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Impacts of reduced water flow on the riverside intakes

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ABSTRACT

Water intakes are designed to carry water supply pipes to reach channel water specifically during periods of minimum water stages. If the water levels fall below expectations, it will cause some of intakes out of service and negative impacts on the intakes. In this paper, the effects of flow reduction ratio values on the intakes along the River Nile from Esna Barrage to Naga Hammadi Barrage are studied numerically. Different scenarios were considered for this reduction and mathematical model (SOBEK-1D) was used to compute water level along River Nile. The results showed that the reduction in water levels produces negative impacts on the intakes and illustrated to assist the decision maker to solve the problems of affected intakes. These reductions are maximum with 8.9% at Naga Hammadi Barrage for the last scenario and minimum with 0.2% for the first scenario, the reduction in water levels decreases Nile water velocities and reduction water level up to 5% produces small influence on the safe navigation. The scenario of only 5% reduction the not working intakes will be more than 59%.

Keywords: Water levels, The River Nile, Esna Barrage, Naga Hammadi Barrage, SOBEK-1D

1. INTRODUCTION

Egypt is the gift of the Nile; Egypt depends entirely on the River Nile for water supply. Egypt will need 81.9 BCM at year 2025 and the main water resources are valued to be 74.3 BCM .This indicated that Egypt will need water in the near future. The needs of water will increase in the future especially after the building of dams on the Nile basin. The impact of flow water reduction on the Nile River was investigated by many researchers. Many researchers studied the effect of Grand Ethiopian Renaissance Dam (GERD) on Egypt. Nile River Protection and Development Project (1991) studied the effect of projects on the Nile River on water levels and known navigation bottlenecks. Nile Research Institute (1992) reported that the flow reduction will effect on intake and the water depth required for safe navigation. Aziz M. and Ismail S. (2003) investigated the flow reduction on the pump stations for water supply High Aswan Dam (HAD) to new Esna Barrage. Z. Barbary (2008) studied the effect of low flow releases during low demand period on the operation of domestic and power stations along the Nile River. S. Ismail and M. Samuel (2011) investigated the effect of scraping on water levels using HEC-RAS computer model on the River Nile. N. Sadek (2012) investigated the effect of implementing of The Ethiopian dams on Egypt's share of water, believed that the water level upstream of High Aswan Dam (HAD) will decrease. N. Sadek (2013) studied the impact of water shortage on drinking pump stations and navigation bottlenecks. A. Nada and H. Fathy (2014) investigated the reduction of water levels and discharges downstream of HAD by using different scenarios of filling GERD, found that the water levels decreased from 0.40 to 0.75 m when discharge decreased from 90 to 80% of the maximum outflow. M. Bastawesy et al (2014) studied the impact of the GERD on the discharge downstream, believed that it will produce more negative impacts for Egypt. F.S. Abdelhaleem and E.Y. Helal (2015) investigated the effect of Grand Ethiopian Renaissance Dam (GERD) on the Nile River in Egypt. Hany G. Radwan and Hussin (2015) investigated the effect of flow reduction on The River Nile for the first reach from HAD to new Esna Barrage, believed that this reduction affected on pump stations. S. Sherine Ismail (2015) studied the effect of flow reduction on The Nile River using Different 21 scenarios, believed that this reduction led to negative influence on the irrigation pump and number of pump stations become out of service. H. Elsersawy and N. Kamal (2017) studied navigation conditions of berths in the Luxor in second reach of the Nile River for efficient and safe navigation conditions. N. Kamal and N. Sadek (2018) evaluating navigation efficiency for the River Nile by developed a computer-based system in the second reach. E. Helal et al, (2020) studied a navigation channel in the Nile River by using different scenarios, believed that dredging operations alone cannot be adopted as a permanent solution for navigation bottlenecks with the riverbed returning to its original state within 10 years. In this study, the impact of study different flow reduction investigate on the water levels along second reach and on the operation water levels of intakes on the reach from new Esna Barrage to Naga Hammadi Barrage with total length 192.8 Km.

2. METHODOLOGY AND MODEL CONSTRUCTION

This study will be performed as follows: selecting the second reach from the Nile River, assembling the available data about the second reach included (bathymetric, topographic survey, hydrological and hydraulic data, etc.), designing the scenarios for the flow reductions and simulating the second reach employing a numerical model (SOBEK-1D).

2.1. Basic Equation Used For SOBEK-1D Computation

In the flow module, the flow is described by the full Saint-Venant equations for unsteady open-channel flow, which read for a regular river application:

- Continuity equation (representing the conservation of mass)

$$\frac{\partial A_t}{\partial t} + \frac{\partial Q}{\partial x} = q_{lat} \qquad (1)$$

- Momentum equation (representing the conservation of momentum):

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

Where:

A_f = conveying cross-sectional area [m^2], A_t = total cross-sectional area [m^2], C= Chézy coefficient [m$^{0.5}$/s], g = gravitational acceleration [m/s^2], h= water level relative to a reference level [m], q_{lat}= lateral inflow per unit width [m^2 / s], Q= flow discharge [m^3 /s], R= hydraulic radius (roughly equal to the water depth) [m], t= time [s], x= distance along the channel [m],α_B = Boussinesq coefficient (see equation 3) [-], The Boussinesq coefficient α_B is a correction factor in the convective acceleration term (in equation 2), to account for non-uniform velocity distribution in the cross-section. It is computed from the following relation:

$$\alpha_B = \frac{\sum_{i=1}^{n} C_i^2 R_i A_{fi}}{C^2 R A_f} \quad and: \quad C^2 R = \left(\frac{\sum_{i=1}^{n} C_i A_{fi} \sqrt{R_i}}{A_f}\right)^2 \qquad (3)$$

Where: i= index indicating type of sub-section in conveying cross-section (i ≤ 3)

The last expression in equation (3), computing a representative C^2 R, is also used in the bed-friction term in equation (2). The Chézy coefficient C is in this model computed as a function of Manning's roughness coefficient n_m:

$$C = \frac{R^{1/6}}{n_m} \qquad (4)$$

For the Nile River model, the Manning's type roughness coefficient provides a good representation of hydraulic roughness for a wide range of flow discharges.

2.2. Model Construction

To construct SOBEK-1D model for this study it was necessary to simulate the Nile River in the model exactly as it behaves in the prototype. To simulate the Nile River, it was necessary to cover the following items

2.2.1. Cross sections data

Topographic and bathymetric surveys were carried out by the Hydraulics Research Institute (HRI) .These data were used to simulate the river banks, islands and cross sections. In SOBEK model, the Nile River was divided into four reaches. We will use the second reach which was carried out by the HRI. This reach extends for 192.8 km starting from the downstream of Esna Barrage and ending at the upstream of Naga Hammadi Barrage. This reach was simulated in the model by 3708 cross sections with a mutual distance of 200 m. Figure 1 illustrates Nile valley and Barrages in Egypt (modified after Hany and Radwan and Hussin)

2.2.2. Hydraulic structure data

The simulated main structures in SOBEK model were the upstream Esna, downstream Naga Hammadi and the intakes along the reach. The hydraulic structure data were mainly found in HRI and Nile Research Institute (NRI). Table (1) shows the locations and dimensions of the intakes along the reach on the Nile River. The daily outflow discharge From Esna barrage defines the upstream boundary conditions of the hydrodynamic model. The time series water levels upstream Naga Hammadi barrage defines the downstream boundary conditions.

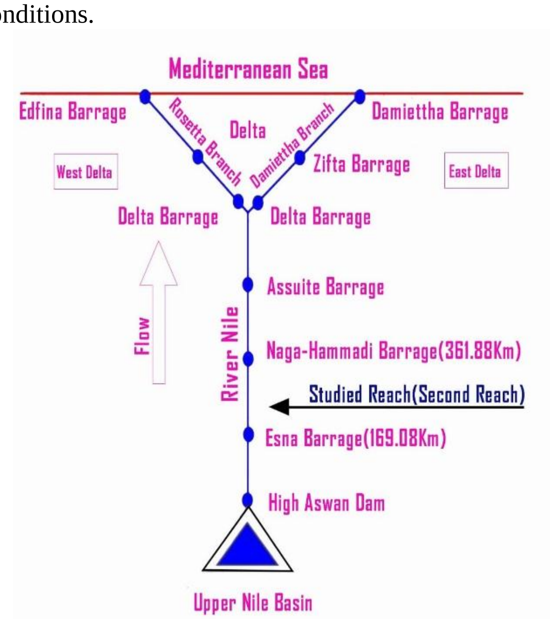

Figure 1: Nile valley and Barrages in Egypt (modified after Hany Radwan and Hussin)

2.2.3. Lateral Off-takes

Two offtakes were found along the second reach on the Nile River .These offtakes were represented in the model as a function of time/discharge. These data were carried out by the Hydraulics Research Institute (HRI).

2.2.4. Upstream and downstream Boundary Conditions

The model upstream boundary conditions will be the daily outflow discharge passing the Nile River during the year of (2013-2014) and the flow discharges that could be released from Esna barrage, which will be varied according to each scenario. The model downstream boundary conditions will be taken as the time series water levels upstream Naga Hammadi Barrage, which will be varied according to each scenario.

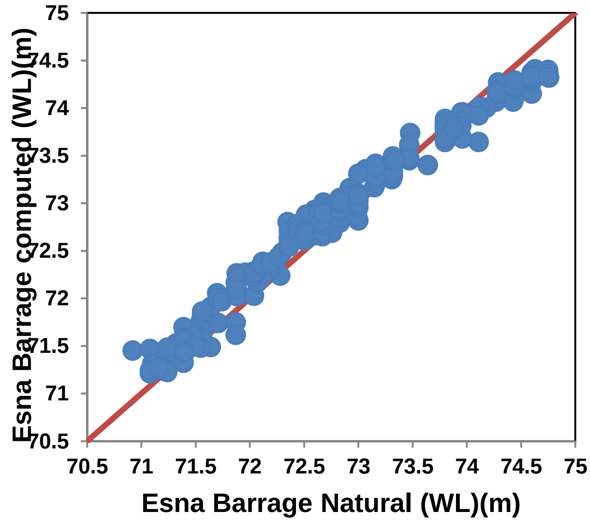

Figure 2: Calibration process results.

2.2.5. Numerical Grid Time Step

The distance between the grid points in all the second reach was defined as 200 m. The second reach was spilt into segments that bounded by two calculation nodes of 200 m apart. The calculations were executed to the segments, structures and the intermediate nodes to produce the water levels, water depths, velocities, discharges and some hydraulic characteristics. The simulation period considered one year.

2.3. Model Calibration

The model was calibrated against the most recent measured data carried out by HRI in august 2013 to Jun 2014 for water levels and flow discharges along the Nile River. The main purpose of the calibration step is to obtain an accurate mathematical representation of reality. Figure 2 shows the calibration of the second reach of the Nile River .This reach extends for 192.80 km extending from the downstream of Esna Barrage to upstream of Nagaa Hammadi Barrage. The model calibration showed the difference between measured and computed water levels range between 0.04% to 0.1%. In this reach, computed water levels and measured water levels are in a good agreement when manning's roughness coefficient is equal to 0.03.

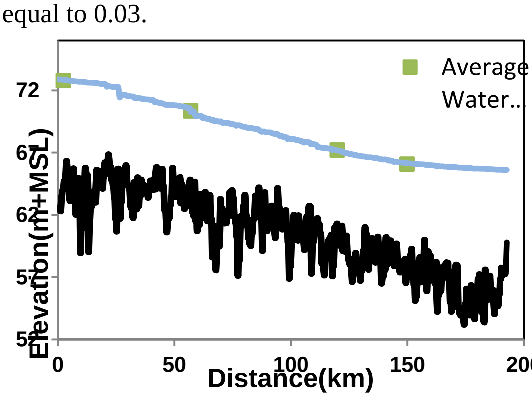

Figure 3: Results of model error of water level.

The model results showed an error percentage between computed and natural model . The error percentage between measured and computed water levels just downstream Esna Barrage was 3.9% and the percentage error between the observed and predicted discharges at Naga Hammadi Barrage was 0.2%. Figure 3 shows the percentage error of the upstream of Esna Barrage in water levels and Figure4 shows the percentage error of the downstream of Naga Hammadi Barrage in discharge. The result of model agrees well with the observed.

Table 1: Intakes characteristics that represented in the model along the second reach on the Nile River (Esna-Naga Hammadi).

Name	Owner	Distance from AOD(Km)	Intake Type	No. of Units	Discharge per Unit (m3/S)	Intake Diam. (m)	Intake Elev. (m+MSL)
1- El Ghoriera (New)	Irrig.Dept.	192.6	Floating	2	0.5	0.8	70
2- El Ghoriera	Irrig.Dept.	199.6	Vertical	3	0.5	0.8	69.92
3- Rozaikat	Irrig.Dept.	198.8	Floating	2	0.14	1	70.06
4- El Rozaikat	Irrig.Dept.	198.88	Vertical	7	0.5	1	70.06
5- El Bayadia	Irrig.Dept.	211.42	Floating	2	1.35	0.7	69.4
6- El Bayadya	Irrig.Dept.	211.42	Vertical	4	2	1	69.53
7-El Shanshouria	Irrig.Dept.	245.07	Vertical	5	5.5	-	67.78
8- El Marashda	Irrig.Dept.	311.6	Vertical	5	8	1.8	64.25
9- El Derb	Irrig.Dept.	344.35	Vertical	4	7.5	2.6	64.75
10- El Derb (Emergency)	Irrig.Dept.	350	Vertical	6	2	0.8	64.75
11- Dandara	Irrig.Dept.	294	Vertical	4	0.5	0.5	65.83
12- El Mallaha	Irrig.Dept.	235	Vertical	3	2	-	64
13- El Baghday (Emergency)	Irrig.Dept.	213	Vertical	2	1.7	1.2	69.43
14- Deshna	Water Supply	330	Vertical	2	0.03	0.2	64.75
15- Deshna El Asissia	Water Supply	330.9	Vertical	3	0.03	0.2	64.75
16-Qena(Safaga)	Water Supply	285	Vertical	6	0.11	0.8	66
17- Qena (New)	Water Supply	288	Vertical	3	0.06	0.2	61
18- Qent	Water Supply	264	Vertical	3	0.06	0.2	66.18
19- Quos	Water Supply	261.6	Vertical	3	0.06	0.2	67.12
20- Luxor	Water Supply	223	Vertical	8	0.05	0.2	69
21- Armant	Water Supply	206	Vertical	5	0.03	0.2	65
22- El Matanna	Water Supply	174.7	Vertical	5	0.03	0.2	65

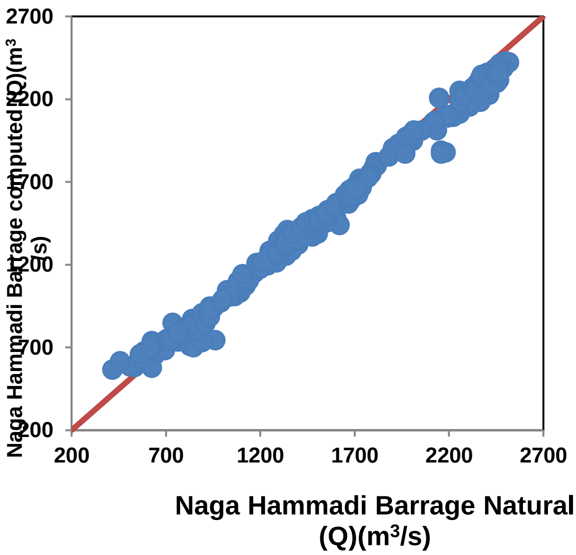

Figure 4: Results of model error of discharge.

2.4. Model Scenarios

After calibrating the SOBEK model to be used for this study, the model was run for different scenarios corresponding to different conditions to simulate the water depth, water level, discharges and velocities along the second reach on the Nile River. The scenarios were designed according to the reduction in the flow discharge downstream Aswan High Dam reported by Abdelhaleem and Helal. The six scenarios are based on developing reduction percentage for the released flow from Esna barrage and the upstream water level of Naga Hammadi barrage with six percentages 5%, 10%, 15%, 20%, 25% and 30%. The expected effects on the parameters were detected as follows: water level, intakes level, water depth, velocities.

3. Analyzing and presenting the model results

Negative influence due to reduction in water flow on the Nile River along the second reach in Egypt resulted from the reduction in water release downstream of Esna Barrage are studied and discussed as follow:

3.1. The impact of reduction flow in the water levels along the second reach

The impacts of reduction flow on the Nile water levels were studied. Figure 5 shows the impacts of the flow reduction downstream of Esna Barrage on Nile water levels. For second reach, some gauging stations were chosen which have average water level. It is obvious that the average water level reduced at the second reach from 0.2%to 3.4% as shown in table (2).

3.2. The impact of reduction flow along the second reach on the riverside intakes levels as following:

The impacts of flow reduction on the operation water levels of intakes were studied. The impacts of flow reduction on the operation water levels of intakes were studied. Figure 6 shows the impacts of the flow reduction Esna barrage on intakes. It is obvious in table 3 that the not operating intakes for scenarios are ranging from59% to 77%. This mean that even on the scenario of only 5% reduction the not working intakes will be more than 59%.

3.3. Impact of flow reduction on flow velocities

The impacts of flow reduction on the Nile water velocities were studied. Figure 7 shows the impacts of the flow reduction Esna Barrage on the Nile water velocities. For second reach, the reduction in velocities at second reach was shown for scenarios. It is obvious that the range is from 0.21 to 3.93m/s. This reduction in velocities may increase the sedimentation process, which may affect the water surface and will effect on the quality of drinking water and the efficiency of pump station.

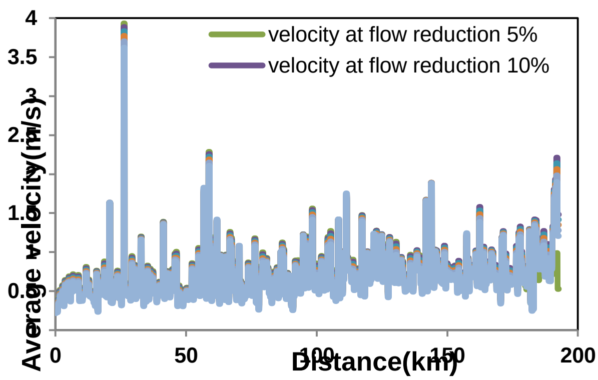

Figure7: Reduction In velocities for the six scenarios

3.4. The impact of reduction flow along the second reach on Impacts on river navigation as following:

The impacts of flow reduction on the available navigation in the River Nile by assuming a minimum required water depth of 2.3 m for navigation process were studied. Figure 8 shows the impacts of the flow reduction Esna Barrage on the Nile water depth .The reduction in water depth at second reach was shown for scenarios. It is obvious that flow reduction had small effect on navigation, where only one location of navigation bottleneck locates at 192.7 km downstream of Esna Barrage with a shallow depth of 2.14 m at 5% reduction and at10% reduction where only two location of navigation bottleneck locates at 192.2 km with a shallow depth of 2.04 m and at 192.7 km with a shallow depth of 0.01 m. At reduction 15% where only two

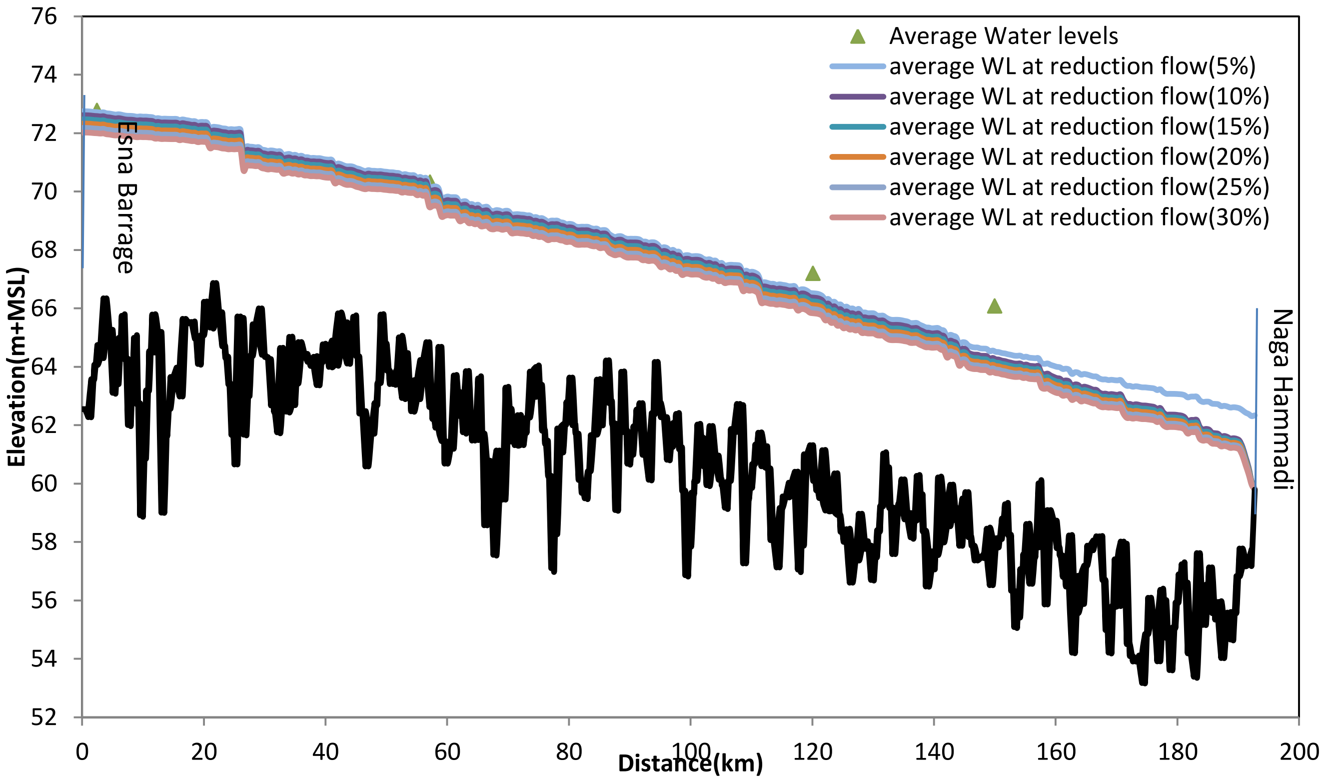

Figure 5: The impacts of reduction flow on water level.

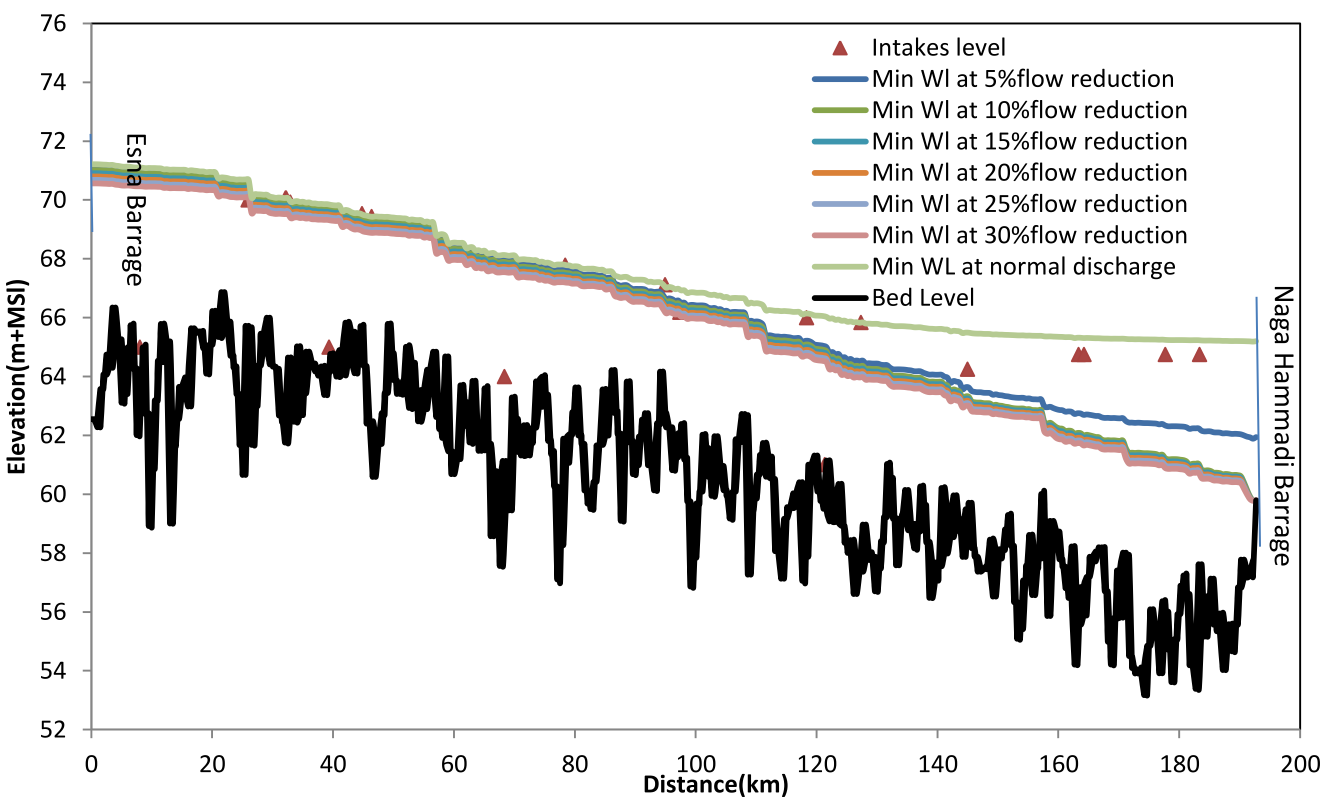

Figure6.:Minimum water level and intakes for the second reach on the River Nile

Table 2: Impacts of reduction flow on water level

station name	Distance from AOD (km)	Distance in second reach in km	Average Water levels	Average water level in reduction flow						
				base case	5%	10%	15%	20%	25%	30%
DS.Esna Barrage	169.08	2.43	72.78	72.85	72.71	72.58	72.44	72.3	72.15	71.99
Luxor	223.8	57.15	70.33	70.27	70.13	70	69.87	69.74	69.61	69.47
Qena	286.75	120.1	67.2	67.17	66.51	66.36	66.24	66.1	65.97	65.83
Deshna	316.6	149.95	66.08	66.15	64.55	64.3	64.18	64.06	63.94	63.82

Table 3: Impacts of flow reduction on intakes * (means out of service).

Name	Distance from AOD (Km)	Intake Elev. (m+MSL)	Flow reduction						
			0%	5%	10%	15%	20%	25%	30%
1-El Ghoriera (New)	192.6	70							
2- El Ghoriera	199.6	69.92			*	*	*	*	*
3- Rozaikat	198.8	70.06		*	*	*	*	*	*
4- El Rozaikat	198.88	70.06		*	*	*	*	*	*
5- El Bayadia	211.42	69.4				*	*	*	*
6- El Bayadya	211.42	69.53		*	*	*	*	*	*
7-El Shanshouria	245.07	67.78		*	*	*	*	*	*
8- El Marashda	311.6	64.25		*	*	*	*	*	*
9- El Derb	344.35	64.75		*	*	*	*	*	*
10- El Derb (Emergency)	350	64.75		*	*	*	*	*	*
11- Dandara	294	65.83		*	*	*	*	*	*
12- El Mallaha	235	64							
13- El Baghday (Emergency)	213	69.43		*	*	*	*	*	*
14- Deshna	330	64.75		*	*	*	*	*	*
15- Deshna El Asissia	330.9	64.75		*	*	*	*	*	*
16-Qena (Safaga)	285	66		*	*	*	*	*	*
17- Qena (New)	288	61							
18- Qent	264	66.18						*	*
19- Quos	261.6	67.12		*	*	*	*	*	*
20- Luxor	223	69					*	*	*
21- Armant	206	65							
22- El Matanna	174.7	65							

location of navigation bottleneck locates at km 192.2 with a shallow depth of 2.03 m and at km 192.7 with a shallow depth of 0.01 m. At reduction 20% where only two location of navigation bottleneck locates at km 192.2 with a shallow depth of 2.03 m and at km 192.7 with a shallow depth of 0.01 m. At reduction 25% where only two location of navigation bottleneck locates at km 192.2 with a shallow depth of 2.02 m and at km 192.7 with a shallow depth of 0.01 m. At reduction 30%where only three location of navigation bottleneck locates at km 192.2 with a shallow depth of 2.02 m, at 94.1 km with a shallow depth of 2.2 m and at km 192.7 with a shallow depth of 0.01 m.

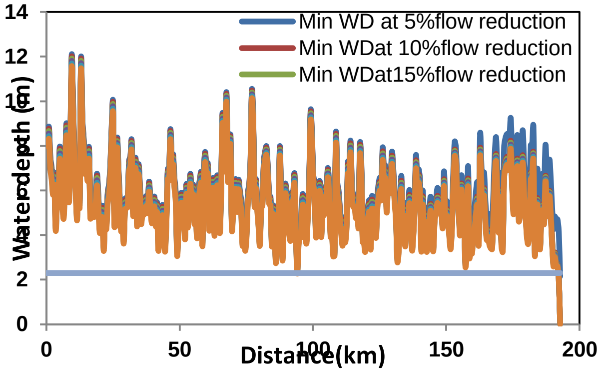

Figure 8: Impact of flow reduction on navigation.

4. CONCLUSION AND RECOMMANDATION

The main purpose of this study is to investigate in this paper the impact of study different flow reduction on the water levels along second reach and on the operation water levels of intakes on the reach from new Esna Barrage to Naga Hammadi Barrage. The conclusions can be summarized as following:-

1- The flow reduction through different scenarios will cause reduction on expected reduction in the water level along the studied reach. These reductions are maximum at Naga Hammadi Barrage with about 8.9% for the last scenario and the minimum drop of about 0.2% is happened at Esna Barrage at first scenario.

2- The reduction in water levels decreases Nile water velocities.

3- Even on the scenario of only 5% reduction the not working intakes will be more than 59% of the total intakes in the reach

4- Reduction water level up to 5% produces small influence on the safe navigation.

The following recommendations are given for helping the decision makers:

1- Review the critical operation water level for the intakes

2- Operating the affected intakes during reduction scenario

3- Construct additional intake to cope with the lowest required scenario.

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Abbreviation

(HAD): High Aswan Dam
(GERD): Grand Ethiopian Renaissance Dam
(HRI): Hydraulics Research Institute
(NRI): Nile Research Institute

Credit Authorship Contribution Statement

Ahmed Sh. Awaad : Validation, Reviewing, Supervision. ***Fahmy S. Abdelhaleem***: Reviewing, Editing, Supervision ***Tarek H. Nassrallah*** : Reviewing, Editing, Supervision,

Basma Sayed: Collecting data, Methodology preparation.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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