The Potential Impacts of Low Releases From Nasser Lake Due to Climate Changes on Irrigation Pump Stations Along The Nile River

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Abstract

In terms of the significance of the Nile River, this research was commenced with the impartial of investigating the potential impacts of low releases from Nasser Lake, due to climate changes, on irrigation pump stations along the river. Accordingly, the paper focuses on the effect of low flows on the pump station water supply. During this research, pump stations, for irrigation purposes, along the Nile River from Old Aswan Dam (OAD) to Delta Barrage were appraised according to their design and critical water level to determine the potential for the expected problems due to passing low discharges as a result of climate changes.

Keywords: Nile River, Nasser Lake, Climate Changes, Irrigation Pump Station, GSTARS, AHD, GCM, Water Level

1. INTRODUCTION

Construction of Aswan High Dam (AHD) on the Nile River in southern Egypt commence in 1960 and was completed in 1970 to develop industries using generated electric power and to stabilize water supply for irrigation. The dam created Nasser Lake, south of Aswan, which is one of the world's largest artificial lakes (Figure 1). The lake covers the area between Lat. 21^{o}30' N and 24^{o}00' N, Long. 31^{o}20' E and 33^{o}30' E (Selim et. al., 2002), and extends to about 500 km in length, of which 150 km stretches in Sudan, with an average width 12 km. The reservoir has a large annual carry-over capacity of 168.90 x 10^9 m^3 (Ministry of Water Resources and Irrigation, 2005). Releases from AHD account for 95% of the water resources of Egypt, making the Nile River the effective single source of freshwater for Egyptian agriculture, population, navigation and industry. Studies of climate change impacts on the Nile River show that the basin is extremely sensitive to temperature and precipitation changes (Strzepek and Yates, 2000). An increase of 10% of average annual precipitation would lead to an average increase in annual flow of 40%. Similarly, a decrease in 10% in precipitation would lead to a reduction of the annual flow with more than 50% (Ministry of water resources and irrigation, 2005).

This paper focuses on climate change projections and impacts on water supplies represented by the Nile flow regime and the water levels so as discharges, downstream AHD. The paper provides a projection of the effect of low water levels on Irrigation pump stations. During this research, pump stations, for irrigation purposes, along the Nile River, downstream Aswan Old Dam (AOD) to Delta Barrage were assessed in terms of their design and critical water level in order to determine the potential for the expected problems due to low discharge due to climate changes in the studied reach, figure (1).

Initially, Nasser Lake operations rules were modelled using the simulated stream flows associated with the climatic General Circulation Models (GCMs) to assess the impact of climate change on extracted releases from Nile River at AHD. This step was followed by using a one-dimensional computer program based on solving the flow equations to compute water levels related to the analyzed discharges. The used mathematical model for this analysis is GSTARS 2.0 which was developed by the U.S. Bureau of Reclamation in 1998. The model was calibrated using the actual water level readings from gauging stations after developing the corresponding rating curve for each station. The computed water levels were compared to the design and critical pump stations water levels to determine the compatibility of water level for pump station supply. Different climate changes scenarios were proposed and simulated and the computed water level and discharge were obtained. Finally, conclusions and recommendations were presented as well. The above investigation phases are presented in this paper under the following headlines:

- Pump stations along Nile River
- Operation Policy of Nasser Lake
- Inflow at Nasser Lake
- Climate change studies on the Nile flows
- Modeled climate change scenarios
- Modelling approach
- Nile flows and climate change
- Water level computations by GSTARS
- Results presentation and analysis
- Conclusions and recommendations

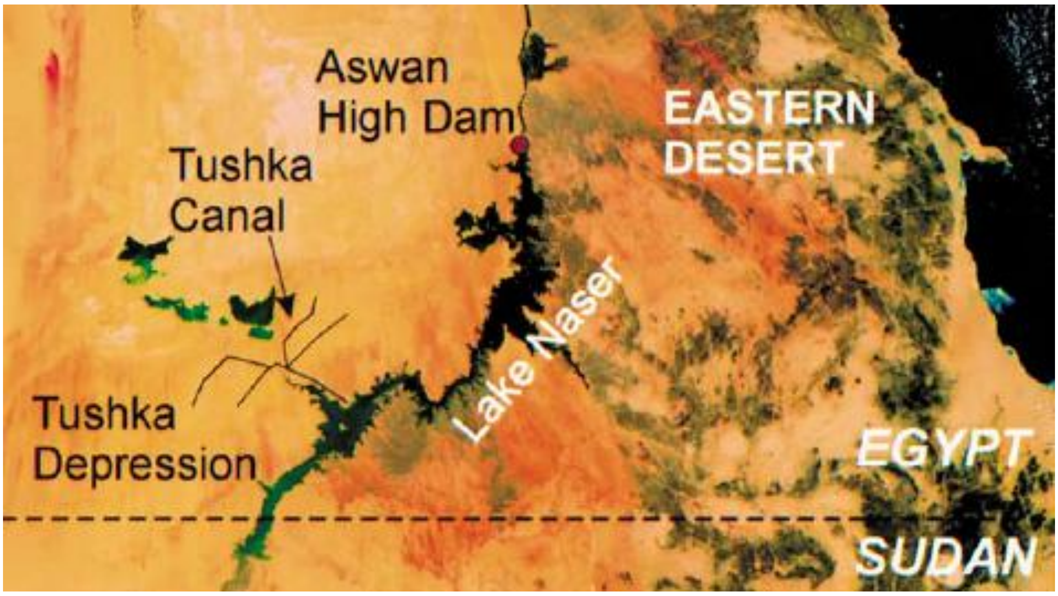

Figure 1: Location of Nasser Lake

2. IRRIGATION PUMP STATIONS ALONG NILE RIVER FROM ASWAN TO DELTA BARRAGES

The Nile River from Aswan to Delta Barrages is divided into four major reaches between each two hydraulic structures as presented on Figure 2 (Ministry of Water Resources and Irrigation, 2005). These four reaches are; First Reach is located between AOD and Esna Barrage with a total length of 167 kilometer. Second Reach is located between Esna Barrage and Naga Hammadi Barrage with a total length of 192 kilometer. Third Reach is located between Naga Hammadi Barrage and Assiut Barrage with a total length of 186 kilometer. Fourth Reach is located between Assiut Barrage and Delta Barrages with a total length of 409 kilometer.

Besides the gravity diversion of Nile water upstream of each above –mentioned barrages, water is also diverted by more than 100 major pumping stations along the Nile from AOD to Delta Barrages and its branches (Table 1) (Ministry of Water Resources and Irrigation, 2005). Some of the irrigation pump stations along the four reaches are floating stations, therefore; they were not affected by the change of water level. Some other stations are constructed for high flow; therefore, they are not operated during normal and low flows (NRI, 2013). In this analysis, the variation of water levels, along the Nile River from AOD to Delta Barrage was evaluated to investigate the climate changes effect on the operation of irrigation pump stations.

Table 1: Major pumping stations (Ministry of water resources and irrigation, 2005)

Nile reach	Number of pumping stations	Total Discharge (m^3/s)
Aswan — Esna	60	95.13
Esna — Naga Hamadi	8	41.22
Naga Hamadi — Asyut	4	15.86
Asyut - Delta Barrage	33	12.68

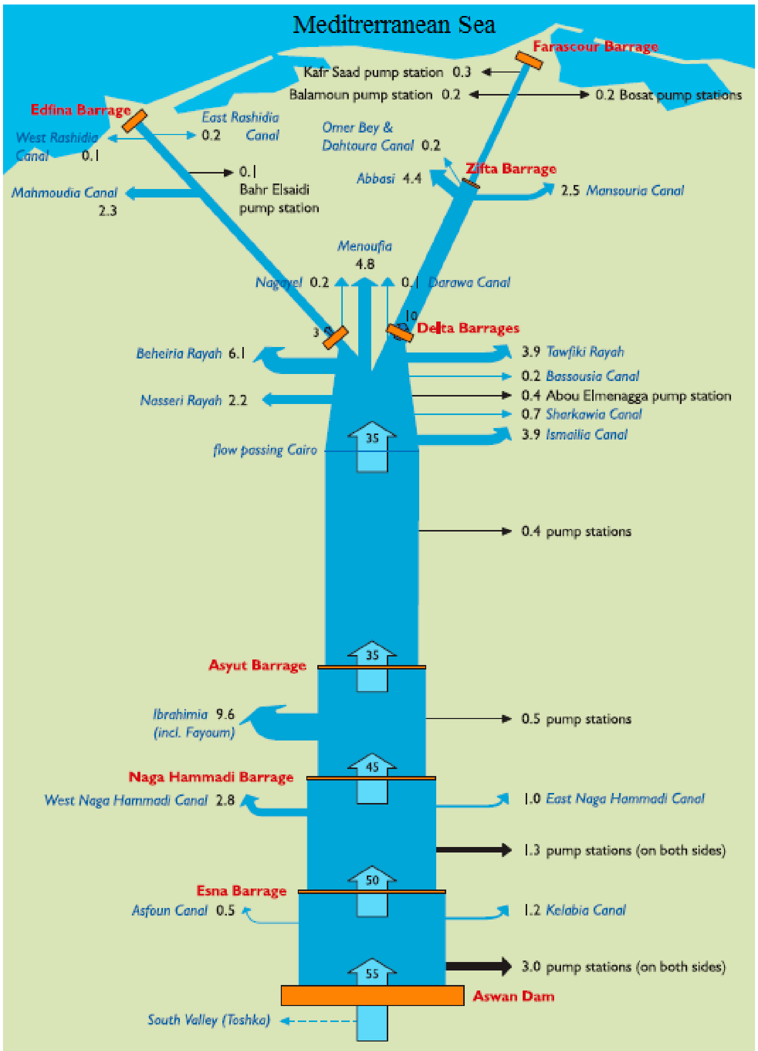

Figure 2: Pump Stations along Nile River (Ministry of water resources and irrigation, 2005)

3. OPERATION POLICY OF NASSER LAKE

AHD is 3600 m long, with a maximum height of 111m. It was constructed in 1968, at a distance of 7km from AOD. The operation policy of the lake is based on dividing the reservoir storage into three zones. The dead storage zone receives sediments during the flood period. It has a top elevation of 147 m above MSL with total volume of about 31.60 x 10^9 m^3. This zone releases no flow, regardless to the downstream requirements. The live storage zone amounts to 89.70 x 10^9 m^3. It includes the buffer zone and the conservation zone. The buffer zone lies between elevation 147 and 150 m while the conservation zone lies between 150 and 175 m. An additional storage volume of 41 x 10^9 m^3 is available for high flood waters. It is between elevation of 175 and 182 m and brings the total reservoir volume up to 162.30 x10^9 m^3 (Whittington & Guariso, 1983). This amount is increased by 7 x 10^9 m^3 in case of raising the water level up to (183m) (NBCBN, 2005). The current lake operation policy can be summarized as follows (Ministry of Water Resources and Irrigation, Egypt, 2013):

- Water level should not exceed 175 m on August 1. This is to accommodate for the floodwater that will follow.
- Releasing water from behind the dam is determined by water demand (mainly in agriculture). This amounts to 55.5 x10^9 m^3 per year.
- The annual average amount of evaporation from the lake is 10 x 10^9 m^3.
- The present water average demand for Toshka Project (South Valley Project) is 5.1 x 10^9 m^3 (14 million m^3/day), this amount is taken directly from Nasser Lake through pumping (Ministry of Water Resources and Irrigation, Egypt, 2005).
- The water level in the reservoir should not exceed 182 m and it can increase up to a maximum of 183 m in emergency situations.
- If the water level exceeds 178 m, water would be released over Toshka spillway.
- The maximum secure limit that can be released from Nasser Lake is 240 – 270 x10^6 m^3 /day.
- If the water level in the reservoir drops, with an anticipated low flood, the released water will be reduced according to a specific percentage of the water share of Egypt and Sudan (This happened in 1968).

4. INFLOW AT NASSER LAKE

Annual inflow records at Dongola in Sudan (representing the inflow to AHDR (Yao and Georgakakos, 2003) were assembled and published by Saad et al., 2001, in order to get an idea about the high and low flows for 33 years during the period 1968-2000 (Figure 3). The inflow ranges between a maximum of 107.05 x 10^9 m^3/year (1998 – 1999) and a minimum of 40.89 x 10^9 m^3/year (1984-1985). These data have a mean of 71.06 x 10^9 m^3/year with a standard deviation of 15.67 x 10^9 m^3/year.

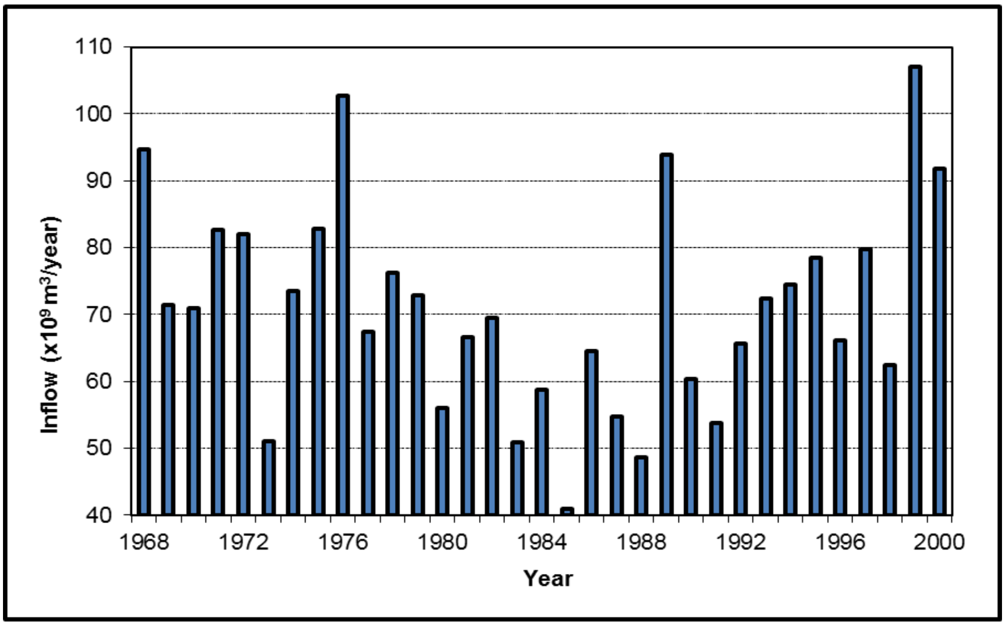

Figure 3: Nile River Yield at Dongola during 1968-2000 (Source: Saad et Al., 2001)

5. CLIMATE CHANGE STUDIES ON THE NILE FLOWS

The Nile River is the focus of several previous studies of climate change using different climate models and techniques. These studies provided the potential for very significant changes in the flow of the

Nile due to its sensitivity to temperature and precipitation changes; Sayed et al., (2004). Conway and Hulme (1996) estimated that future flow in the Blue Nile in 2025 could range between an increase of 15% and a decrease of 9%. Strzepek et al., (2001) estimated the 2020 flow g into the AHD could decrease by 10 to 50% (Beyene et al., 2010). El-Shamy et al., (2009c) used bias-corrected statistical downscaling of 17 general circulation models (GCMs) to estimate an average reduction in flow of the Blue Nile of 15% by the end of the century and a range of change between a decrease of 60% and an increase of 45% was provided. Beyene et al., (2009) implemented bias-corrected statistical downscaling of 11 GCMs and found a change in flow at the AHD ranging between a decrease of 32% and an increase of 15%. These researchers used the estimates of change in flow of El-Shamy et al, (2009) in their change in water supplies calculations.

Stratus (2012) briefly reviewed the literature on potential climate change impacts on Egypt's water resources and pointed out the high sensitivity of the Nile flow to changes in climate as it crosses arid and semi-arid climate zones. In such areas, runoff is typically very sensitive to changes in climate. As mentioned in the Second National Communication report (SNC-2010), a 10% decrease in precipitation over the sources of the Nile can result in a 31% decrease in flow of the river at Khartoum, whereas a 10% increase in precipitation is estimated to result in a 36% increase in flow at the same location. Flow is also very sensitive to changes in temperature.

6. MODELLED CLIMATE CHANGE SCENARIOS

Strzepek and McCluskey (2007) employed a version of a conceptual rainfall-runoff model called Wat-Bal (Water Balance) to ascertain the possible impacts of climate change on surface water availability for Egypt. A subset of the 20 scenarios produced by the Climate Research Unit (CRU), University of East Anglia, Norwich, UK. These data, provided on a 0.50 grid, represent the World Meteorological Organization's (WMO) standard reference 'baseline' for climate change impact studies. The available data was employed to represent a range of equally plausible future climates (expressed as anomalies of the baseline 1961–1990 climate) with differences attributable to the different climate models used and to different emission scenarios that the world may follow. This study derived 20 scenarios using five different models (CSIRO2, HadCM3, CGCM2, ECHAM and PCM) based on two different emission scenarios (A2 & B2), where:

CSIRO2: CSIRO Atmospheric Research, Australia.
HadCM3: Hadley Center for Climate and Prediction and Research, UK.
CGCM2: Meteorological Research Institute, Japan.
ECHAM: Max Planck Institute for Meteorology, Germany.
PCM : National Center for Atmospheric Research, USA.

A2 : describes a very heterogeneous world with high population growth, slow economic development and slow technological change.

B2 : describes a world with intermediate population and economic growth, emphasizing local solutions to economic, social, and environmental sustainability.

The results for decadal average changes for 2050 and 2100 in annual values for stream flow are presented in Table 2.

To estimate the effect of low water levels on Irrigation pump stations, 5 scenarios were selected from the climate change scenarios generated by Strzepek and McCluskey and presented in Table 3. The selected climate change scenarios will be used as a multiplier to the historical natural series (1968-2000) to the model for simulation future inflows to the lake.

Table 2: The results for decadal average changes for 2050 and 2100 in annual values (Strzepek & McCluskey, 2007)

	A2- Scenarios									
	CGCM2-A2		**CSIRO2-A2**		**ECHAM-A2**		**HadCM3-A2**		**PCM-A2**	
Base-line	2050	2100	2050	2100	2050	2100	2050	2100	2050	2100
100%	75%	50%	92%	87%	107%	124%	97%	99%	100 %	114 %
	B2- Scenarios									
	CGCM2-B2		**CSIRO2-B2**		**ECHAM-B2**		**HadCM3-B2**		**PCM-B2**	
Base-line	2050	2100	2050	2100	2050	2100	2050	2100	2050	2100
100%	81%	70%	88%	82%	111%	124%	96%	96%	114 %	193 %

Table 3: Selected scenarios for % change in stream flow at the entrance of Nasser Lake used in the simulation that generated from Blue M model

Scenarios	**% change in stream flow**
1	100 % "Baseline"
2	92 % (decreased by 8 %) in comparing by scenario 1
3	81 % (decreased by 19 %) in comparing by scenario 1
4	70 % (decreased by 30 %) in comparing by scenario 1
5	50 % (decreased by50%) in comparing by scenario 1

7. THE MODELING APPROACH

Nasser Lake is modeled and its operation is simulated using the software BlueM (Lohr, 2001). BlueM, developed by the Institute for Hydraulics and Water Resources Engineering, Darmstadt University of Technology, Germany, is a software package for river basin management. It allows for the integrated simulation, analysis and optimization of discharge in rural and urban catchments, including processes in the water body, using physically-based hydrologic approaches. Figure 4 shows the communication between BlueM components and their external usage. The model core BlueM.Sim has two interfaces: an interface which complies with the OpenMI standard and a .NET interface that provides direct access to the model. Additionally, simulation results are also saved in an ASCII file. BlueM.Analyzer is a pure OpenMI-component (implementing the IListener-Interface of OpenMI). BlueM.Wave imports result data from ASCII files. BlueM.Opt can access model engines via a generic interface (implemented as a strategy pattern) or via text files.

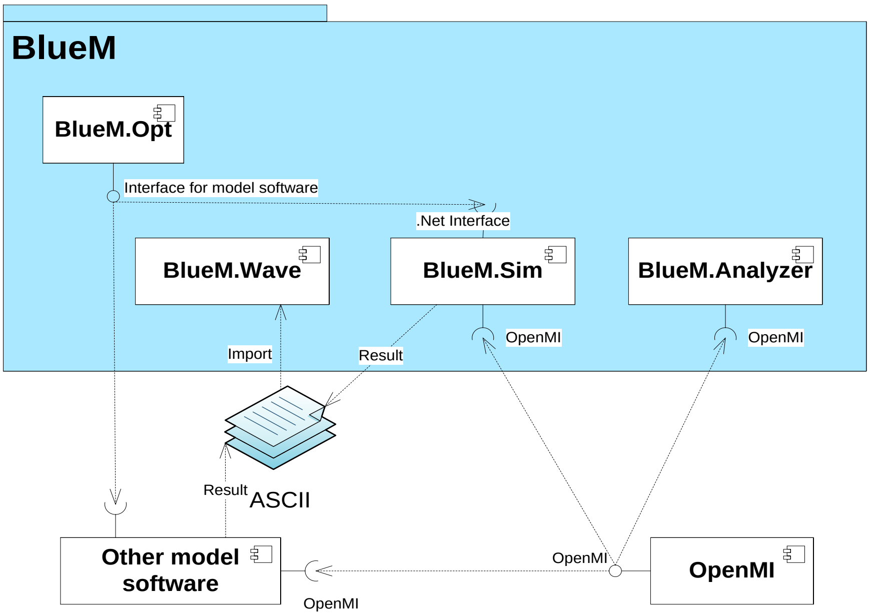

Figure 4: Interfaces of the BlueM components and outer word interfaces

The operation of Nasser Lake is described by the water balance equation under various constraints concerning storage volume, outflow from the lake and water losses, figure 5. The water balance equation applied on a monthly basis has the following form:

$$\frac{dV(t)}{dt} = \sum_{i=1}^{n_{in}} Q_{in,i} + \sum_{j=1}^{n_{out}} Q_{out,j} \qquad \text{(1)}$$

$$\frac{dV(t)}{dt} = I_t - Q_t - M_t - D_t - T_t - S_t - E_t \qquad \text{(2)}$$

Where:

I_t = Mean inflow to the storage in month t (m^3).

Q_t = Amount of water discharged from the storage in month t downstream the dam (m^3).

M_t = Amount of water released from the emergency spillway in the dam in month t (m^3).

D_t = The water demand for Toshka project (South Valley) in month t (m^3).

T_t = Amount of released water from Toshka spillway in month t (m^3).

S_t = Seepage losses from the lake in month t (m^3).

E_t = Mean evaporation from the lake in month t (m^3).

E_t = $((A_t + A_{t+1}) / 2) * C_t*1000$

A_t = Lake area at beginning of month t (km^2).

A_{t+1} = Lake area as at the end of month t (km^2).

C_t = Evaporation coefficient pertaining to month t (mm).

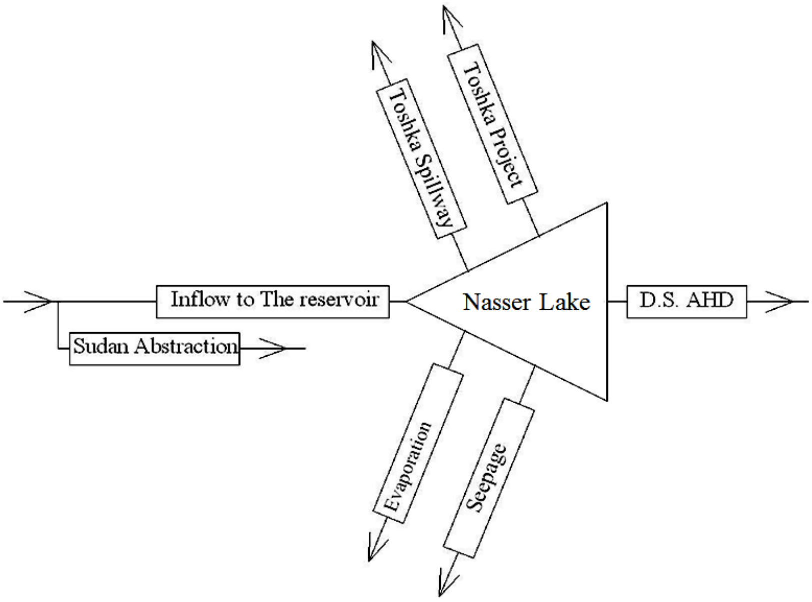

Figure 5: Management Nasser Lake

8. SENSITIVITY OF NILE FLOWS DOWNSTREAM NASSER LAKE TO CLIMATE CHANGE

Applying the BlueM model on the selected changes in flow entering Nasser Lake (as shown in Table 3) showed that under drying climate scenarios, the mean annual withdrawal from Nasser Lake for the five scenarios (1, 2, 3, 4, and 5) will be 55.50, 51.80, 47.10, 42.75 and 33.76 x 10^9 m^3, respectively. This means that Egypt will fall short of its target demand in the future. Excluding withdrawals for the Toshka project, taken directly from Nasser Lake, the water release downstream AHD would amount to 50.93, 46.72, 41.97, 37.56 and 28.55 x 10^9 m3, respectively. Figure 6 and Table 4 present the average monthly releases downstream AHD for the five scenarios (1, 2, 3, 4, and 5). The maximum discharges (occurring in July) for the five scenarios (1, 2, 3, 4, and 5) are 219, 201,182, 164 and 126 x 10^6 m^3 per day, respectively. The minimum discharges (occurring in December) for the five scenarios (1, 2, 3, 4, and 5) are 86, 78, 70, 62 and 46 x 10^6 m^3 per day, respectively (Table 4).

This study focused on the effect of passing the lowest releases from Nasser Lake (i.e. during December) on the pump stations along the four reaches. The proposed discharges for the four reaches are presented in Table 5.

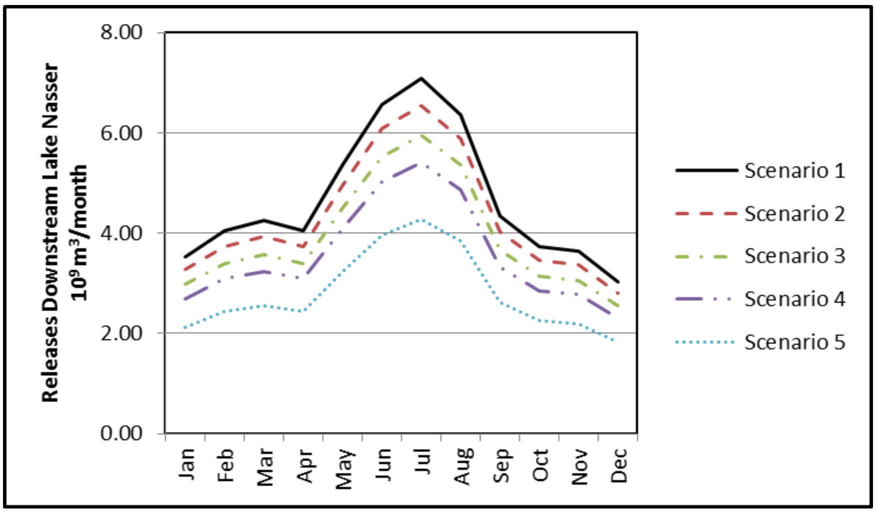

Figure 6: Average monthly releases from Nasser Lake (10^9 m^3/month) for the modelled scenarios

Table 4: Average monthly releases from Nasser Lake (10^6 m^3/day) for the first reach for the modelled scenarios

Scenarios	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
1	102	117	126	119	162	202	219	195	129	109	106	86
2	94	107	115	109	149	186	201	180	118	100	97	78
3	84	95	103	98	134	168	182	162	106	89	87	70
4	75	83	93	87	120	151	164	146	95	80	77	62
5	56	63	70	66	92	116	126	112	72	60	58	46

Table 5: The proposed discharges for this analysis (10^6 m^3/day)

Reaches \ Scenarios	1	2	3	4	5
Reach 1	86	78	70	62	46
Reach 2	76	68	60	52	36
Reach 3	66	58	50	42	26
Reach 4	63.7	55.7	47.7	39.7	23.7

9. WATER LEVEL COMPUTATIONS BY GSTARS

The used mathematical model for this analysis is GSTARS 2.0 Model which was developed by the U.S. Bureau of Reclamation in 1998. It is a one –dimensional model with a number of capabilities such as:

- It has the capability of computing hydraulic parameters for open channels for fixed and movable bed boundaries.
- It has the capability of computing water surface profile for subcritical, super critical and mixed type flow.
- It has the capability of predicting and simulating the change of alluvial channel profile and cross sectional geometry.

9.1. Backwater Computations

GSTARS 2.0 solves the energy equation based on the standard step method for backwater computations. For cases of change between subcritical and supercritical flow conditions, the momentum equation is used instead.

- **Energy Equation**

For water profile computations, the used energy equation is (Chow, 1957):

$$Z_1 + Y_1 + \alpha_1 \frac{V_1^2}{2g} = Z_2 + Y_2 + \alpha_2 \frac{V_2^2}{2g} + H_t \tag{3}$$

Where:

Z = Bed elevation.
Y = Water depth.
V = Velocity.
α = Velocity distribution coefficient.
H_t = Total energy loss between sections 1 & 2.
g = Gravity acceleration.
1&2 = Denote sections 1 & 2, respectively.

The standard step method is a trial and error iterative procedure for solving energy equation for water surface profile.

- **Momentum Equation**

The momentum equation is used for flow regime change, which means that the flow will change from subcritical to supercritical or vice versa. The momentum equation is:

$$\frac{Q\gamma}{g} = (\beta_2 V_2 - \beta_1 V_1) = p_1 - p_2 + W \sin\theta - F_f \tag{4}$$

Where:

γ = Unit weight of water.
β = Momentum coefficient.
θ = Angle of inclination of channel.
W = Weight of water enclosed between sections 1 & 2.
F_f = Total external friction force acting along the channel boundaries.

9.2. Model Calibration

The first step of model application is to calibrate the model for water levels and this step is important step to get roughness coefficient "n". The following data are entered to the model as input files:

(A) Cross sections geometry and locations.
The cross sections were extracted from the hydrographic and topographic maps produced by the Nile Research Institute during the period from 2003 to 2009.
(B) Discharge time relationship.
The daily discharge and the daily water level according these discharges for all the gauging stations are used to develop the rating curves.
(C) Cross section bed grain size distribution.
(D) Boundary condition for each flow.
The discharge downstream the barrages (upstream boundary condition) and the upstream water level of the barrages according to these discharges (downstream boundary condition).

The value of Manning coefficient "n" is basically depends on many factors:

1- The geometric properties of the cross sections.
2- The discharges through the study reach and the water levels corresponding it.
3- The available data of sediment transport.

Calibration is an important process to tune the model parameter in order to force the model to produce results nearly similar to the measured ones. Calibration is an effort to better parameterize a model to a given set of local conditions, thereby reducing the prediction uncertainty. Model calibration is performed by carefully selecting values for model input parameters (n Manning coefficient) by comparing model predictions (output) for a given set of assumed conditions with observed data for the same conditions. Different gauging stations along each reach were used for this calibration. These gauging stations are presented in Table 6.

The model runs for 10 days for each scenario to be sure that the model will reach to the steady state condition (the proposed discharge passing through the whole of the study reach from upstream to downstream). The calibration is followed by a verification process. The field data was split into 2 groups (one group for the calibration and the other for verification). To verify the model after completing its calibration, the model was re-run under another flow condition and using the same calibration parameters (Manning coefficient) and comparing the results with "observed" data for the new flow condition.

Figure 7 provides the calibration results for the first scenario for the four reaches. From this figure it can be concluded that there is a close agreement between the measured and the predicted water levels. Confident with the calibration process, simulation process was initiated from which results were obtained.

Table 6: Selected water level gauging stations (NRI, 2010)

No.	Site Name	Km	No.	Site Name	Km
R 1-1	Gaafra	33.75	R 3-5	Sohag	445.95
R 1-2	Kom Ombo	49.65	R 3-6	Koramat	457.60
R 1-3	Ekleet	62.45	R 3-7	Maragha	470.00
R 1-4	Salwa Bahry	85.45	R 3-8	Khazend	479.10
R 1-5	Ramady	102.50	R 3-9	Magris	509.50
R 1-6	Baseles	131.00	R 3-10	Aboteeg	520.50
R 1-7	U.S. Esna	166.65	R 3-11	U.S. Assiut	544.78
R 2-1	D.S. Esna	166.65	R 4-1	D.S. Assiut	544.78
R 2-2	Mateena	174.70	R 4-2	Maaabda	576.20
R 2-3	Armant	203.80	R 4-3	Mandra	612.10
R 2-4	Luxor	224.10	R 4-4	Menia	687.55
R 2-5	Hela	255.60	R 4-5	Fadl	735.25
R 2-6	Sharikia	264.90	R 4-6	Beba	789.00
R 2-7	Qena	286.70	R 4-7	Baniswafe	808.60
R 2-8	Naga Hamadi	346.45	R 4-8	Korimate	839.10
R 2-9	U.S. Naga	359.48	R 4-9	Lethy	873.70
R 3-1	D.S. Naga	359.48	R 4-10	Eksas	887.00
R 3-2	Dom	363.20	R 4-11	Roda	927.00
R 3-3	Baliana	386.60	R 4-12	D.S. Delta	953.00
R 3-4	Gerga	405.10			

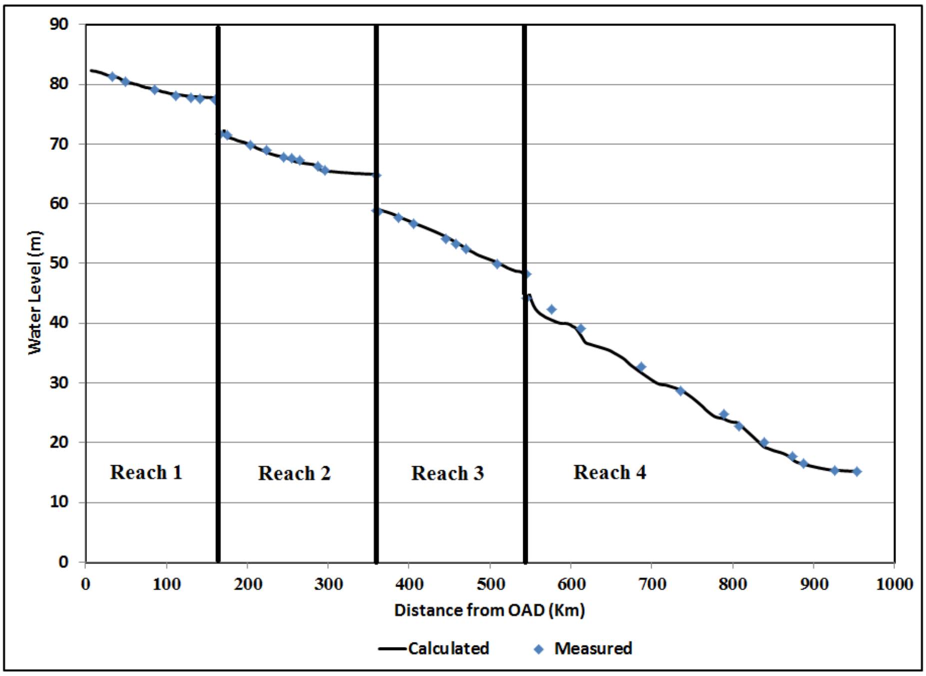

Figure 7: Model Calibration Results for first scenario

10. RESULTS PRESENTATION AND ANALYSIS

Figure 8 shows the results for different scenarios for the first reach. It indicates the critical operation level for the fixed pump stations. If the station is subjected to any of the studied scenarios, it could be operated under this scenario. If the critical operation level for the station is located above any scenario, it means that the station will not be operated under this scenario during the time with the discharge used in the computation. The results identified the percentage of pumps on the first reach that will not operate under the effect of the five scenarios (1, 2, 3, 4, and 5) would be 23 %, 35 %, 40 %, 47 % and 62 %, respectively. Figure 9 shows the results for the different scenarios for the second reach, this figure shows the critical operation level for the fixed stations. The results indicated the percentage of pumps on the second reach that will not operate for the five scenarios (1, 2, 3, 4, and 5) would be 41 %, 47 %, 52 %, 65 % and 82 %, respectively. Figure 10 shows the results for the different scenarios for the third reach, this figure indicated the critical operation level for the fixed stations. The results indicated the percentage of pumps on the third reach that will not operate for the five scenarios (1, 2, 3, 4, and 5) would be 50 % for all scenarios. Figure 11 shows the results for the different scenarios for the fourth reach. It shows the critical operation level for the fixed stations. The results indicated the percentage of pumps on the fourth reach that will not operate for the five scenarios (1, 2, 3, 4, and 5) would be 54 %, 54 %, 61 %, 69 % and 84 %, respectively.

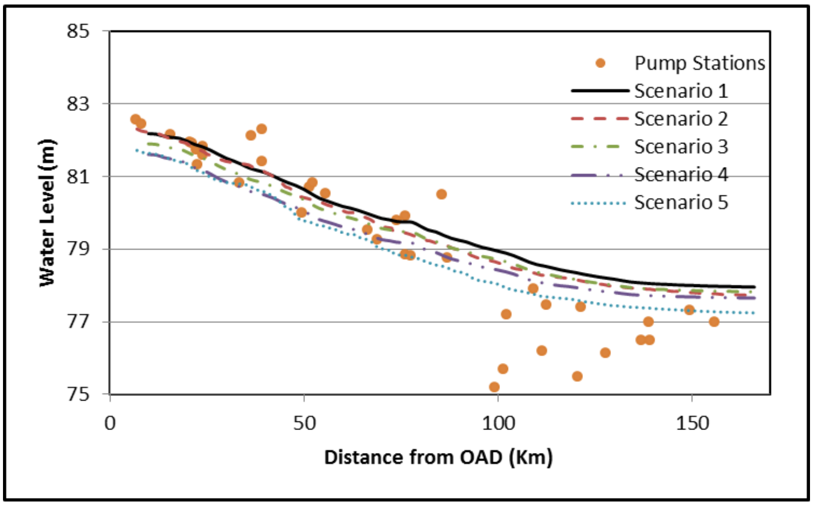

Figure 8: Analysis results for the first reach

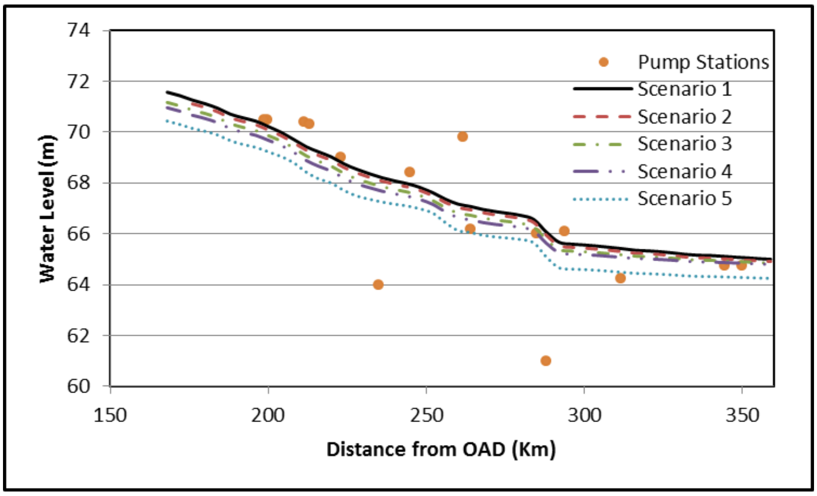

Figure 9: Analysis results for the second reach

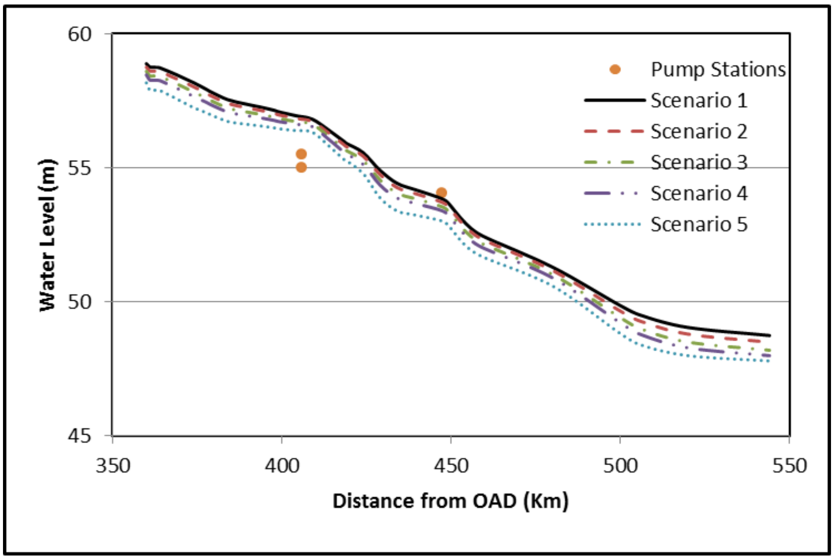

Figure 10: Analysis results for the third reach

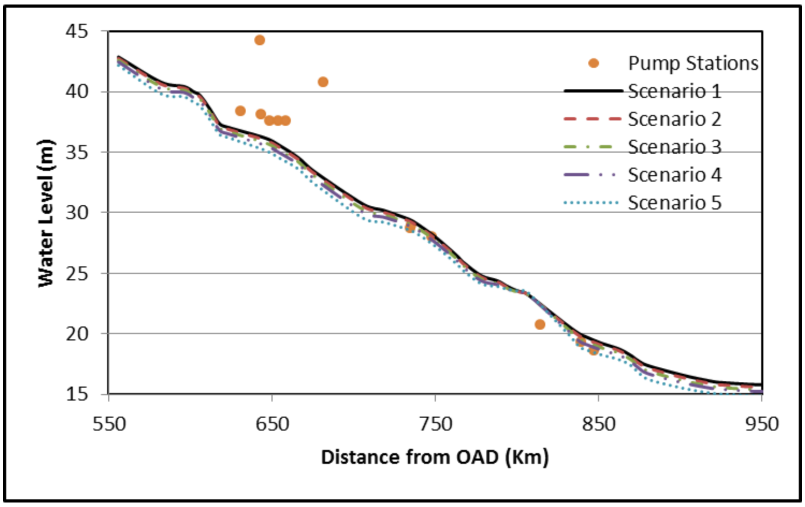

Figure 11: Analysis results for the fourth reach

11. CONCLUSIONS AND RECOMMENDATIONS

During this research, pump stations along all reaches from AOD to Delta Barrages were assessed according to their design and critical water level to determine the potential for expected problems in these reaches due to passing the low releases from Nasser Lake as a result of climate changes. Several conclusions are drawn from this work:

1- A simulation model for Nasser Lake was implemented to simulate the impact of climate change on operating AHD and the change in the volume of water flowing from the lake to Egypt. The model projected that, under dry climate scenario, the mean annual withdrawal from Nasser Lake for the five scenarios (1, 2, 3, 4, and 5) would be 55.50, 51.80, 47.10, 42.75 and 33.76 x 10^9 m^3, respectively. That means Egypt falls short of its target demand in all of the future periods as represented by scenarios 2, 3, 4, and 5.

2- A mathematical model based on solving the energy and flow equations was developed to compute water levels related to the analyzed discharged. The computed water levels were compared to the design and critical pump station water level to determine the adequacy of the water level for pump station supply. The results indicated that the pumps in the first reach that will not operate for certain scenarios during the lowest discharges (in December) are ranging from 23% (scenario 1) to 62% (scenario 5). For the second reach, the pumps that would not operate for certain scenario would range between 41% (scenario 1) and 82% (scenario 21). For the third reach, the not operating pumps for certain scenario are 50 % for all scenarios. For the fourth reach, the pumps that would not operate for certain scenario would range between 54% (scenario 1) and 84% (scenario 5).

3- If there are more than one pumping station serve the same area (For example for the same area we have 2 or 3 pumping stations serve this area and due to the reduction of flow and water level 1 or 2 of them is not operated but the others work, at this time only we can say that the non-operable pump stations are not important because this is the period of low requirements and we do not need to use all the pumps). This may not be serious for irrigation requirements in December and may be a few other months. Also we should check the water requirements and the crop pattern for each area served by pumps that cannot be operated to be sure about that.

4- It is recommended to review the critical operation water level for the pumping stations and importance of operating the affected pumps during reduction scenarios .In very important cases, it is recommended to construct additional intakes to cope with the lowest required scenario or using floating stations.

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13. SYMBOLS

A_t	Lake area at beginning of month t (km^2).
A_{t+1}	Lake area as at the end of month t (km^2).
C_t	Evaporation coefficient pertaining to month t (mm).
D_t	The water demand for Toshka project (South Valley) in month t (m^3).
E_t	Mean evaporation from the lake in month t (m^3).
E_t	$((A_t + A_{t+1}) / 2) * C_t*1000$
F_f	Total external friction force acting along the channel boundaries.
g	Gravity acceleration.
H_t	Total energy loss between sections 1 & 2.
I_t	Mean inflow to the storage in month t (m^3).
M_t	Amount of water released from the emergency spillway in the dam in month t (m^3).
Q_t	Amount of water discharged from the storage in month t downstream the dam (m^3).
S_t	Seepage losses from the lake in month t (m^3).
T_t	Amount of released water from Toshka spillway in month t (m^3).
V	Velocity.
W	Weight of water enclosed between sections 1 & 2.
Y	Water depth.
Z	Bed elevation.
1&2	Denote sections 1 & 2, respectively.

α	Velocity distribution coefficient.
γ	Unit weight of water.
β	Momentum coefficient.
θ	Angle of inclination of channel.

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