Impact of the Hydroelectric Peak Load on Water Levels Downstream of Aswan Old Dam and Establishing New Criteria for Navigation

N. M. Eshra[1], and M. M. Qottob[2]

***Abstract*--** **The paper objective is assessing the hydropower contribution during the daily peak load and evaluating its effect on the water level downstream Aswan Old Dam (AOD) and the navigation during low flow. Data are collected over 32 years. The data are daily water levels, upstream and downstream Aswan High Dam (AHD) and AOD discharge and the generated hydropower. As the basin is utilized to accommodate the daily peak load discharge; GIS technique is applied to estimate the volume of the basin between the two dams. Quasi two dimension model "GStare-W" is applied, Rating curve is produced and simple regression is applied. Criteria for navigation in first reach are established.**

***Key Words*--** **Hydropower; Peak Load; Aswan High Dam; Aswan Old Dam; Water-Level Fluctuation**

I. INTRODUCTION

AOD is the first practical solution of water storage problem in Egypt. It is constructed in 1902. It has two powerhouses, Aswan I, consists of 9 turbines and Aswan II consist of 4 turbines. Total generation capacity of AOD 500 Mw. The construction of AHD aimed at providing irrigation water, domestic and industrial uses, hydroelectric power generation, and flood control. It was built in 1970 at a distance of 6.5 km south of AOD. AHD power station has twelve turbines each one producing 175 megawatts, with a total of 2100 megawatts. Figure 1 represents the elevation of the basin between two dams. Hydropower generation is considered one of the cheapest and cleanest sources of electric power. But the percentage of hydropower generation in Egypt is decreasing in spite of all its advantages. The paper objective is asses the participation of the AHD power generation in the peak load and its effect on both; water levels downstream of AOD and the navigation path in the Nile River especially in low inflow. In order to accomplish this objective many computer programs and techniques are used, such as AutoCAD, Microsoft Excel, a statistical program, GIS, and numerical model. The research phases will cover many points such as:

- Reviewing of literatures
- Data Assembling
- Producing rating curves
- Determining the volume of the basin
- Implementing a numerical model
- Establishing criteria for navigation

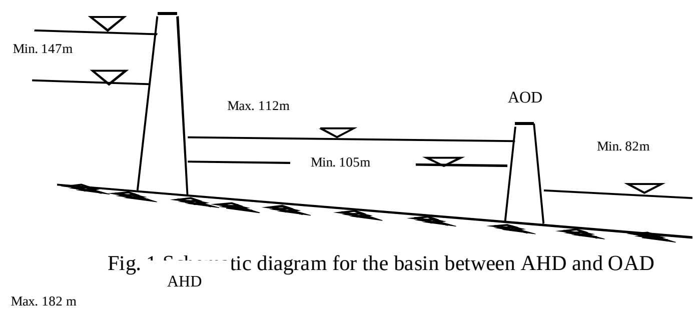

Fig. 1 Schematic diagram for the basin between AHD and OAD

II. REVIEW OF LITERATURE

Based on the literature on river engineering and hydroelectric power generating, many reports and researches were available, from which it was clear that: The Nile River is considered the main route of inland navigation in Egypt. It is divided into four reaches. First reach encompasses the main truism, [1]. More than 2.9 million tons of cargo is transported per year which represents only 20% of the waterways navigation capacity [2]. The stream in Aswan region is characterized by the presence of rocks irregular in shape, which indicates that any fluctuation in downstream induces danger to the navigation, [3]. Enhances the estimation of irrigation water demand from the reservoir downstream agricultural area three priority scenarios (water supply only, hydropower generation only, and equal priority), can improve the reservoir operation for both water supply and hydropower generation,[4]. Electric Peak load is considered the maximum average load over a designated interval of time, and it represents a big problem for any nation. Hydropower is more responsive than most other energy sources for meeting peak demands because it can be started or stopped almost instantly. Water can be stored overnight in a reservoir until needed during the day, and then released through turbines to generate power to help supply the peak load demand. When hydropower meets peak load requirements, a power station is turned on at a particular time during the day, generates power at a constant load for a certain number of hours, and is then turned off or set to a different load for another time period, resulting in a high variability in flow discharges. When reservoir hydro-schemes are operated

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primarily to provide peak load services, there are particular environmental risks that should be considered in any environmental impact assessment, [5].The system load which is a combination of the base load and peak load varies by time. If the total demand is supplied from one power plant having an installed capacity M, the plant will be running under-loaded most of the time, thus making the operation system uneconomical [5 & 6]. So the load should be divided into two parts through line AB, one below the line AB (base load) and the other above the line AB (peak load). These two loads are supplied from separate plants called the base load plant and peak load plant. A base load plant operates at a high load factor and should have low operating costs. The peak load plant operates at a low load factor. This mixing of power sources offers a utility company the flexibility to operate steam plants most efficiently as base plants while meeting peak needs with the help of hydropower. This technique can help ensure reliable supplies and may help eliminate brownouts and blackouts caused by partial or total power failures,[7]. AHD power station represents the biggest hydropower station in Egypt; it was supplied the united electric network with 69% from the total power generation at 1974; this percentage decrease to 8.9% in 2010/2011. Although the percentage share of hydro resources to total electric resources is very small, AHD turbine are used as base load and peak load, on other side the annual growth rate in electricity demand is recorded variance 9.5% increase in 2011/2012. Moreover, a greater increase is expected to occur in the coming years,[8].. Using AHD power station as a peak load, by increasing the released discharge downstream AHD during the peak load period and decreasing the discharge during the rest of the day, represents a big problem. This is attributed to the fact that this operation mode system caused fluctuation in the downstream of AOD and affects the navigation path in the main stream especially in the stream at Aswan region. Figure (2) represents the participation of hydropower generation and the thermal generation in peak load in different years..

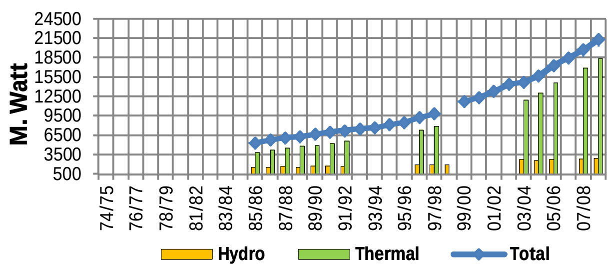


Fig. 2, Contribution of Hydropower and thermal generation in Peak Load

• Aswan High Dam Turbine (AHDT) contributes in the united network by both base and peak load, so it is very important to study the operation rule of AHD to reach the optimum and economic operation conditions.

• The hourly hydropower generation from AHD is available from 1988 to 2000. Based on the operation condition of AHD turbines and using Mini-Tab statistical program, regression relation between three poles of hydropower generation, downstream AHD discharge, the head on turbines, and generated power, have been used to develop Equation (1), [9].

$$\mathbf{P_{AHD} = -1007 + 166 * Q_1 + 14.2 * H_t} \qquad (1)$$

Where:

-P_{AHD} is the generated power in Miga Watt
-H_t is the head on turbines in (m)
-Q_1 is the discharge downstream AHD in ($M.m^3/h$)
-The square root of equation "R-Sq" is 98.8%

Noting that, this equation especial to AHD power station, table 1 presents the limits of Q_1 and H_t

Table1, the Equation Limits

	Q_1 $M.m^3/h$	H_t m
Max.	10.6	73.6
Min.	3.06	48.18

• The missing data of hydropower have been estimated by the equation in terms of the AHD discharge and head on turbines. Table 2 presents the confidence factors of the developed equation. The estimated generated power is compared with actual generated power. The average square root of the deviation between the actual data and estimated values is very small.

Table 2, Confidence factors of the developed Equation

Predictor	Coef	StDev	T	P
Constant	-1007	33.89	-29.72	0.000
Q	166	1.496	110.7	0.000
h	14.2	0.4975	28.64	000

Where

The p-value are used to test whether the constant and slope are equal to zero or not. In this study the p-values close to 0.0, and these significantly different from zero. And concluded that the constant and slope play a significant role in the regression model. In general, with a p-value of 0.0, there is very strong evidence to suggest that the simple linear regression model is useful for P_{AHD}

Based on the above cited literature one could say that the new in this paper illustrates the relation between Electric Peak load and the navigation path in Nile river.

III. DATA ASSEMBLING

Data were assembled from different sources; Yearly generation of hydropower and thermal power was assembled from 1969 to 2009 (***Egyptian Electricity Holding Company, Ministry of Electricity and Energy***). Daily water levels and discharge downstream of AOD were assembled from 1989 to 2005 (***Nile Research Institute Database***). Hourly discharge downstream AHD and head on turbines for the years 1991, 1992, 1995, 2000, 2004, and 2005 (***Aswan High Dam Authority***). Hydrographic survey maps of scale 1:5000 for basin between the AHD and AOD which was produced in 1978 were also assembled.

The assembled data was analyzed. Statistical analyses were carried out using the above mentioned data to develop the equations. A relation between the water level and discharge downstream of AOD as a rating curve was produced using the rating curve equation. The volume of the basin between AHD and AOD was determined for different water levels using GIS technique. A numerical model was implemented to estimate the water levels downstream of AOD. Criteria of the navigation path in the first reach, from OAD dam to Esna Barrage, to assess the fluctuation of the water levels downstream of AOD were established.

IV. THEORETICAL FORMULATION AND METHODOLOGY

A. Rating Curve Produced

Flow in the Nile River is characterized by two seasons, high water flow; which is started in June and ends in September, and low water flow; which starts in December and ends in February. The present investigation focuses on the low water flow, where it is the most influential on the navigation because the water level is decreased to critical value. Rating curves were produced in order to clarify the extent of the close relationship between the downstream of AOD and water levels. The available data of daily water level and discharge downstream AOD for year 2004 were used to obtain the rating curve which represented in equation (2). Figure 3 shows the produced rating curve

W.L = 0.0188 * Q $_{OAD}$ + 80.9 **(2)**

Where

W.L. is water level downstream AOD in (m), $\mathbf{Q_{AOD}}$ = discharge downstream AOD in (M.m3/day)

The correlation factor was **0.9929**

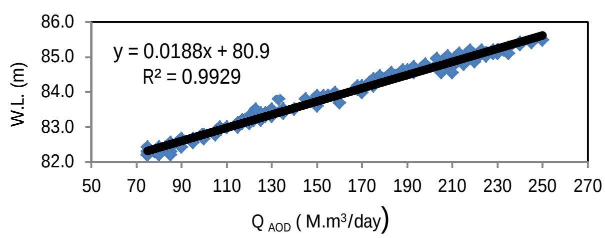


Fig.3, Rating curve in daily basis and its equation, 2004

B. Estimate the Capacity of Basin between Two Dams

The volume of the basin between the dams was determined using GIS technique. The actual value of the hour discharge downstream of AOD was estimated by knowing the measured hourly discharge downstream AHD (+ or **-**) the change in volume in the basin between the two dams. Many processing steps took place as following:

- Using hydrographic survey maps with scale 1:5000.
- Converting the maps to spatial format.
- Using 3D analysis tool to carry out the suitable environment for the calculation of surface area and volume.
- Calculating the net volume and surface area in the basin between the different water levels, from 105 to 112 by increments of 0.2. Figure 4 (a) and (b) presents some of the processing steps on GIS.

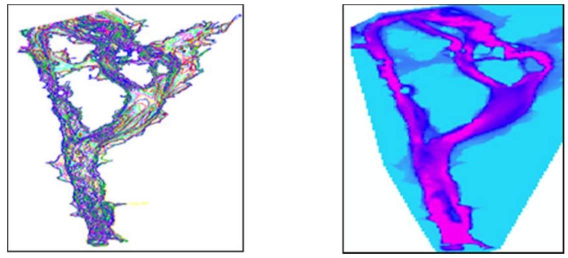


Fig. 4, (a) Digitizing map and, (b) Raster map for the basin between two Dams

C. Application of Numerical Model

G-STARS model is used to estimate water level downstream of AOD in terms of estimation of the volume in basin "Q AOD" in two seasons of low inflow and high inflow. This model is a series of computer models, [10]. It is able to compute water surface profiles in single channels, simple channel networks, and complex channel networks. GSTARS model is quasi-steady flow model representing an unsteady hydrograph by a series of steps of constant discharge Q with a finite duration Δt. The basic concepts for water surface profile computational procedures are based on solving the energy equation using the standard-step method for subcritical flows. The momentum equation is used for supercritical flow. The energy equation can be written as:

$$z + Y + \alpha\frac{V^2}{2g} = H \qquad (3)$$

Where: z = bed elevation; Y = water depth; V = flow velocity; α = velocity distribution coefficient; H = elevation of the energy line above the datum; and g = gravitational acceleration

The momentum equation can be written as:

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

Where: γ= unit weight of water; β= momentum coefficient; *P*= pressure acting on a given cross section; W_g = weight of water enclosed between sections 1 and 2; Θ = angle of inclination of channel; and F_f = total external friction force acting along the channel boundary

GSTAR model is applied on the first reach which starts from AOD and ends at Esna Barrage under boundary conditions as the discharge downstream of AOD which was 60 M.m^3 in low inflow period and 250 M.m^3 in high inflow period was used as upstream boundary condition. The water level upstream of Esna barrage which was 82m in low season and 86m in high season was used as downstream boundary condition. The input files for the model contains discharge of AOD "Q $_{AOD}$" for about 20 cross sections to represent the first reach in the Nile River, by distance step 10 km where the whole distance for the reach is 200 km. The whole time used is 240 hours or 10 days with time step of one hour.

Calibration of the Model: A calibrated steady flow water surface profile model should compute water surface elevations that are essentially the same as observed elevations (from high water marks or gauge readings) not only for the set of conditions used in calibration but for others as well. This is accomplished with a trial-and-error procedure in which a water surface profile is computed with an initial set of parameters and compared to the observed data. The parameters are adjusted on the basis of the comparison, and the procedure is repeated until a suitable fit is obtained. The mathematical model was calibrated using the surveyed cross-sections and different water levels, which correspond to the minimum and maximum discharge D.S. of AOD and along the first reach, which were estimated at about 60 and 250 Mm^3/day, respectively. These discharge values were identified from the actual measuring stations at different elevations along the reach. Figure 5a shows the calibration for the case of 250 $M.m^3$/day, while figure 5b shows the calibration results for the discharge of 60 $M.m^3$/day.

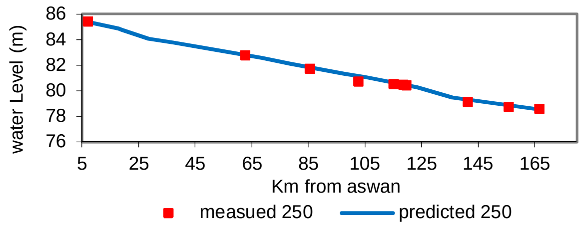


Fig. 5, (a) Calibration for case Q=250 $M.m^3$/day,

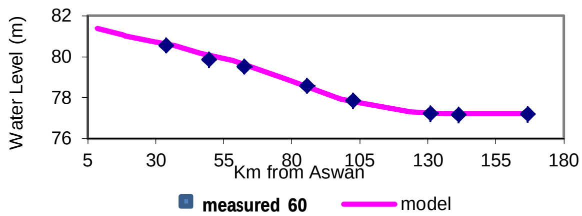


Fig. 5, (b) Calibration for case Q=60 $M.m^3$/day

Output of model is tabulated in Tables (3) and (4). They represent the estimation of AOD discharge corresponding to the fluctuation in basin between AHD and AOD as different areas and different volumes and estimation of the water level downstream of AOD. Table (3) represents the low inflow calculations and table (4) represents the high inflow calculations. For both tables there are four columns; (Q_1= Q_{AHD}) is discharge up stream of Old Aswan Dam, second column is the water level in the basin between the two dams AHD and AOD, (Q_2=Q_{OAD}) is discharge downstream of AOD, and forth column is the water level estimation.

V. ESTABLISING CRITERIA FOR THE NAVIGATION IN THE NILE

The River Transport Authority (RTA) divided the waterways in Egypt (1999) into three classes depending on specific criteria. The main concern here from these criteria is the minimum water level of safety for the navigation, while the lowest level allowed for the navigation in the downstream AOD is 81.7 m which considers the flow water depth as 2.3m.Figure 6 represents the cross section at Km 920.

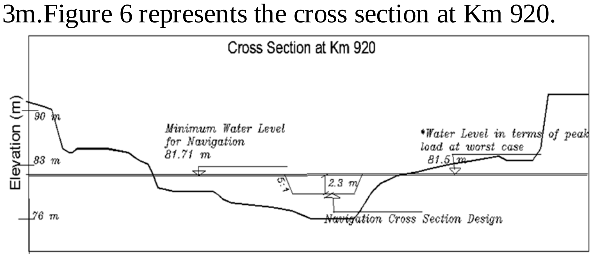


Fig. 6, Schematic diagram for the Criterion of Navigation Path in First Reach

VI. Results and Discussion

The study includes three parts integrated together to achieve the aim of the research.

*The first part i*s review of the literature for the hydrograph of hydropower and thermal generation from 1975 to 2009. The percentage of contribution of hydropower generation dropped from 69.5% in 1975 to 8.9% in 2011.

Second and third parts: the second part determined the net volume between levels 105 to 112m by increments of 0.2m, based on knowing the measured hourly discharge downstream of AHD (+ or -). This volume was estimated to be 60 million cubic meters and not enough to satisfy the peak load. The third part presented the usage of a numerical model to hourly water level downstream of AOD. Table (3) represents the results of the third part, where the processing for low inflow season. The period from January10 to 20, 2005 is taken as a sample for this case; the result is clear in Figure (8).

Establish criterion for the navigation in first reach in Nile; Peak load period occurred daily for some hours ranged between 4 to 7 hours, started in hour 16 and continuous to hour 22 this period causes a big problem for the navigation especially in first reach. The navigation path in this region is designed based on the minimum water level to allow for the ship draft and the required clearance under the ship. It is designed to allow for 2.3 meter depth under the minimum water levels for River Nile , main canals, and Damitta branch,[1].

Table3, The Estimated daily Water level downstream OAD for Low flow

Daily hours	Q1=Q AHD M.m3/h	W.L in basin(m)	Q2=Q OAD M.m3/h	Estimated W.L(m)
1	1.66	111.55	3.33	82.6
2	1.66	111.4	2.77	81.8
3	1.66	111.3	4.17	82.9
4	1.94	111.1	2.43	82.3
5	1.93	111.05	3.87	83.2
6	1.66	110.85	2.76	83.1
7	1.66	110.75	3.3	83.0
8	1.91	110.6	4.1	83.4
9	1.89	110.4	2.98	82.7
10	1.31	110.3	2.94	82.8
11	1.22	110.15	4.47	83.6
12	1.12	109.85	3.73	82.7
13	1.87	109.6	3.94	83.5
14	1.84	109.4	3.37	83.3
15	1.19	109.25	1.49	81.8
16	1.28	108,85	3.78	**81.5**
17	2.16	108.7	2.68	82.3
18	10.66	108.85	3.19	83.1
19	9.65	109.6	3.95	83.5
20	10.08	110.15	1.43	81.6
21	9.47	110.95	5.61	83.9
22	7.99	111.13	2.99	83.3
23	5.78	111.75	3.53	83.5
24	1.87	111.95	4.13	

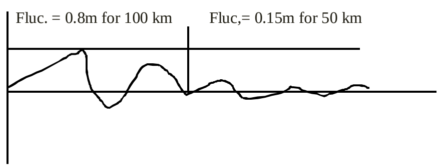
Due to the impact of fluctuation of the water levels during peak loads, the water level downstream AOD is dropped under the minimum water level by about 0.2 meters the impact of additional drop of water levels should be included in navigation path design and also in any port with the length of the water level fluctuation determined in this study by about 100 km. the dropped is decreased to 0.15 metres for distance about 50 km and the fluctuation decays at end of the reach. Which lead us to think in three options to cope this fluctuation as;

a) The first; decreased the ship draft around 0.3 m to be 1.5m instead of 1.8m and modified the load of ships in the river commensurate the new design, whether in tourism or transport of goods.

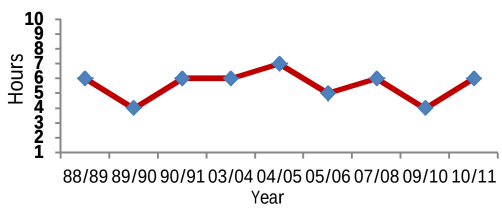
b) The second, using AHD power station as base load plant only and look for another source for the peak load periods.

c) The third; minimum water level downstream AOD should be increased around 0.3 m to be 82.0 m instead of 81.7m to achieve the navigation safety, which is increased the suffering of the ministry to pass around 5 $M.m^3$ in the period of high peak load hours over the daily scheduled of discharge and reversed it gradually in the rest hours along the day.

Figure 7,(a) shows the fluctuation distance and figure 7,(b) shows the estimated peak load hours from; 88/89 to 10/11, (EECH Reports). These hours caused big problem daily in the navigation.



Figure,7a Fluctuation due to peak load in first reach



Figure,7b peak load Hours from 88/89 to 10/11

<u>The results have many important points</u>:

- Assessment of the fluctuation in both; basin between two dams AHD and AOD, and the fluctuation in winter level downstream AOD in first reach. Output of the model, gives clear vision to the hourly fluctuations. Figure, 8 represents the fluctuation in AOD discharge in basin. These fluctuations have a great impact on all river structures. The concerning impact in the study are represented in figure 6, which combines the lower level is security of the navigation at this region "ferial gage at Km 920" which is 81.71 m and the minimum water level get it from the model as 81.5, this represents a big problem because this cause the ship aground in the bed river.

<u>A comparison the actual value for the water level downstream OAD and the results of model was executed.</u> Tables (5) represents the result of comparison in both seasons high and low inflow. The fluctuation in high inflow season for actual data is ranged between 1m and 1.15m and in result of model is 1.8m through one day. The fluctuation in low inflow seasons for actual data between 1m and 1.2m and in the model results is 2.2 m through one day.

Table 5, Model Results and Measurement data for Down Stream AOD Water Level

Model Results				Actual Recorded Data			
High Inflow Season*		Low Inflow Season**		High Inflow Season		Low Inflow Season	
Max	Min.	Max.	Min	Min.	Max	Min.	Max
87.3	85.5	84.1	82.9	86.9	88.9	83.3	84.5

* Data for model and actual recorded data represents for August 2004
**Data for model and actual recorded represents for January 2005

Correlation for (water level - surface area) and (water level – volume) in the basin are carried out. Figures 9, illustrates this correlation. This figure could be used to the volume at any level in basin. The numerical model could be used along the river to predict any fluctuation.

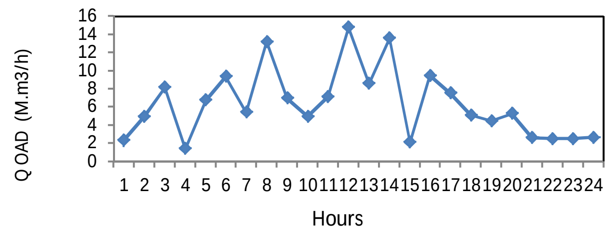


Fig. 8, AOD discharge at 15/2/2005

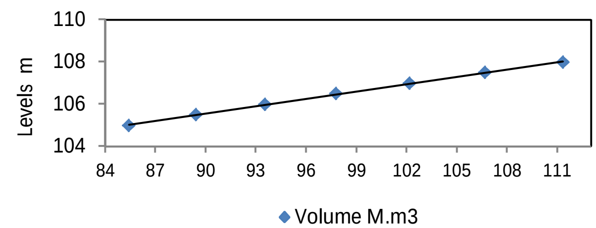


Fig. 9, Volume & Water Level .Curve

VII. CONCLUSION AND RECOMENDATION

- The small percentage of participation in peak load periods is causing a big hourly fluctuation in both basin between the two dams and in water levels downstream of AOD.
- The fluctuation in low inflow ranged between 20 cm and 4.4 m in basin and reach to 80 cm in downstream AOD through hours of one day; this induces a negative impact on the stability of the river embankments and the navigation especially during the low discharge.
- The fluctuation of discharge of AOD downstream caused disturbance in the water management on a daily basis.

Three options to cope fluctuation impact on navigation are proposed. They can be ranged depending on their influence on the Water Resources & Irrigation Ministry as following:

a) The first; decreased the ship draft around 0.3 m to be 1.5m instead of 1.8m and modified the load of ships in the river commensurate the new design, whether in tourism or transport of goods.

b) The second, using AHD power station as base load plant only and look for another source for the peak load periods.

c) The third; minimum water level downstream AOD should be increased around 0.3 m to be 82.0 m instead of 81.7m to achieve the navigation safety, which is increased the suffering of the ministry to pass around 5 $M.m^3$ in the period of high peak load hours over the daily scheduled of discharge and decreased this amount gradually during the rest hours of day.

- There is a problem in the recorded data at some gauges along the River Nile.

<u>The following is thus recommended:</u>

- A new technology for the instruments of all gauges in the Nile to make sure that the data is correctly recorded.
- This approach should be applied in other reaches of Nile River to verify that the water level corresponds to the navigation.
- Egyptian government should give less eclectic tariff price for consumers at night period, for example from 10 pm to 9 am the following day, to overcome the peak load.
- Replace the hydropower contribution in the peak load by another electric source; solar energy can be used as an alternative, as Aswan Region is characterized by bright and strong sunshine throughout the day.
- Use of a pump storage approach can be used to accommodate the fluctuation in raising the amount of water and to use it in the electrical generation through the peak load period.

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