 cells each of 400 m^2 (200 x 200). Table (1) shows the main structures characteristics that represented in the model while Table (2) lists lateral off-takes along the Nile River represented in the model. Table (3) presents initial discharges and water levels at main barrages. Table (4) presents the declared emergency flow discharges and flood duration by the Ministry of Water Resources and Irrigation.

Table 1: Main Simulated Hydraulic Structures in the Model

Hydraulic Structure	Distance D.S. Aswan Dam (km)	Gate opening (m)	No. of vents	Vent Width (m)	Gate Height (m)	Crest level (m)
Old Aswan Dam	**0.00**	**10**	**65**	**6.0**	**7.0**	**92**
New Esna Brg.	**167.700**	**4.29**	**11**	**12.0**	**12.90**	**67**
New Naga Hammadi Brg.	**352.750**	**4.312**	**7**	**17.0**	**14.90**	**52.80**
Assiut Brg.	**544.800**	**0.833**	**110**	**5.0**	**7.0**	**44.75**

Table 2: Lateral Off-takes along the Nile River

No.	Off- take	Location	Distance D.S. of OAD (km)	Maximum Discharge	
				(M.m^3/day)	(m^3/s)
1	Kalabia canal	U.S Esna Barrages	170.090	5.2	60.19
2	Asfoun canal	U.S Esna Barrages	170.340	4.74	54.86
3	Naga Hammadi -West	U.S Naga Hammadi Brg.	358.974	3.91	45.25
4	Naga Hammadi -East	U. S Naga Hammadi Brg.	358.934	12.02	139.12
5	Ebrahimia canal	U.S Assuit Barrages	544.400	41.8	483.80
6	Al Sharkawia canal	U.S Delta Barrages	951.500	3.3	38.19
7	El Bassossia canal	U.S Delta Barrages	951.570	1.4	16.20
8	El-Rayah El Tawfiky	U.S Delta Barrages	952.75	18.65	215.86
0	El-Rayiah El Menoufy	U.S Delta Barrages	952.679	25	289.35
10	El Rayiah El Nassery	U.S Delta Barrages	952.000	11.5	133.10
11	El-Rayiah El Beheiry	U.S Delta Barrages	952.000	27.5	318.29

Table 3: Initial Discharges and Water Levels at Main Barrages

No.	Hydraulic Structure	Water level (m)+MSL		Q_{max}	
		U.S	D.S	(Mm^3/d)	(m^3/s)
1	High Aswan Dam	(122.00)	(86.74)	275.00	3182.87
2	New Esna Brg.	(79.44)	(75.70)	244.12	2825.46
3	New Naga Hammadi Brg.	(65.90)	(62.10)	228.40	2643.52
4	Assiut Brg.	(50.80)	(47.56)	184.71	2137.85
5	Delta Brg.	(16.74)	-	-	-

Table 4: Emergency Discharges

Step No.	Flood Duration (months)	Discharge	
		(M.m^3/day)	(m^3/s)
1	3	275	3182.87
2	3	300	3472.22
3	3	350	4050.93
4	3	400	4629.63

3. MODEL CALIBRATION AND VALIDATION

The model was calibrated utilizing the most recent measured data of water levels and discharges along the Nile River which were carried out by HRI in January 2010, Fahmy S .A. [5, 6, 7]. Table (5) shows hydraulic roughness Coefficient (Manning-n) determined by model calibration. Validation adjustments were related to the data of flood season of years 1998/1999 which revealed good agreements between measured and computed water level data.

Table 5: Hydraulic Roughness Coefficient Determined by the Model

Reach	Reach	Estimated Manning Coefficient (n)
R1	Aswan – Esna	0.029
R2	Esna –Naga Hammadi	0.027
R3	Naga Hammadi –Assiut	0.024
R4	Assiut –Delta Barrages	0.028

4. MODELED SCENARIOS

As the calibration and validation test were successfully carried out, different scenarios have been examined at different flow conditions to simulate the failure of main barrages along the Nile River. Failure scenarios were classified into two different groups; the first one corresponds to the maximum recent passed flow through the Nile River during the last twelve years. While the second one corresponds to the emergency flow discharges that declared by the Ministry of Water Resources and Irrigation.

4.1 Main Scenarios Assumptions

Some assumptions were taken into consideration during the present study which can be as follows:
1- Bank failure doesn't occur due to excessive discharges.
2- The debris that exists in the barrages fore bays that could obstruct the vent during the passage of flood wave is not exist.
3- All bridges along the Nile River are sabotaged when the water level reaches their dick.
4- Erosion doesn't take place during simulation.
5- The passing discharges through lateral off takes, all side canals and rayahs upstream the barrages are equivalent to their maximum capacity during all scenarios

4.2 Failure scenarios

Twelve failure scenarios were tested to simulate the failure of each individual barrages as illustrated in Table (6). Study failure of New Esna Barrages was simulated in the model by scenario groups S1, S2, S3 and S4. Study failure of New Naga Hammadi Barrages was simulated by scenario groups S5, S6, S7 and S8. Study failure of Assiut Barrages was simulated by scenario groups S9, S10, S11 and S12. Each scenario simulates the failure of each barrages at different flow conditions. The simulated flow discharges ranged from 275 to 400 million m^3/d. The results of each modelled scenario give a brief view of the Nile valley at failure. Comparison between each of bank and water surface levels, the change in flow discharges and velocities, estimated flood wave time and the total flooded areas at each failure scenario.were accomplished by the combined SOBEK 1D-2D software package.

Table 6: Detailed Data of Different Modeled Scenarios

Scenario	Hydraulic flow conditions	Initial Condition	Failure case	U.S control boundary	D.S control boundary
S1	Max. recent flow	Max. water levels and discharges	New Esna Barrages	275 Mm^3/d	Max. U.S W.L at Delta barrages
S2	Emergency flow discharges	Max. water levels and discharges	New Esna Barrages	300 Mm^3/d	Max. U.S W.L at Delta barrages
S3	Emergency flow discharges	Max. water levels and discharges	New Esna Barrages	350 Mm^3/d	Max U.S W.L at Delta barrages
S4	Emergency flow discharges	Max. water levels and max discharges	New Esna Barrages	400 Mm^3/d	Max. U.S W.L at Delta barrages
S5	Max. recent flow	Max. water levels and discharges	New Nagaa Hammadi Barrages	275 Mm^3/d	Max. U.S W.L at Delta barrages
S6	Emergency flow discharges	Max. water levels and discharges	New Nagaa Hammadi Barrages	300 Mm^3/d	Max. U.S W.L at Delta barrages
S7	Emergency flow discharges	Max. water levels and discharges	New Nagaa Hammadi Barrages	350 Mm^3/d	Max. U.S W.L at Delta barrage
S8	Emergency flow discharges	Max. water levels and discharges	New Nagaa Hammadi Barrages	400 Mm^3/d	Max. U.S W.L at Delta barrages
S9	Max. recent flow	Max. water levels and discharges	Assiut Barrages	275Mm^3/d	Max. U.S W.L at Delta barrages
S10	Emergency flow discharges	Max. water levels and discharges	Assiut Barrages	300 Mm^3/d	Max. U.S W.L at Delta barrages
S11	Emergency flow discharges	Max. water levels and discharges	Assiut Barrages	350 Mm^3/d	Max. U.S W.L at Delta barrages
S12	Emergency flow discharges	Max. water levels and discharges	Assiut Barrages	400 Mm^3/d	Max. U.S W.L at Delta barrages

5. RESULTS AND DISCUSSION

The attainable results from the study would be provided in this section in view point of the following hydraulic parameters:

- Locations and lengths of the overtopped bank along the Nile River
- Changes in passing flow discharges.
- Changes in main downstream flow velocity
- Flood wave propagation
- Total flooded areas

The applied scenarios were studied when each of the selected four discharges was steadily flowing upstream the concerned hydraulic structure for each individual passed discharge. This in other words means that the flow condition at each studied hydraulic structure would be independently presented according to the provided flow feature. Moreover, the studied scenarios for the failure of each hydraulic structure was simulated in model according to emergency flow discharges and flow duration that declared by the Ministry of Water Resources and Irrigation as listed in Table (4). Therefore, the presented failure of each hydraulic structure would not be due to flowing discharges and hydraulic conditions but owned to other outer circumstances (such as structural failure, terrorist attack,).

The above mentioned hydraulic parameters would be illustrated for each of the studied barrages and flow discharge cases as follows:

5.1 Bank Overtopping

The allocated bank overtopping lengths along the four Nile River reaches were estimated as 111.560 km which are allocated along 4.00, 38.13, 17.33 and 52.10 Km of reaches R1, R2, R3 and R4 respectively as listed in Table (7), raising the existing bank levels along those critical lengths should be urgently carried out.

Table 7: Locations of Bank Overtopping at Modeled Scenarios

<table>
<tr><th>Reach</th><th>Location (km)</th><th>Reach</th><th>Location (km)</th><th>Reach</th><th>Location (km)</th></tr>
<tr><td>R1</td><td>From km155.32 to km 159.31</td><td rowspan="7">R3</td><td>From km 409.21 to km 411.22</td><td rowspan="7">R4</td><td>From km 853.00 to km 887.60</td></tr>
<tr><td rowspan="6">R2</td><td>From km 169.86 to km 187.98</td><td>At km 413.22</td><td>From km 863.10 to km 866.60</td></tr>
<tr><td>From km 191.45 to km 198.97</td><td>From km 416.72 to km 418.72</td><td>From km 890.61 km 893.11</td></tr>
<tr><td>From km 212.00 to km 217.50</td><td>From km 425.00 to km 429.73</td><td>From km 904.61 to km 905.11</td></tr>
<tr><td>From km 251.37 to km 252.37</td><td>From km 440.70 to km 445.24</td><td>From km 911.11 to km 912.62</td></tr>
<tr><td rowspan="2">From km 260.87 to km 266.87</td><td rowspan="2">From km 453.20 to km 456.25</td><td>From km 924.62 to km 925.12</td></tr>
<tr><td>From km 928.62 to km 937.62</td></tr>
<tr><td>Total length (km)</td><td>42.13</td><td colspan="2">17.33</td><td colspan="2">52.1</td></tr>
</table>

5.2 Changes in Flow Discharges

The attainable results for different applied scenarios with respect to the changes in passing flow discharges are shown in Figures (1, 2 and 3) and listed in Table (8) which can be illustrated as follows:

- ***New Esna Barrages failure***: The passing flow discharge downstream of New Esna Barrages would be ranged from 3182.87 m^3/s to 4628.63 m^3/s before failure at normal conditions, while failure occurred at maximum passed flow ranged from 5390.72 m^3/s to 6502.90 m^3/s. Figure (1) shows the relation between discharge and time downstream New Esna Barrages during failure scenarios at scenarios S1, S2, S3 and S4. Table (8) lists maximum flow discharges downstream failure sites during Esna Barrage failure scenarios

- ***New Naga Hammadi Barrages failure:*** The passed flow discharge downstream New Naga Hammadi Barrages ranged from 2784.50 m^3/s to 4231.85 m^3/s before failure, while failure occurred when maximum passed flow ranged from 4055.24 m^3/s to 5560.32 m^3/s. Figure (2) shows the relation between discharge and time downstream New Naga Hammadi Barrages at scenarios S5, S6, S7 and S8. Table (9) lists maximum flow discharges downstream failure sites during Naga Hammadi Barrage failure scenarios.

- ***Assiut Barrages failure***: The passed flow discharge downstream Assiut Barrages ranged from 2299.90 m^3/s to 3747.04 m^3/s before failure, while failure took place when maximum passed flow ranged from 3707.53 m^3/s to 5233.29 m^3/s. Figure (3) shows the relation between discharge and time downstream Assiut Barrages at scenarios S9, S10, S11 and S12. Table (10) lists maximum flow discharges downstream failure sites during Assuit Barrages failure scenarios.

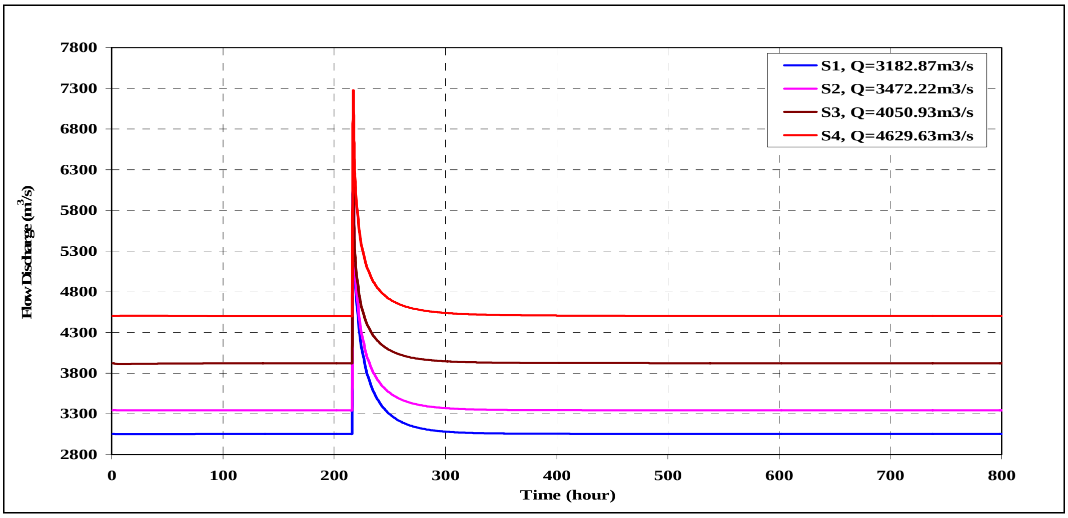

Figure 1: Failure Results Downstream New Esna Barrages at Scenarios S1, S2, S3 and S4

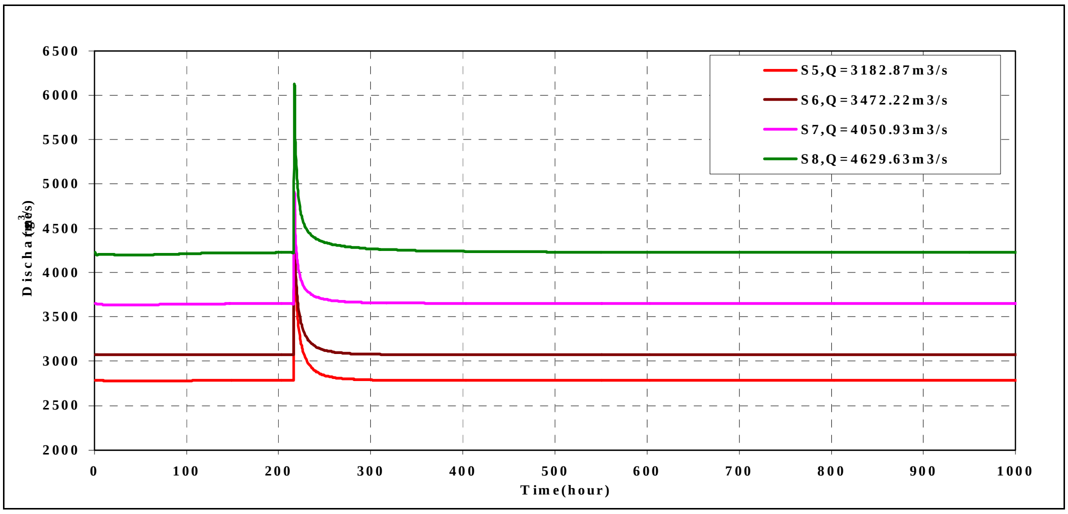

Figure 2: Failure Results D.S. New Naga Hammadi Brg. at Scenarios S5, S6, S7 and S8

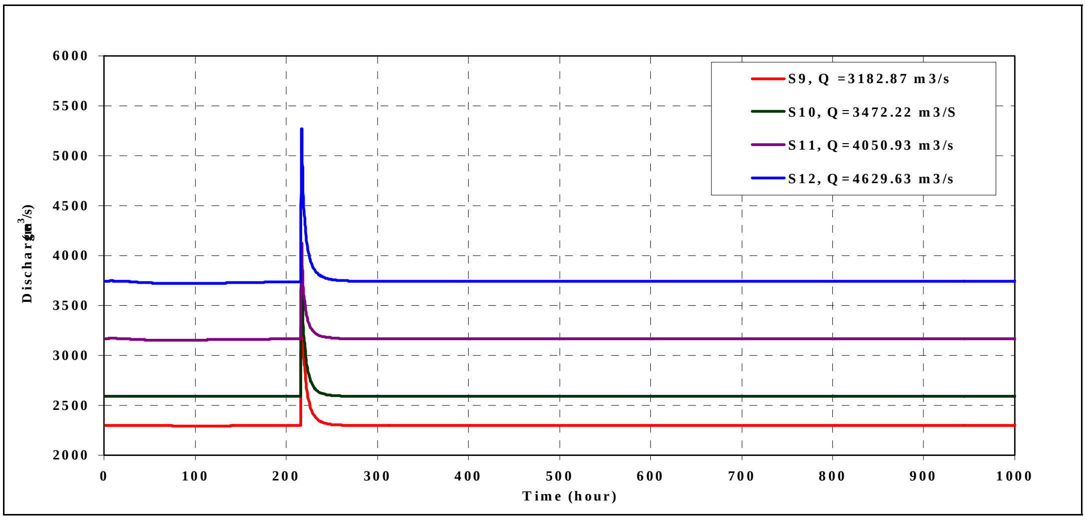

Figure 3: Failure Results Downstream Assiut Barrages at Scenarios S9, S10, S11 and S12

Table 8: Maximum Flow Discharges during New Esna Barrages Failure Scenarios

Scenario	Flow Discharge (m3/s)							
	D.S New Esna		D.S New Naga Hammadi		D.S Assiut		U.S Delta	
	Before failure	After failure	Before failure	After failure	Before failure	After failure	Before failure	After failure
S1	3182.87	5390.72	2784.50	3141.61	2299.90	2557.74	2079.35	2300.76
S2	3472.22	5434.62	3074.85	3415.54	2591.29	2847.43	2372.84	2582
S3	4050.93	5503.29	3652.48	3891.29	3180.33	3367.46	2907.90	3024.86
S4	4628.63	6502.90	4231.85	4412.62	3747.04	3901.15	3498.47	3585.28

Table 9: Maximum Flow Discharges during New Naga Hammadi Barrages Failure Scenarios

Scenario	Discharge (m^3/s)					
	D.S New Nagaa Hammadi		D.S Assuit		U.S Delta	
	Before failure	After failure	Before failure	After failure	Before failure	After failure
S5	2784.50	4055.24	2299.90	2490.34	2079.35	2203.25
S6	3074.85	4176.91	2591.29	2778.44	2372.84	2484.63
S7	3652.48	4481.52	3180.33	3338.60	2907.90	2978.61
S8	4231.85	5560.32	3747.04	3967.43	3498.47	3577.40

Table 10: Maximum Flow Discharges at Main Barrages at Assiut Barrage Failure Scenarios

Scenario	Discharge (m^3/s)			
	D.S Assiut		U.S Delta	
	Before failure	After failure	Before failure	After failure
S9	2299.90	3707.53	2079.35	2194.65
S10	2591.29	3870.36	2372.84	2476.77
S11	3180.33	4102.55	2907.90	2962.29
S12	3747.04	5233.29	3498.47	3549.06

5.3 Changes in Flow Velocity

The attainable results for different applied scenarios with respect to the variation in flow velocity are shown in Figures (4, 5, and 6) and listed in Tables (11, 12 and 13) which can be illustrated as follows:

- ***D.S of New Esna Barrages:*** The main downstream flow velocity would be ranged from 0.43 m/s to 0.56 m/s before failure and reached maximum value of 0.67 m/s to 0.81 m/s at failure. Figure (4) shows the relation between the flow velocity and the time downstream of New Esna Barrages for Scenarios S1, S2, S3 and S4. Table (11) lists maximum flow velocities downstream failure sites during New Esna Barrages failure scenarios.

- ***D.S of New Naga Hammadi Barrages:*** The main downstream flow velocity would be ranged from 0.72 m/s to 0.94 m/s before failure and reached maximum value of 0.95 m/s to 1.26 m/s at failure. Figure (5) shows the relation between the flow velocity and the time downstream of New Naga Hammadi Barrages for Scenarios S5, S6, S7 and S8. Table (12) lists maximum flow velocities downstream failure sites during New Naga Hammadi Barrages failure scenarios.

- ***D.S of Assiut Barrages:*** The main downstream flow velocity would be ranged from 0.64 m/s to 0.68 m/s before failure and reached its maximum value of 0.80 m/s to 0.85 m/s at failure. Figure (6) shows the relation between the flow velocity and the time downstream of Assiut Barrages for Scenarios S9, S10, S11 and S12. Table (13) lists maximum flow velocities downstream failure sites during Assiut Barrages failure scenarios.

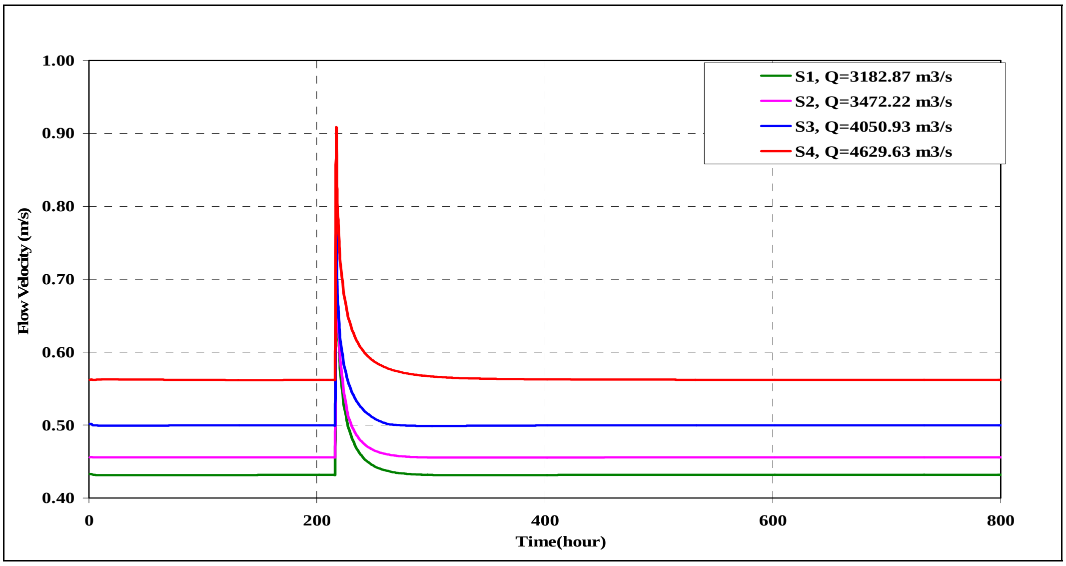

Figure 4: Flow Velocities D.S. of New Esna Barrages For Scenarios S1, S2, S3 and S4

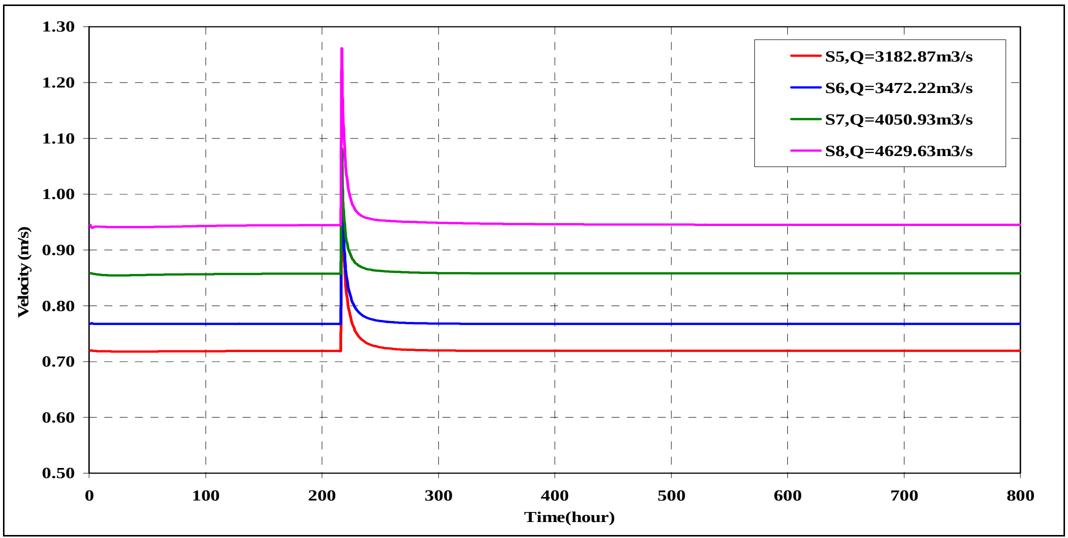

Figure 5: Flow Velocities D.S. of New Naga Hammadi Bgs. at Scenarios S5, S6, S7 and S8

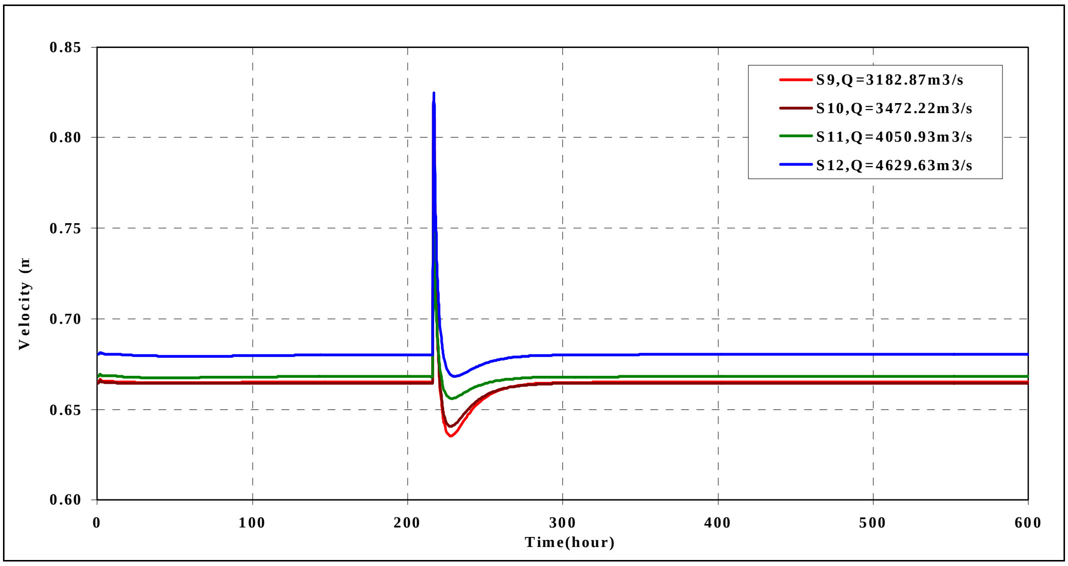

Figure 6: Flow Velocities D.S. of Assiut Barrages at Scenarios S9, S10, S11 and S12

Table 11: Maximum Flow Velocities at all Bgs. during New Esna Barrage Failure Scenarios

Scenario	Flow Velocity (m/s)							
	D.S Esna		D.S Naga hammadi		D.S Assuit		U.S Delta	
	Before failure	After failure	Before failure	After failure	Before failure	After failure	Before failure	After failure
S1	0.43	0.67	0.72	0.78	0.66	0.67	0.45	0.50
S2	0.46	0.68	0.79	0.84	0.66	0.675	0.51	0.56
S3	0.50	0.69	0.86	0.89	0.67	0.68	0.62	0.64
S4	0.56	0.81	0.94	0.97	0.68	0.69	0.73	0.75

Table 12: Maximum Flow Velocities at all Bgs. during New Nagaa Hammadi Failure Scenarios

Scenario	Flow Velocity (m/s)				
	New Naga hammadi		Assiut		U.S Delta Barrages
	Before Failure	After Failure	U.S	D.S	
S5	0.72	0.95	0.81	0.67	0.48
S6	0.77	0.96	0.88	0.67	0.43
S7	0.86	1.03	0.95	0.68	0.60
S8	0.94	1.26	1.03	0.69	0.63

Table 13: Maximum Flow Velocities at Main Barrages during Assuit Barrage Failure Scenarios

Scenario	Flow Velocity (m/s)	
	D.S Assiut	U.S Delta
S9	0.80	0.48
S10	0.82	0.54
S11	0.83	0.62
S12	0.85	0.74

5.4 Flood Wave Propagation

At main Barrages failure, it was necessary to determine the arrival time of flood wave upstream of each barrage along the Nile River and the time of maximum flood wave to step on the safety procedures at each barrage.

- ***At New Esna Barrage failure*** the first flood wave reached New Naga Hammadi Barrages after 5 to 11 hr time after failure moment. The maximum flood wave height was 1.41 m at scenario S4. Figure

(7) shows flood wave propagation during the tested scenarios downstream of Esna Barrages**.** Table (14) shows flood wave propagation during Esna Barrages failure scenarios

- ***At Naga Hammadi Barrage failure*** the first flood wave reached Assiut Barrages after 8 hr to 11 hr time after failure moment. The maximum flood wave height was 1.61 m at scenario S8. Figure (8) shows flood wave propagation during the tested scenarios downstream of New Naga Hammadi Barrage**s.** Table (15) shows flood wave propagation during New Naga Hammadi barrages failure scenarios.

- ***At Assiut Barrage failure*** the first flood wave reached Delta Barrages after 52 hr to 32 hr time after failure moment. The maximum flood wave height was 0.22 m at scenario S12. Figure (9) shows flood wave propagation during the tested scenarios downstream of New New Naga Hammadi barrages**.** Table (16) shows flood wave propagation during Assiut Barrages failure scenarios

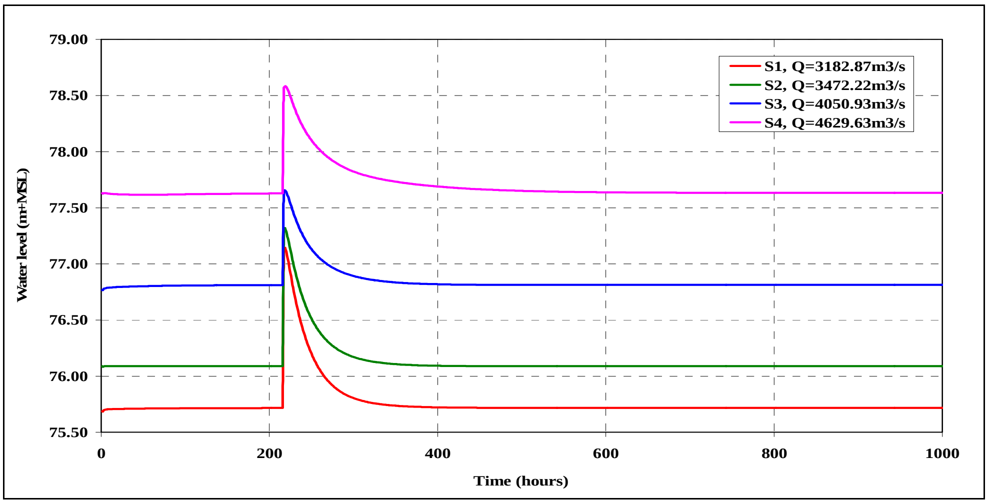

Figure 7: Flood Wave Propagation D.S. of New Esna Barrages at Scenarios S1, S2, S3 and S4

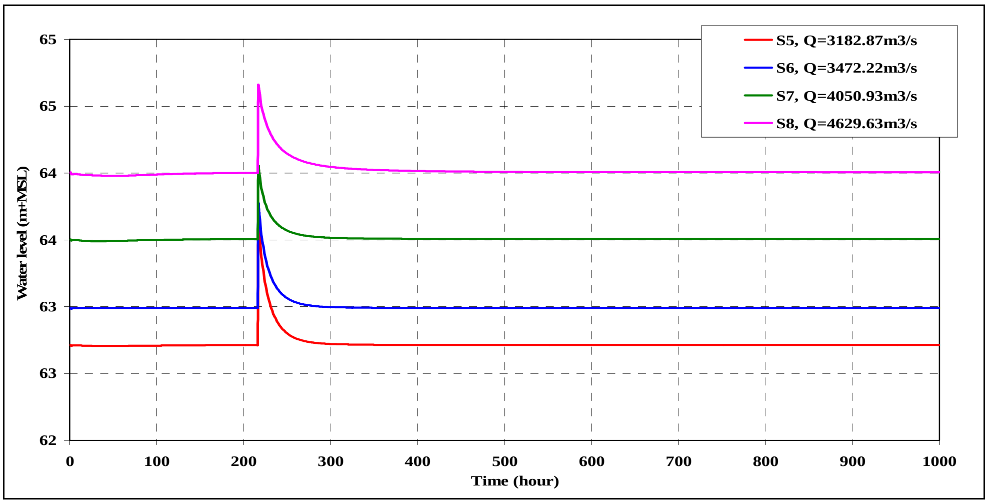

Figure 8: Flood Wave Propagation D.S. New Naga Hammadi Bgs. at Scenarios S5, S6, S7 and S8

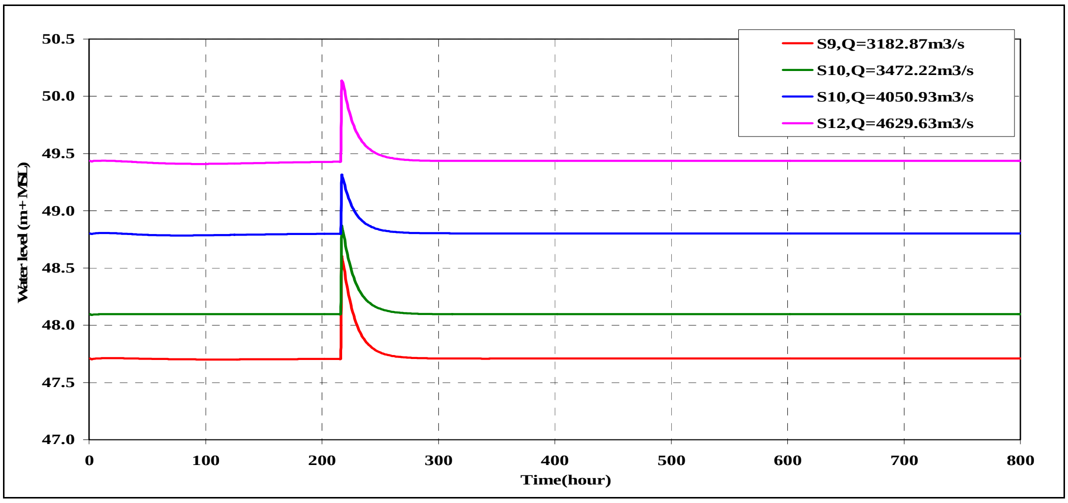

Figure 9: Flood Wave Propagation D.S. Assiut Barrage at Scenarios S9, S10, S11 and S12

Table 14: Flood Wave Propagation U.S. Main Barrages at Esna Barrage Failure Scenarios

Scenario	Naga Hammadi		Assuit		Delta	
	Max. Wave Height (m)	Time of wave Arrival (hr)	Max. Wave Height (m)	Time of Wave Arrival (hr)	Max. Wave Height (m)	Time of Wave Arrival (hr)
S1	0.48	11	0.61	37	0.08	100
S2	0.97	9	0.95	35	0.11	94
S3	1.25	8	0.52	33	0.15	90
S4	1.41	5	1.48	28	0.23	85

Table 15: Flood Wave Propagation U.S. Main Barrages at New Naga Hammadi Barrages Failure Scenarios

Scenario	Assiut		Delta	
	Max. Wave Height (m)	Time of Wave Arrival (hr)	Max. Wave Height (m)	Time of Wave Arrival (hr)
S5	0.54	11	0.07	84
S6	0.72	11	0.10	80
S7	0.80	10	0.15	75
S8	1.61	8	0.23	72

Table 16: Flood Wave Propagation U.S. Main Barrages at Assiut Barrages Failure Scenarios

Scenarios	Delta Barrages	
	Max. Wave Height (m)	Time of Wave Arrival (hr)
S9	0.07	53
S10	0.10	41
S11	0.15	35
S12	0.22	32

5.5 Total Flooded Areas

The total flooded areas corresponding to each failure scenario that were affected by flood wave propagation were established as follows:

New Esna Barrages Failure Scenarios:
No inundation areas were resulted during scenarios S1 and S2. While the total flooded areas at scenario S3 were 126 $K.m^2$ and 335 $K.m^2$ at scenario S4.

New Naga Hammadi Barrages Failure Scenarios:
No inundation areas were resulted during scenarios S5 and S6. While the total flooded areas at scenario S7 were 140 Km^2 and 311 Km^2 at scenario S8.

Assiut Barrage Failure Scenarios
No inundation areas were resulted during scenarios S9 and S10. While the total flooded areas at scenario S11 were 160 Km^2 and 344 Km^2 at scenario S12.

6. CONCLUSIONS AND RECOMENDATIONS

The present study can be considered as preliminary notification for the decision makers in the Ministry of Water Resources and Irrigation to adopt the convenient plan for saving the main hydraulic structures on the Nile River. For this reason, the study aimed to evaluate the impact of main barrages failure on the Nile Valley through number of scenarios at different flow conditions by employing the combined SOBEK 1D-2D software package to simulate the failure of each barrages individually.

Therefore, based on the studied scenarios for the main barrages failure along the Nile River and its consequences and effects on the surrounding areas and the study results and conclusions, the following recommendations would be beneficial:

1. As the conducted study showed overtopping and possible inundation along a total length of 111.560 km which are allocated along 4.00, 38.13, 17.33 and 52.10 Km of reaches R1, R2, R3 and R4 respectively as listed in Table (7), raising the existing bank levels along those critical lengths should be urgently carried out.
2. In order to support decision makers of the Ministry of Water Resources and Irrigation to minimize the expected malfunction of such failure, early warning system should be established at the site of each main barrages along the Nile River.
3. Evacuation plan must be established to be applied in emergency case, and some training tests would be carried out to facilitate the real application.
4. Additional studies should be carried out to investigate the effect of main barrages failure on the stability of the existing bridges along the main Nile River stream and the other hydraulic structures along the branched canals.
5. A distinguished concern should be directed to the located areas just downstream each of the main barrages along the Nile River which would be suddenly subjected to enormous increase in flow discharges and flood wave just at the beginning of any failure for the main Nile River barrages. Some special materials should be stored on both sides of the river to minimize the expected bed scour due to the sudden increase in flow velocities.
6. The latest recent land use and the corresponding management lines maps for located lands on both sides of the main Nile River stream should be established as a rehabilitation measure to classify and arrange the necessary efforts to meet any hydraulic structure failure in the future.

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